Grass invasion in urban lowland fynbos fragments on the Cape Flats: Does nutrient addition play a role ?

Daniel T. Wilson

Botany Honours Project, 1999
Supervisor: William Bond

ABSTRACT

Invasion by exotic grasses is a major threat to natural ecosystems in many parts of the world. On the Cape Flats in Cape Town, grasses were observed to be invading lowland fynbos fragments which are a high priority for conservation. The observation in other parts of the world that nutrient additions from deposition of airborne pollutants were responsible for increased dominance of grass in natural ecosystems, led us to test whether this was the case on the Cape flats. Phytometers were used to gauge the favourability for growth of soils from urban sites compared to those from rural control sites. An attempt is also made to demonstrate the negative effects of grass invasion on seedling establishment and diversity of native species by removal of grass cover and addition of smoke water. Phytometer results were inconclusive, but soil from city sites generally had higher total N than control sites for comparable amounts of organic matter, suggesting that N addition may be occurring. Total seedling emergence was significantly increased by removal of grass cover ($p<0.001$) and smoke water addition ($p<0.05$). The implications of our results for conservation of urban fynbos fragments are discussed and further, more detailed investigation of this topic is recommended.

INTRODUCTION

At present invasive exotic plant species are the greatest threat to the remaining natural vegetation of the fynbos biome. Although the list of invasive species inhabiting the fynbos includes many grasses, exotic trees and shrubs are generally considered to be a greater cause for concern (Macdonald 1984, Richardson *et al.* 1992), and as such, have received most attention in the past. However, two studies documenting the problem of grass invasion in lowland fynbos (Campbell *et al.* 1980, Vlok 1988) have demonstrated the marked negative effect of exotic grasses on the diversity of native species, suggesting that grass invasion may be an underestimated threat to the indigenous flora. The fact that grass invasion is most apparent in lowland areas (Vlok 1988) is particularly worrying, as lowland fynbos is amongst the most threatened vegetation types in South Africa and contains many rare and endemic plant species.

Exotic grass invasion represents a serious threat to natural ecosystems in many parts of the world (D'Antonio & Vitousek 1992). Not only have grasses been shown to be capable of outcompeting native species in a wide variety of ecosystems, but they may also alter ecosystem processes by producing changes in rates of nutrient cycling (Wedin and Tilman 1990) and fire frequency (D'Antonio and Vitousek 1992).
As well as being responsible for the movement of exotic grasses to all parts of the globe, man is also the primary culprit in the invasion of natural vegetation by grass (D'Antonio & Vitousek 1992). A number of different forms of anthropogenic disturbance may trigger grass invasion or increased dominance of grasses in natural vegetation.. One of these is the addition to natural areas of nutrients, and in particular nitrogenous compounds, from sources such as agricultural fertilizers and airborne pollution. (Bobbink, Hornung & Roelofs 1998). A direct effect of nitrogen addition in N-limited environments is a change in competitive interactions between species, with more nitrophilic species being favoured over characteristic species (Bobbink *et al.* 1998, Lee & Caporn 1998). It is well known that grasses often fall into the former

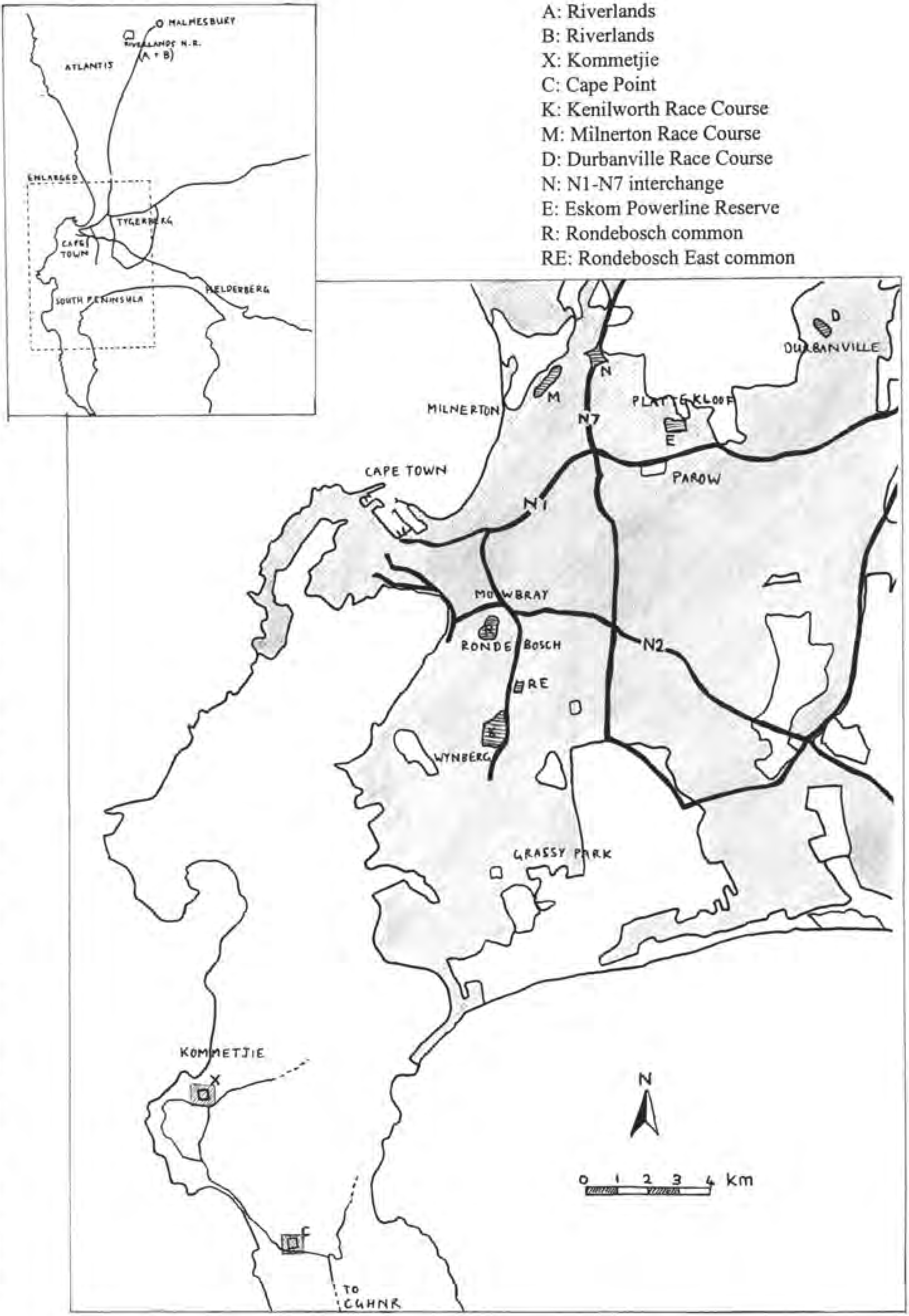
group, increasing strongly in vegetation as a result of increased nutrient availability. Nutrient poor systems such as heathlands are particularly vulnerable to the effects of nutrient addition as species from these environments are generally only competitive on soils with low nitrogen levels (Chapin 1980) and may be negatively affected by even low levels of N addition (Lamb and Klaussner 1988)

Anthropogenic emissions of nitrogenous air pollutants have resulted in rates of atmospheric N deposition that are 5-20 times higher than natural levels in many parts of Europe and North America (Stulen *et al.* 1998). They occur predominantly in industrialized regions, largely from fossil fuel combustion. The accumulation of nitrogenous compounds in the soil as a result of atmospheric deposition, has proved to be an important factor in allowing increased dominance of certain grasses in many European ecosystems (Bobbink & Willems 1987, Bobbink *et al.* 1998, Bobbink 1998, Lee & Caporn 1998). Some of the worst affected vegetation types in countries such as Holland, Britain, Norway and Sweden, are heathlands which, in places, have been transformed into monospecific stands of grass in response to comparatively low levels of N addition.

The Cape Flats of the South Western Cape, South Africa, are home to acid sand plain fynbos, a highly endangered type of lowland heath. Here, 92 Red Data Book species and 14 Cape Flats endemics occur in remnant patches of natural vegetation amongst the urban sprawl of Cape Town (Rebelo 1992). The Cape Flats are also the centre of industrial activity in the Greater Cape Town Metropolitan Area. Thus, the worrying observation that grass invasion is taking place in many of the remnant fynbos sites in the area prompted us to consider whether nutrient additions from deposition of airborne pollutants or other sources might be a contributing factor. The current study is a preliminary investigation of this possibility. A nitrophilic species (radish) is used as a phytometer, to gauge the favourability for growth of soils from urban sites compared to those from rural control sites. An attempt is also made to demonstrate the negative effects of grass invasion on seedling establishment and diversity of native species at Kenilworth race course, by removal of grass cover and addition of smoke water.

STUDY SITES

The study was conducted at a number of sites in the South-Western Cape province, South Africa (Figure 1). Brief site descriptions are included in Appendix 1.
In order to test our hypothesis that sites in closer proximity to urban areas would be affected to a greater degree by nutrient addition, it was necessary to include both inner city sites and more rural sites (controls) in our experiment. While the sites needed to be drawn from a fairly wide area, it was also necessary to chose sites which were as similar as possible in terms of soil type, drainage and vegetation in order for growth data from the different locations to be comparable in a meaningful way. Thus, all sites chosen, with the exception of Cape Point (a fairly wet lowland fynbos flat just outside the CGHNR), can be broadly classified as acid sand-plain fynbos. Eight core sites were chosen for the phytometer experiment. The four city sites were Kenilworth Race Course (K), Milnerton Race Course (M), Eskom Powerline Reserve (E) and N1-N7 interchange (N). Very few acid sand plain fynbos sites presented themselves as



A: Riverlands
B: Riverlands
X: Kommetjie
C: Cape Point
K: Kenilworth Race Course
M: Milnerton Race Course
D: Durbanville Race Course
N: N1-N7 interchange
E: Eskom Powerline Reserve
R: Rondebosch common
RE: Rondebosch East common

Figure 1: A map of the Greater Cape Town Metropolitan area, showing the study sites. Control sites are shown in blue and city sites in red.Grey indicates built up areas.

controls for the city sites. It was decided to include two sites south of the Cape Town at Kommetjie (X) and Cape Point (C), and two sites at Riverlands (A & B) about 60 km north of the city. In addition to the eight core sites, a further three city sites, Durbanville Race Course (D), Rondebosch common (R) and Rondebosch-East common (RE) were included in other analyses. Care was taken to avoid core sites which showed signs of having been severely disturbed, invaded by woody exotic species such as alien *Acacias*, or burnt in the recent past. Two of the additional sites (RE and R) can be considered to be fairly seriously disturbed, however. It was also later dicovered that the Eskom PLR had in the past, been subject to fairly dense invasion by alien *Acacias* in parts, although it is not clear whether the sampled area was one of these.

Methods

The study was divided into three parts:

Part A attempted to establish whether the level of grass invasion is more pronounced in city sites than in rural locations. Nine sites, five close to developed areas (Kenilworth, Milnerton, Plattekloof, Durbanville and N1-N7 interchange) and four further afield (Riverlands A and B, Wildevoelvlei and Cape Point) were sampled. In each site, a 50m transect was walked through undisturbed vegetation and the dominant element at a point was noted every 10 cm. The following categories were used: Open (i.e. no cover. Sparse cover with small/weedy herbaceous perennials e.g. *Oxalis, Cotula* was also considered to be open), Indigenous (mostly shrubs and restioids, including indigenous grasses) and Exotic grass. Buffalo grass (*Stenotaphrum secundatum*) and Kweek (*Cynodon dactylon*) were considered here to be exotic grasses, and the presence of *S. secundatum* was also noted separately. Observations of grass were subdivided into those where grass occurred in the open and those where grass was established under or amongst indigenous vegetation. These data were then used to calculate percentages of invasive grasses present at each of the sites and to assess the degree to which grass establishes under the indigenous overstorey.

In order to address the question of whether grass invasion in control sites is limited by grass supply, ten *S. secundatum* runners (± ten nodes and a growing tip) were planted out at Riverlands, five each at sites A and B, in late May. Surviving plants were removed in mid- October.

Part B investigated the hypothesis that grass invasion in lowland fynbos fragments is, to some extent, aided by nutrient additions to the soil from air pollution (deposition of nitrogenous compounds) and/or other sources.

Phytometers

Phytometers were used to determine whether the soil from urban sites provided better conditions for the growth of weedy species than soil collected from control sites. Eight sites were chosen, four urban (Plattekloof, N1-N7 interchange, Kenilworth, Milnerton), and four further afield (Riverlands A and B, Wildevoelvlei, Cape Point). At each site ten soil cores were extracted from the ground using an open-ended piece of black PVC piping as a corer. Cores were taken in open, ungrassed patches in order to exclude, as far as possible, any effects of grass litter on soil nutrient levels. Areas disturbed by moles or molerats were avoided. The corer was inserted into the ground so as not to disturb the strata and a soil core (approximately 20 cm long and 7 cm in diameter) was extracted. The corer was then placed on top of a growth core made of the same PVC piping glued to a base of strong plastic. The growth cores also had small holes (about 2-3mm wide) drilled into the columns near the base for drainage. The core of soil was then slid down into the growth core using an aerosol can of a suitable size as a plunger. Care was taken to prevent significant mixing of the soil layers so that the topsoil layer was transferred to the growth core intact and in an upright position . The cores were stored in a dark cupboard for between 1 and 3 weeks prior to the growth experiment.

The 80 soil cores collected were transferred to a growth chamber (25°C,14 hrs light:10 hrs dark). Each core was planted with three "Cherry Belle" radish seeds obtained from Starke-Ayres at about 20 mm deep. Plants were watered every second day. After approximately a week the comparatively less successful seedlings were removed leaving one seedling per core. Plants were harvested after 24 days, oven dried for 24 hours at 60°C and weighed to three decimal places. The means for city and control sites were tested for statistical differences using a Kruskal -Wallis non-parametric ANOVA (STATISTICA version 5.1, Statsoft, USA,1998).

Organic matter, Total N and pH

At each of the 11 sites, surface soil was sampled from ungrassed patches and combined to make up bulk soil samples of 500g or larger. As with the cores it was attempted as far as possible to avoid recently disturbed soil. In addition to this, bulk soil samples were also collected for Kenilworth R.C., Milnerton R.C. and Plattekloof from under exotic grass cover. The fourteen soil samples were oven dried at 100°C for 24 hours and sieved (2mm mesh) in preparation for determination of organic matter content, total N content and pH.

Organic matter content

Crucibles were weighed, filled with the soil samples and placed in a drying oven for an hour. Following this they were transferred to a dessicator, weighed and placed in a muffle furnace at 450°C for 24 hours. The samples were then transferred once more to a dessicator and weighed. Initial and final weights were used to calculate % organic matter content.

Total N

Soil total N analysis was by Kjehldahl digestion and titration against an acid standard

PH

Samples were prepared according to the method of Rowell (1994) and pH was measured with a WTW pH 320/set-2 pH meter.

Part C: Effects of exotic grass invasion on the diversity and abundance of indigenous species.

Grass removal and smoke water addition

Negative effects of grass cover on seedling establishment were investigated by removal of grass cover and comparison with control plots. An attempt was also made to stimulate germination of dormant seeds by the addition of smoked water.

Kenilworth was chosen as the study site because of its high concentration of rare or endangered species and the high level of grass invasion. The most important grass species in the area is *Stenotaphrum secundatum* which dominates the understorey, forming a dense mat. An area of about $100m^2$ was selected which was subject to fairly severe grass invasion and twenty 2m x 2m plots were demarcated in grassy patches with low shrub cover. The plots were then randomly assigned to one of four treatments so that each treatment was replicated on five plots. The treatments were as follows: 1.Grass cleared, Smoke water applied, 2. Grass cleared, Pure water applied 3. Grass not cleared, Smoke water applied, 4. Grass not cleared, Pure water applied. Grass removal took place on the 20/06/99. The predominant exotic grass species, *S. secundatum* spreads by surface runners which are removed relatively easily without much damage to the surrounding area. Removal of indigenous species was avoided as far as possible, but some cases of mistaken identity were unavoidable. Water/smoked water treatments were carried out the following day. Smoke plots were sprinkled evenly with 4l of smoke water using a watering can, while control plots were watered with plain tap water. Smoke water is produced by bubbling smoke derived from *Passerina vulgaris* and grass material, through water (see Brown 1993 for more detail), and is commercially obtainable from the seed biology unit at NBI.

Plots were sampled on the 14/09, after a growth period of around 12 weeks, in order to quantify the effects of grass removal and smoke water addition on seedling emergence. Three 25 x 25cm quadrats were placed randomly in each plot and the number of seedlings were counted. 'Seedlings' were defined as new individuals smaller than about 5cm, germinating from seed or appearing from underground storage organs, except in the case of Iridaceae, where individuals below about 15cm were considered to be seedlings . Seedlings were generally rather small and difficult to identify to any level of taxonomic precision. They were thus assigned to one of the following categories: Wachendorfia (*W. paniculata*), Iridaceae (probably including Hypoxidaceae), Oxalis (inluding *O. purpurea* and *O. versicolor*), Cliffortia (probably *C. ferruginea*), Passerina (*P.vulgaris*), Psoralea , Asteraceae (including *Stoebe*, *Helichrysum* and others), Sedge, and Other (unidentified dicots). Number of seedlings in the three quadrats were then totalled for each 2x2m plot and used to estimate plot diversity, defined as the number of the above categories including 3 or more individuals.

In order for results to be compared statistically it was necessary to pool the above categories into four, as follows: Total seedlings (all the above categories); Monocots (Irids, Wachendorfia and sedges), Dicots (Passerina, Asteraceae, Cliffortia, Psoralea and Other - not including Oxalis) and Oxalis. The inclusion of Oxalis in the analysis is questionable as it was unclear whether all the seedlings counted were in fact new individuals. The effects of smoke, grass clearance, and their interaction on the above-mentioned four categories as well as diversity, were investigated using a two-way ANOVA, after data had been tested for normality (Lilliefors test) and heterogeneity of variances (Levene's test). However, because recruitment in control plots was very low for both normal and smoke water, analysis by ANOVA obscured the effects of smoke on seedling emergence to a large extent. Thus it was decided to investigate the effects of smoke water on all 11 original categories by comparing growth in cleared plots only, using a t-test for independent samples. Data with heterogenous variances were log transformed and if this did not solve the variance problem, a Mann-Whitney U-test was used. Because of the variable nature of the data and the size constraints on experimental design, statistical power was rather weak, and thus P-values are considered significant at the ten percent level ($P < 0.10$) rather than the standard level of five percent.

Establishment of geophytes and response to grass cover

The abundant flowering of geophyte species at Kenilworth R.C. during the experimental period provided an ideal opportunity to test whether flowering geophytes showed a negative response to grass cover. A 30m line transect was walked through a patch of vegetation where two geophytic species, *Wachendorfia paniculata* (Haemadoraceae) and *Spiloxene capensis* (Hypoxidaceae) were flowering, and the type of vegetation cover (grass or indigenous veg), or lack thereof, was noted every 20 cm. All flowering individuals of *W.paniculata* and *S.capensis* within approximately 1 m on either side of the transect were examined, and it was noted whether they were established in the categories of grass, indigenous vegetation (mostly restios) or open patches. The observed frequencies with which the species occurred in each of the categories were then compared to the frequencies, calculated from the line transect, with which the species would be expected to occur if there was no preference for one category or the other. This was done by means of a Chi-square test.

Results

Part A: Extent of grass invasion

Grass invasion as measured along the transects was clearly higher in the city sites than in the controls and was most pronounced at Kenilworth (Figure 2). At Milnerton, Durbanville and Kenilworth, Buffalo grass (*Stenotaphrum secundatum*) was the most dominant invasive species accounting for 76%, 88% and 89% of grass observations, respectively. *S. secundatum* was not present at the other sites. With the exception of Cape Point, control sites had a greater proportion of open ground relative to city sites (Figure 2). Grass in the five city sites was established in the open and under or amongst indigenous vegetation in roughly equal proportions (46.4 ± 7.1 % under indigenous vegetation)

Of the ten *Stenotaphrum* runners planted out at Riverlands, only two were retrieved, both from site B. Both runners were shrunken and unhealthy looking, with very little foliage present. The other eight runners were presumably eaten by herbivores, as there was no sign of them.

Part B: Determinants of grass invasion

Growth of phytometers was generally poor and was highly variable both within and between sites (Figure 3). This is particularly true of Milnerton and Kenilworth. For instance, certain cores from Kenilworth were notably more clayey than others, and lack of drainage in these cases seemed to negatively affect growth. Although city sites as a whole had faster growth rates than control sites (Kruskal-Wallis ANOVA, $H = 6.68$, $N = 78$, $p < 0.0098$), this pattern is by no means consistent when individual sites

~~Figs 2 and 3~~

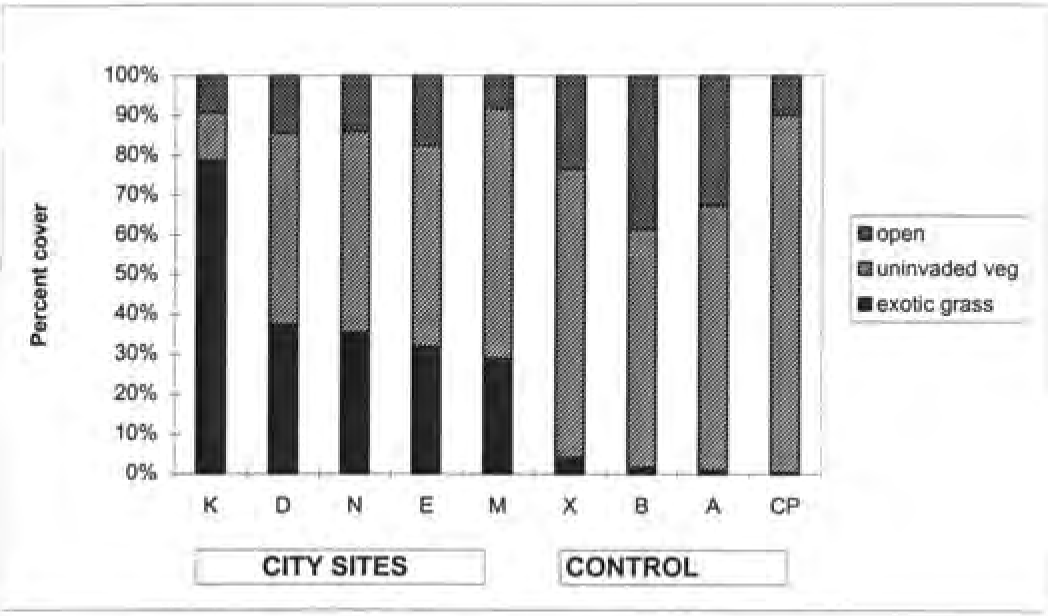


Figure 2: Percentage cover of open ground, natural vegetation and exotic grass as determined from 50m transects.

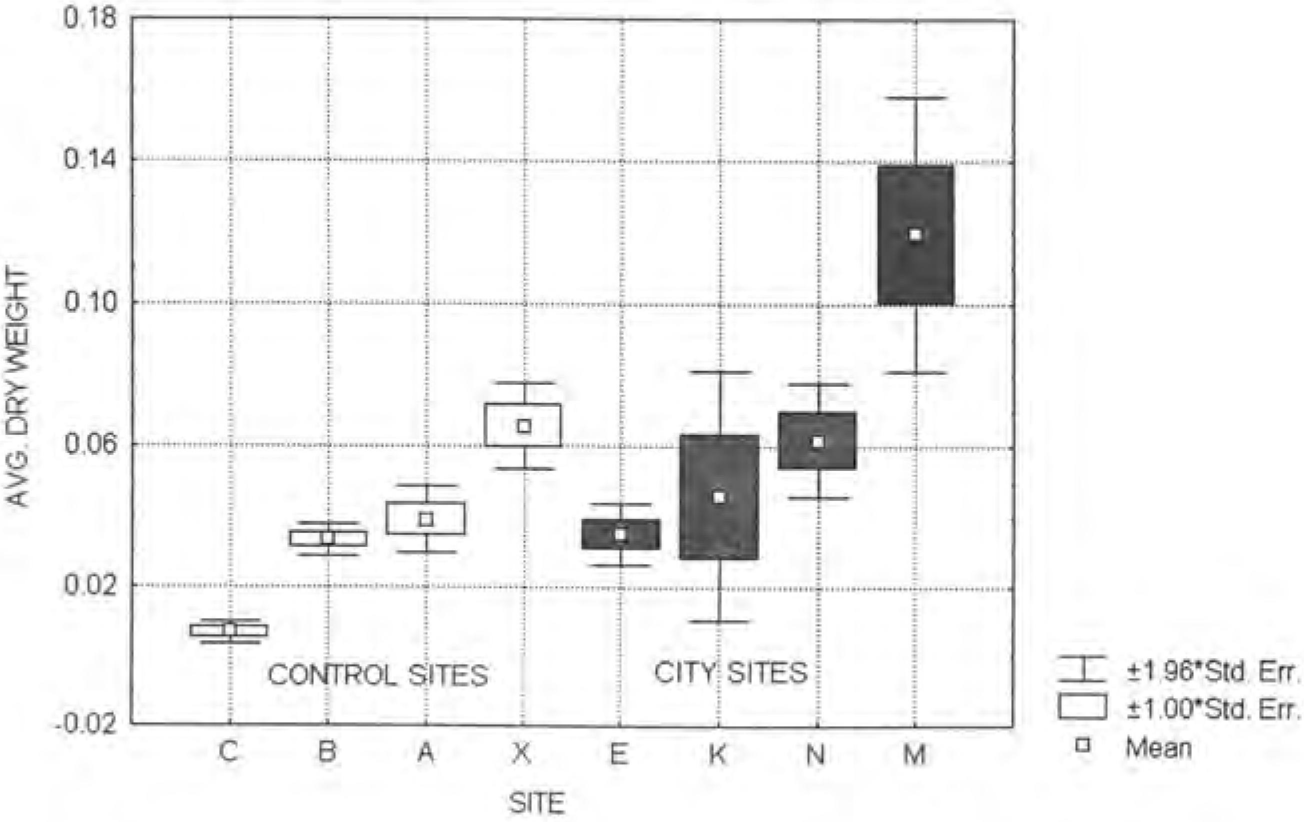


Figure 3: Average dry weight of radish phytometers for the eight core sites after 24 days growth under controlled light and temperature conditions.

are compared. In fact, the most important factor affecting growth appears to be soil pH (Table 1). A regression of pH against dry weight shows that, on the whole, growth is better in more alkaline soils (Figure 4). On observing Figure 4 it is apparent that the control sites all lie below the regression line while the city sites, with the exception of Eskom PLR, lie on or above the line. In particular, Kenilworth and Milnerton have much higher growth rates than predicted by the regression line. As is often observed, total N is well correlated with soil organic matter ($R^2 = 0.92$). However, the very high values measured for Kenilworth make this an extremely influential site. If the two Kenilworth measurements are removed, the correlation is not as clear and a (possibly) interesting trend is observed (Figure 5). The control sites fall on or below the regression line while the city sites, with a few exceptions, fall above the line i.e. city sites tend to have slightly higher soil total N content than predicted by their organic matter contents.

It is evident from Table 1 that soil organic matter, pH and total N are all increased under grass cover for Kenilworth and Milnerton. The opposite situation observed for Eskom PLR is likely to be a result of a sampling error.

Part C: Negative effects of grass invasion on natural vegetation

Grass removal and smoke water addition

The effects of grass removal, smoke water addition, and the interaction of these two treatments on seedling emergence are illustrated in Figures 6-10 for various vegetation components. Approximately 4 months after grass removal, numbers of seedlings in cleared plots were significantly higher than in uncleared plots for total seedlings, dicots and monocots (Table 2). Diversity of seedlings was also significantly higher in cleared plots. Establishment of *Oxalis* seedlings was not significantly affected by removal of grass, however.

Table 2: F-values and statistical significance for the 2-way ANOVA testing the effects of grass clearance, smoke water addition and their interaction on seedling emergence at Kenilworth Race Course. For data see Figures 6-10

	Smoke water	Grass clearance	Interaction
Total seedlings	3.46 *	19.90 ***	3.54 *
Dicots	2.13	11.62 ***	2.06
Monocots (non-graminoid)	0.23	10.33 ***	0.39
Oxalis	0.57	0.22	0.57
Diversity	0.17	16.56 **	3.22 *

* P<0.1, ** P<0.05, *** P<0.01, n.s = not significant

While the ANOVA results show that smoke water addition and the interaction of smoke water and grass removal had a significant effect ($p < 0.10$) on the total number of seedlings emerging per plot, clear significant results were prevented by the fact that smoke water had little influence on recruitment in uncleared plots. However, when cleared plots treated with water and smoke water were compared by means of a t-test, results were only slightly better (Table 3).

Table 1: Soil organic matter, pH and total N content for the 11 study sites. Also included are values for soil collected from under grass cover at Kenilworth, Milnerton and Eskom PLR. Error values are 1 S.D.

Site	Organic matter (%)	pH	Total N (ppm)
Cape Point	1.80	3.9	0.047
Riverlands B	0.78	4.7	0.034
Riverlands A	0.92	4.6	0.047
Wildevoelvlei	1.04	5.4	0.046
AVERAGE	**1.14 ± 0.46**	**4.7 ± 0.61**	**0.044 ± 0.006**
Eskom PLR	1.10	4.9	0.050
Kenilworth RC	3.95	3.9	0.110
Milnerton RC	1.10	5.6	0.057
N1 interchange	0.86	5.0	0.048
Durbanville RC	1.90	4.7	0.060
Rondebosch Common	1.38	4.3	0.064
Rondebosch-East Common	1.94	4.5	0.081
AVERAGE	**1.75 ± 1.05**	**4.7 ± 0.54**	**0.067 ± 0.021**
Eskom PLR (under grass)	1.06	4.6	0.042
Kenilworth RC (under grass)	5.43	4.0	0.145
Milnerton RC (under grass)	1.31	6.3	0.068

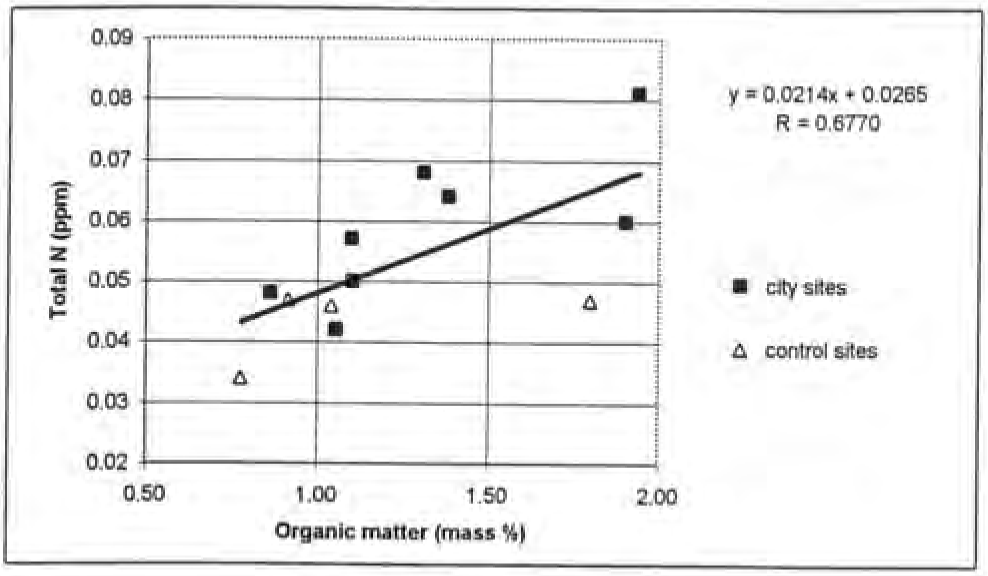


Figure 4: Linear regression of soil pH against average dry weight of radish phytometers for core sites

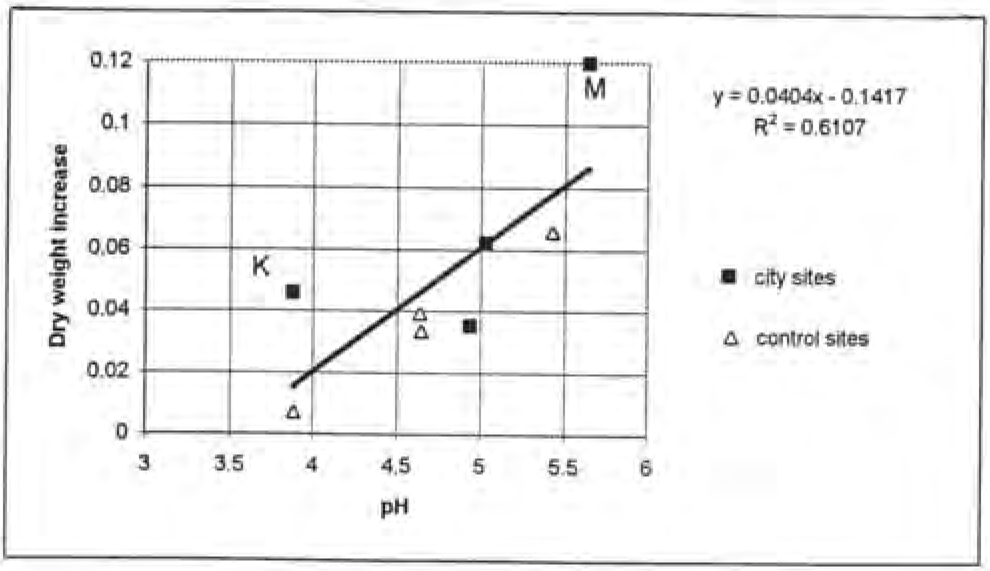


Figure 5: Linear regression of soil organic matter content against soil total N for all sites excluding Kenilworth Race Course.

Figures 6-10: The effects of grass removal and smoke water addition on seedling emergence after 12 weeks at Kenilworth Race Course.

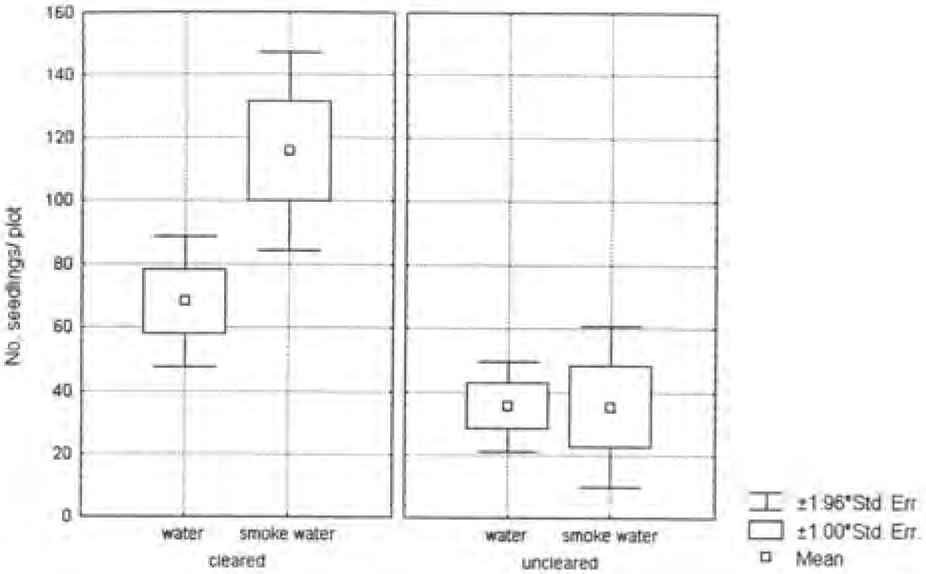


Figure 6: Total seedlings

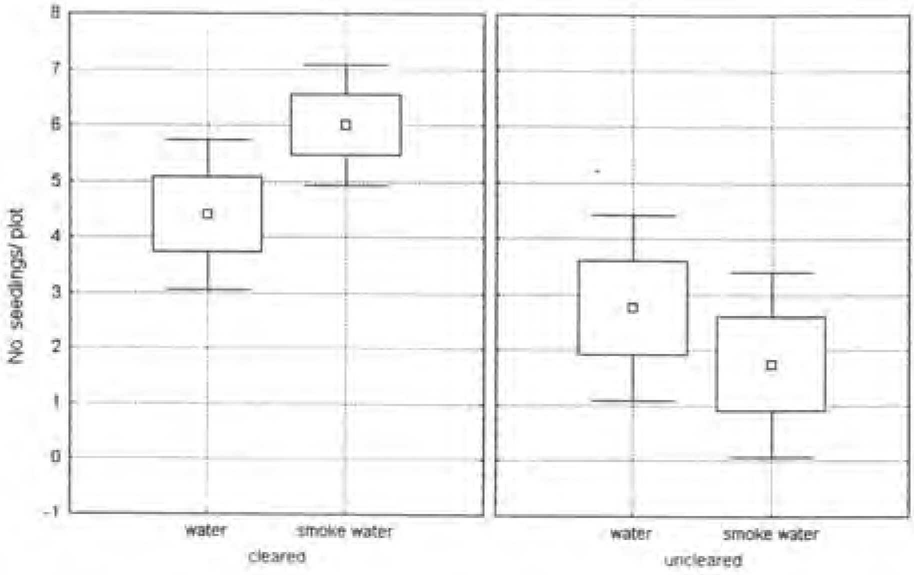


Figure 7: Diversity

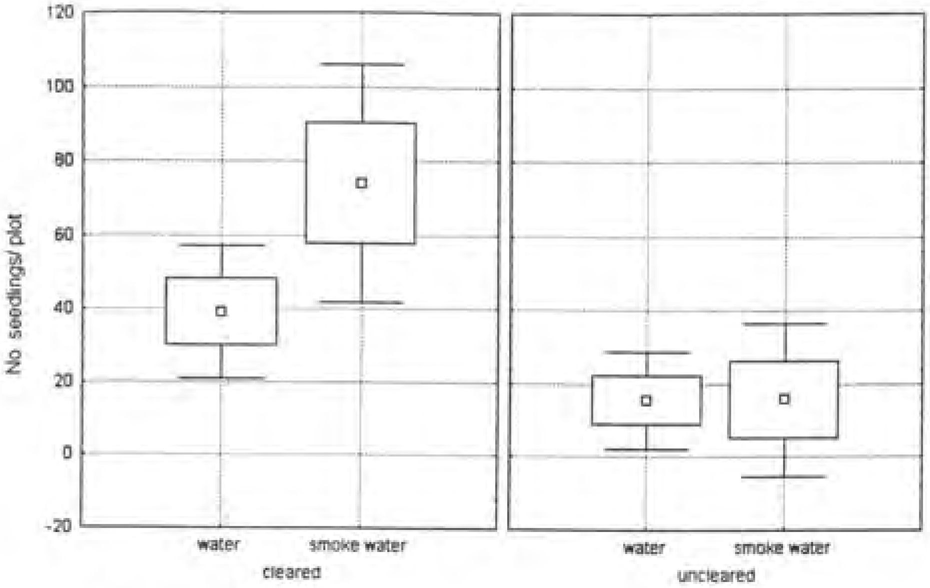


Figure 8: Dicots

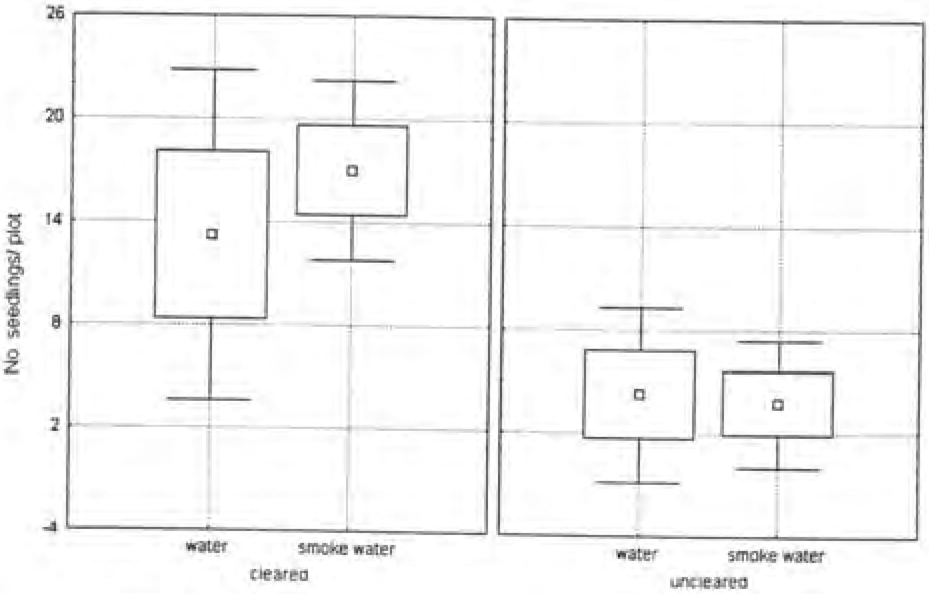


Figure 9: Monocots

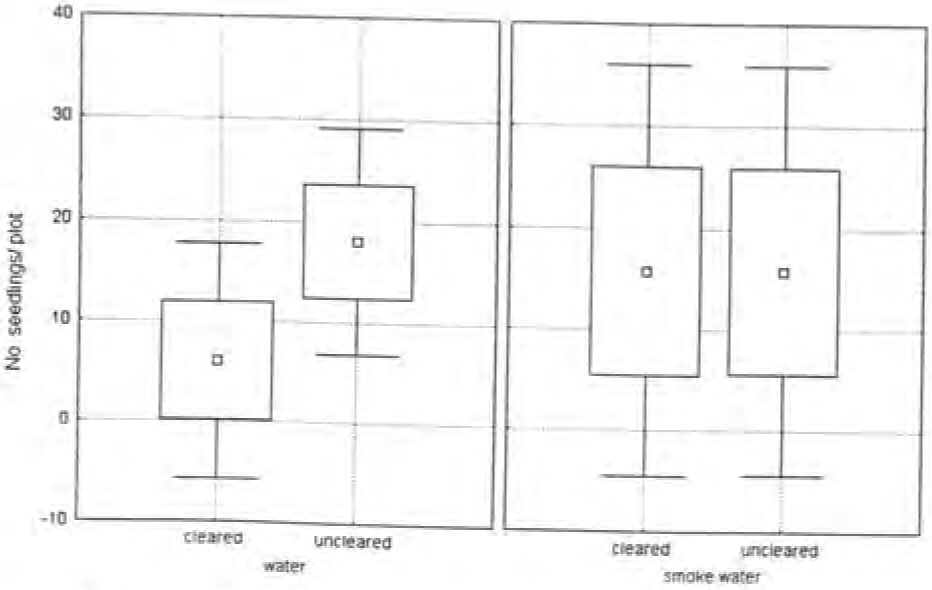


Figure 10: Oxalis

Table 3: The effects of smoke water addition on seedling emergence in cleared plots at Kenilworth Race Course. Analysis is by means of a Tukey t-test for independent samples (df =8)

	Mean no.	**seedlings**		
Variable	**water**	**smoke water**	**t**	**Significance**
Total seedlings	68.2	115.6	-2.48	$p < 0.05$
Dicots	39.2	74	-1.85	n.s.
Monocots	13.2	17	-0.68	n.s.
Diversity	4.4	6	-1.83	n.s.
Asteraceae	2	6.4	-2.107	$p < 0.10$
Passerina	12.8	37.6	-1.97	$p < 0.10$
Oxalis	6	18	-1.45	n.s.

n.s.= not significant

Of the pooled groups, only total seedlings was significantly higher in smoke water plots. Although dicots as a whole did not respond significantly to smoke water addition, response in Passerina and Asteraceae was significant at the ten percent level (Table 3). Responses of all other categories were not significant and are not reported here.

Establishment of geophytes in relation to grass cover

The investigation of geophyte response to grass cover shows that the two species respond differently (Table 4). *Spiloxene capensis* shows no preference for gaps over grassed or covered patches, while *Wachendorfia paniculata* clearly prefers to establish in open patches.

Table 4: Frequency of Wachendorfia paniculata and Spiloxene capensis in grassed or ungrassed patches in comparison to degree of grass cover. Comparison between observed and expected values is by means of a Chi-square test.

	W.paniculata		*S. capensis*	
observations	observed	expected	observed	expected
in grass	35	51.5	21	20.25
in open	49	22	6	8.65
under indig. veg.	5	15.5	8	6.10
total	**89**		**35**	
	$\chi^2 = 45.54$ df = 2 $p < 0.0001$ significant		$\chi^2 = 1.437$ df = 2 $p < 0.489$ n.s.	

DISCUSSION

Where is grass invading ?

Many of the sites discussed in this study are fairly heterogeneous in terms of vegetation, and grass invasion levels may vary widely within sites. Thus more replication would be needed to accurately gauge grass invasion levels in city sites relative to controls. However, a brief visit to any of the sand-plain fynbos remnants on the Cape Flats will reveal that invasion by non-native grasses is a reality. In fact, as we discovered, it is difficult to find uninvaded lowland fynbos control sites for the purposes of comparison. In contrast to lowland fynbos, exotic grasses are, for the most part, conspicuous in their absence from mountain fynbos. Vlok (1988) attributed this, in part, to the fact that lowland fynbos is generally more open than mountain fynbos. Our results show that the control sites, with the exception of Cape Point, have a greater proportion of open ground than the invaded city sites, indicating that grass is able to occupy these gaps in the city sites. However, approximately 50 % of grass recorded was established beneath or within the canopy of indigenous shrubs or restioids. At Kenilworth, cases were observed where *Stenotaphrum* had completely over-run small shrubs. Thus, the suggestion of Jobst (1996) that shrub cover is a major factor in reducing annual grass invasion in fynbos, does not appear to hold for lowland fynbos, particularly in the case of perennial grasses such as *Stenotaphrum*.
It seems likely that the explanation for high levels of grass invasion in lowland fynbos sites lies in their close proximity to urbanised areas, rather than any fundamental difference in vegetation structure between lowland fynbos and mountain fynbos.

Nutrient addition ?

One of the primary objectives of this study was to ascertain whether nutrient additions from atmospheric or other sources of pollution are triggering grass invasion in lowland fynbos sites within the environs of Cape Town. Our results do not provide a conclusive answer to this question one way or another. There are a number of reasons for this. The major difficulty was that a number of different factors seemed to interact in determining the growth of our phytometers. Our results indicate, at least for radishes, that pH is the primary factor controlling growth rate. The probable reason for this is that low pH reduces the ability of the plant to acquire nutrients from the soil. Substantially higher growth rates occurred at Milnerton and Kenilworth than were predicted by the pH regression line. This is likely to be a result of the higher soil total nitrogen at these sites (Table 1), although, as discussed earlier, total N is not an accurate indication of the N available for uptake. Other factors influencing phytometer growth rates might have included drainage and concentrations of other limiting nutrients such as phosphorus.

Total N is, in turn, influenced greatly by soil organic matter content. In general, city sites had higher organic matter content than controls. Although no attempt was made to measure water content at our sites, this pattern is likely to relate to soil moisture, with slower breakdown of organic matter occurring in wetter sites. It also seems possible that this was due, in part, to the input of grass litter, even though sampling was conducted so as to exclude this influence as far as possible. Despite these complications however, city sites in general had higher N contents than control sites for comparable levels of organic matter (Figure 6). This might be interpreted as an indication that some other source of nitrogen is contributing towards the higher values in city sites, although the number of other variables involved makes this interpretation somewhat uncertain. We believe however, that the findings of this preliminary study are suggestive enough to warrant further, more intensive investigation of this potential threat.

Why is grass invading ?

Although our results are inconclusive, nutrient addition is a factor which may be contributing grass invasion on the Cape flats. Pollution levels in Cape Town, and particularly over the Cape flats, may be fairly substantial, although deposition of emissions is likely to be limited by the prevailing winds in Cape Town, which regularly disperse air pollution out to sea (Stock and Allsopp, 1992). Never the less, natural atmospheric input of nitrogen in the South-Western Cape is low (Stock and Lewis, 1986), and small changes in rates of input due to deposition of airborne pollution could be important in a nutrient-poor vegetation type such as sand-plain fynbos. It is also important to note that the severity of impact depends on the duration of input (Bobbink *et al.* 1998), and thus continual slow rates of N deposition may, in the long term, constitute significant inputs. In addition to possible problem of deposition of airborne pollutants, other sources of nitrogen pollution including herbicides, insecticides, fire retardants, runoff from fertilized land and fertilizer, deliberately applied to natural vegetation, could also be important in certain areas (Stock and Allsopp, 1992). The extremely species rich natural vegetation surviving at the three race courses included in the present study (Milnerton, Kenilworth and Durbanville) may be particularly at risk from fertilizer drift, as the natural areas consist of tiny islands surrounded on all sides by carefully maintained race-track to which fertilizer is applied. In public open spaces such as Eskom PLR and Rondebosch and Rondebosch-East commons, dog faeces and urine may even represent a significant nitrogen input.

Even if nitrogen addition is shown to be occurring, it is difficult to infer a direct link with grass invasion, as a number of other factors could be partly responsible or could interact with nitrogen addition to trigger the invasion of grass. For example, in Holland, many species-rich wet heathland sites have become become monospecific stands of the grass *Molinia caerulea*, which is able to outcompete the dominant shrubs at high N availability (Bobbink *et al.* 1998). However, in dryer lowland heaths dominated by the ericoid *Calluna vulgaris*, increased N only seems to allow grass to flourish once some form of disturbance (in this case, herbivory by chrysomelid beetles) opens up the dwarf shrub canopy. Disturbance, both anthropogenic and natural, is often cited as being an important factor initiating grass invasion (e.g. Richardson *et al.* 1992, Macdonald 1987, D'Antonio and Vitousek 1992) by creating open spaces which may be rapidly colonized. Undoubtedly, anthropogenic disturbances such as trampling, vegetation clearance and too frequent fires, have played a substantial role in the invasion of grasses in city sites. Another disturbance agent that may be particularly prominent in lowland fynbos is burrowing activity of molerats, as these animals show a preference for loose sandy substrates, which occur mainly in the lowlands (Smithers 1983). However, pristine sand plain fynbos is a rather open vegetation type with large bare spaces usually occurring between indigenous shrubs (see Figure 1), and molerats constantly creating new gaps. Thus it seems unlikely that grass invasion into undisturbed vegetation at our control sites is limited by a lack of open space. If nutrient addition is a real problem in urban lowland fynbos fragments, however, the interaction between increased N availability and soil disturbance is likely to produce particularly favourable conditions for grass invasion.

Another possibility is that invasion may be limited by the proximity of grass. Sites near the city are likely to be subject to higher levels of grass seed supply than those further afield. Our attempt to transplant *Stenotaphrum secundatum* into the uninvaded Riverlands sites was aimed at addressing this question. The fact that *S. secundatum* was able to survive at/may suggest that dispersal is limiting invasion by this species, although this is unlikely for a number of reasons. First of all, the two runners retrieved were extremely dehydrated and unhealthy, indicating that the plants were barely surviving. In counter to this argument, *S. secundatum* may have been a bad choice of species for transplantation, as it seems to prefer wet conditions. However, the fynbos sites at Riverlands are surrounded by fields which support many exotic grass species, but these are hardly ever observed amongst the pristine fynbos.
The fact that the other eighteen *S.secundatum* runners were in all likelihood, eaten by grazers, raises the question of whether seed predation or grazing of newly established plants limits grass invasion. In an experiment at Riverlands, Jobst (1996) observed high rates of both seed predation by rodents and grazing by antelope and concluded that seed predation was a very important controlling factor of grass invasion. It is conceivable that the absence of large herbivores and perhaps, reduced numbers of seed predators in the city sites, may contribute to the success with which grass is able to invade in these areas.

When discussing grass invasion, it is probably inaccurate to generalise, as different grass species are likely to be favoured under different conditions. Previous studies by Vlok (1988), Campbell (1980) and Jobst (1996) have focused only on the problem of invasion by annual species. One of the most serious problem species identified in this study is the prostrate perennial, *Stenotaphrum secundatum*. Although, *S. secundatum* was listed as a problem plant in South Africa by Wells *et al.* (1986), the species is generally considered to be harmless, and is widely promoted as an ecologically friendly lawn grass. In the current experiment, *S. secundatum* was only identified as a problem at Kenilworth, Durbanville and Milnerton race courses. Several properties of these sites might make them particularly susceptible to invasion by *S. secundatum*. Firstly, all three sites can be classified as seasonal wetlands. While *S. secundatum* is able to withstand dry conditions as demonstrated by our transplants at Riverlands, it seems to favour wetter conditions and can often be found growing on seeps and riverbanks and not in the surrounding areas (pers. obs.). However, seasonal wetlands also occur at Cape Point and Riverlands, and *S. secundatum* is absent from these areas. A second factor which might allow *S. secundatum* to dominate is an absence of fire. Whereas many grass species are favoured by frequent fires (D'Antonio and Vitousek, 1992), *S. secundatum* seems for the most part to be killed by fire (pers. obs), spreading as it does by surface runners. The three race courses in the present study are unique, in that fire has been excluded from these areas for long periods (more than 60 years in the case of Kenilworth- phone McDowell). In fact, senescence of older shrubs may be one of the factors which creates the opportunity for *Stenotaphrum* to invade. Finally, as discussed earlier, contamination by fertilizers may be particularly important at race-courses, although our sites may just be particularly susceptible to grass invasion by virtue of naturally higher soil N levels. Thus, a long fire cycle in combination with favourable conditions such as high N and plentiful water supply, may allow this *S. secundatum* to dominate at these sites.

Effects of grass invasion on natural vegetation

The much higher levels of seedling emergence observed in cleared plots relative to controls appears to demonstrate clearly that the dominance of grass, and in particular *S.secundatum*, at Kenilworth race course has a negative effect on seedling establishment of indigenous species. It is important to recognize, however, that this result may be somewhat exaggerated, as direct disruption of the seed bank (which is unavoidable during grass removal) is known to stimulate seed germination (D'Antonio *et al.* 1998). Despite this complication, the effects of grass invasion were plain to see. Almost no seedlings were found beneath *S. secundatum*, and in uncleared plots, seedlings were only able to survive in small gaps without grass cover. *Oxalis* and to a lesser extent, *Cliffortia* seedlings were particularly dominant in these gaps, hence the result that number of *Oxalis* 'seedlings' was not significantly affected by grass removal. The very low levels of seedling emergence under *S. secundatum* can be attributed for the most part to a lack of light reaching the soil surface. It is likely, however, that *S. secundatum* is also able to compete successfully with established individuals for other resources. Grasses have been shown to compete effectively with indigenous species for light (e.g. Thompson and Harper, 1988), water (e.g. Melgoza et al. 1988, Eissenstat & Caldwell, 1988) and nutrients (e.g. D'Antonio *et al.* 1998). Because of their shallow root systems, grasses are likely to be particularly competitive against seedlings or other shallow rooted species with which they are in direct competition for resources (D'Antonio & Vitousek 1992).

Although grass cover was shown to significantly affect diversity of emerging seedlings, it is unfortunate that a more accurate estimate of this effect was prevented by the difficulties with identification. Kenilworth race course is very species rich (McDowell & Low 1990) and diversity is likely to be greatly reduced by grass cover in the long term. Annuals and geophytes, which are summer dormant, would be likely to be particularly badly affected, as was shown by Campbell *et al.*(1980) and Vlok (1988) for other lowland fynbos sites. Amongst the geophytes, Vlok (1988) noted that taller species (above 30 cm) were more tolerant of grass invasion and suggested that this was due to the fact that taller plants are better able to compete for light. Personal observation suggests that this is generally the case at Kenilworth. However, the different responses of *Wachendorfia* and *Spiloxene* to grass cover (both of which are generally taller than 30 cm), indicated by our experiment, suggest that certain species are better able to cope with grass invasion than others, by virtue of factors other than height.

Smoke water

Persistant elements at Kenilworth, such as perennial shrubs, are likely to be less affected by grass invasion than annuals and geophytes, because they are long-lived and may have deep roots which do not compete directly with grasses for resources. Furthermore, the seeds of many of these plants require stimulation by fire in order for

germination to occur. In our experiment, clearance did have a significant effect on germination in shrub seedlings e.g. *Passerina*, although this may largely have been the result of seedbank disturbance. Overall rates of germination were significantly increased by the addition of smoke water, however, indicating the possible usefulness of smoke water in restoration ecology. The two specific groups which responded most significantly, *Passerina* and Asteraceae, have been shown in the past to be particularly responsive to smoke water (Brown 1996). The lack of a significant response in (petaloid) monocots and *Oxalis* was to be expected, as these species are emerging from underground storage organs rather than germinating from seed, and thus are not stimulated by smoke.
The effect of smoke water on diversity of seedlings germinating was not as pronounced as might have been hoped. This is likely to be due to the fact that smoke water was applied so late in the growing season (late June). In the past, maximum seedling recruitment in the fynbos has been achieved when smoke water is applied in February or March, before the arrival of the rainy season (Brown 1993, Brown *et al*. 1994). Because smoke water was applied so late in the current experiment, it is likely that seedling regeneration may be delayed until next year in certain species (Brown, pers. comm.). It would thus be of interest to monitor the Kenilworth experimental plots in future, to see if this is the case.

Ideally, in order for the high species diversity at Kenilworth race course to be maintained in the long term, controlled burning is necessary. It is suggested that, apart from being essential part of the life cycle of many species at Kenilworth, a burn would also be an effective means of dealing with the problem of grass invasion, presuming that *S. secundatum* is killed by fire (although it is conceivable that other grass species present in the area may benefit from fire and become dominant in the post-fire environment). Burning of land within the environs of Cape Town is, however, a sensitive issue. Concern on the part of race course officials and local residents is understandable and the matter needs to be carefully negotiated. If, for some reason, a burn is not allowed, the removal of grass and the use of smoke water as a germination cue for soil stored seed is likely to be the next best thing. This approach would, however, be far more costly than a burn, and would be unlikely to achieve as good a result. In particular, species which require heat in order to break seed dormancy would not be affected by smoke water.

CONCLUSION

The invasion of acid sand-plain fynbos fragments on the Cape flats by exotic grasses is a wide-spread problem that has the potential to seriously affect species diversity. The reasons for grass invasion in these areas are likely to be various but may include the addition of nitrogenous compounds from atmospheric pollution and other sources in combination with disturbance. Given the very high conservation priority of these areas, we believe that the findings of this preliminary study are suggestive enough to warrant further, more intensive investigation of this potential threat.

ACKNOWLEDGEMENTS

The following people are thanked for advice and personal communications; Neville Brown, Doug Jeffery, Kristal Maze and Clive McDowell. Thanks to Eddie Luff for allowing me to conduct experiments at Kenilworth Race Course. Steve Gibson, Dave Gwynne-Evans, Adam Harrower, Jeff Shapiro, Michael Wilson and Peter Wilson helped with sampling. Finally, thanks to my supervisor William Bond for his constant encouragement and admirable patience.

REFERENCES

Bobbink R & Willems JH (1987) Increasing dominance of Brachypodium pinnatum (L.) Beauv. in chalk grasslands: a threat to a species rich ecosystem. *Biol. Conserv* **40**:301-314.

Bobbink R (1998) Impacts of tropospheric ozone and airborne nitrogenous pollutants on natural and semi-natural ecosystems: a commentary. *New Phytologist* **139**:161-168

Bobbink R, Hornung M & Roelofs JGM (1998) The effects of air-borne nitrogen pollutants on species deiversity in natural and semi-natural European vegetation. *J. Ecol.* **86**:717-738.

Brown NAC (1993) Promotion of germination of fynbos seeds by plant-derived smoke. *New Phytologist* **123**:575-583

Brown NAC, de Lange JH, van Staden J & Baxter BJM (1994) Plant derived smoke: An important, newly-discovered natural cue for seed germination. Current research and its application to Australian plant species.In: O'Connell KA & Barrett DR (eds.) *Proceedings of the 3rd international conference on environmental issues and waste management in energy and mineral production.* University of technology, Perth.

Campbell BM, Gubb A & Moll EJ (1980) The vegetation of the Edith Stevens Cape Flats Flora Reserve. *Jl.. S. Afr. Bot.* **46**:141-148.

Chapin FS (1980) The mineral nutrition of wild plants. *Annu. Rev. Ecol. Syst.* **11**: 233-260

Cowling RM (1991) A preliminary report on the flora and vegetation of the Wildevoelvlei flats in the Noordhoek/ Kommetjie basin. *FCC report* **91/2**. Botanical Society of South Africa.

D'Antonio CM & Vitousek PM (1992) Biological invasion by non-native grasses, the grass/fire cycle and global change. *Annu Rev. Ecol Syst.* **23**:63-87.

D'Antonio CM, Hughes RF, Mack M, Hitchcock D & Vitousek PM (1998) The response of native species to removal of invasive exotic grasses in a seasonally dry Hawaiian woodland.

Eissenstat DM & Caldwell MM (1988) Competitive ability is linked to rates of water extraction. A field study of two aridland tussock grasses. *Oecologia* **75**:1-7

Jobst P (1996) *The invasive potential of non-native annual grasses in the Western Cape*. Honours thesis, University of Cape Town.

Killian D (1995) Dreams for the Dassenberg: A report on the current conservation status and future options for flora conservation in the Dassenberg-Mamre-Riverlands area. *FCC Report* **95/2**. Botanical Society of South Africa.

Lamb AJ & Klaussner E (1988). Response of the fynbos shrubs Protea repens and Eric plukenetii to low levels of nitrogen and phosphorus applications. *S. Afr. J. Bot.* **54**:558-564.

Lee JA & Caporn SJM (1998) Ecological effects of atmospheric reactive nitrogen deposition on semi-natural terrestrial ecosystems. *New Phytologist* **139**:127-134.

Macdonald IAW (1984). Is the fynbos biome especially susceptible to invasion by alien plants ? A re-analysis of available data. *S. Afr. J. Sci.*. **80**:369-377.

Macdonald IAW, Clark DL & Taylor HC (1987). The alien flora of the Cape of Good Hope Nature Reserve. *S. Afr. J. Bot.* **53**:398-404.

McDowell CR & Low AB (1990) *Conservation priority survey of the Cape Flats*. University of the Western Cape, Cape Town.

McDowell CR (1991) Environmental survey and management plan for the Plattekloof Natural Heritage site. Environmental education and resources unit, University of the Western Cape.

Melgoza G, Nowak RS & Tausch RJ (1990) Soil water exploitation after fire: competition between *Bromus tectorum* (cheatgrass) and two native species. *Oecologia* **83**:7-13

Rebelo AG (1992) Preservation of biotic diversity. In: Cowling RM(ed.). *The Ecology of Fynbos; Nutrients, Fire and Diversity* p.309-344. Oxford University Press. Cape Town.

Richardson DM, Macdonald IAW, Holmes PM & Cowling RM (1992) Plant and animal invasions. In: Cowling RM(ed.). *The Ecology of Fynbos; Nutrients, Fire and Diversity* p.271-308. Oxford University Press. Cape Town.

Rowell DL (1994) Soil Science: Methods and Applications. Longman Scientific and Technical, New York.

Smithers, R.H.N. (1983) *The Mammals of the Southern African Subregion*. University of Pretoria. Pretoria.

Stock WD & Allsopp N (1992) Functional perspective of ecosystems. In: Cowling RM(ed.). *The Ecology of Fynbos; Nutrients, Fire and Diversity* p.241-259. Oxford University Press. Cape Town.

Stock WD & Lewis OAM (1986) Atmospheric input of nitrogen to a coastal fynbos ecosystem of the south-western Cape Province, South Africa. *S. Afr. J. Bot.* **52**:273-276

Stulen I, Perez-Soba M, De Kok LJ & van der Eerden L (1998) Impact of gaseous nitrogen deposition on plant functioning. *New Phytologist* **139**: 61-70

Thompson L & Harper JL (1988). The effect of grasses on the quality of transmitted radiation and its influence on the growth of white clover Trifolium repens. *Oecologia* **75**:343-347.

Vlok JHJ (1998) Alpha diversity of lowland fynbos herbs at various levels of infestation by alien annuals. *S. Afr. J. Bot.* **54**:623-627.

Wedin DA & Tilman D (1990) Species effects on nitrogen cycling: A test with perennial grasses. *Oecologia* **84**:433-441

Wells MJ, Balsinhas AA, Joffe H, Engelbrecht VM, Harding G & Stirton CH (1986) A catalogue of problem plants in Southern Africa. *Memoirs of the Botanical Survey of South Africa* **53**.

APPENDIX: Study sites

CONTROL SITES

Riverlands (A & B)

(Killian 1995)

Vegetation Type: Site A: fynbos on white acid sands with a clay layer at 50cm
Site B: fynbos on deep, yellow acid sands

Conservation status: Nature reserve

Species richness: Very high

Comments: Riverlands Nature Reserve is extremely species-rich and is home to at least 41 critically rare and endangered plant species (Killian 1995). The main threat to conservation in the area is the invasion of alien acacias which are dominant at the margins of the reserve. Sampling was conducted in the relatively alien-free central area of the reserve although a few *Acacia* seedlings were observed.

Cape Point (C)

Vegetation Type: fynbos on acid sands.

Conservation status: none

Species richness: high

Comments: The site sampled was a wet flat dominated by restios and *Serruria sp* and was situated near the road margin, a short distance outside the CGHNR.
Although the site cannot strictly be classified as acid sand-plain fynbos, it was considered sufficiently similar for comparison, as it was situated on deep acid sands with no rocks impeding drainage.

Kommetjie (X)

(Cowling 1991)

Vegetation type: fynbos on deep orange acid sands overlying limestone.

Conservation status: falls within the CPPNE.

Species richness: very high

Comments: Sampling was done in a small patch of fynbos on the margin of the Wildevoelvlei flats, accessible from Wireless Road in Kommetjie (± 2min walk). At the time of sampling, parts of the stand had been earmarked for development and damage by construction vehicles was evident on the outskirts. The vegetation at Wildevoelvlei flats is the last remaining patch of its type within the Peninsula and Cape flats and contains at least 16 threatened taxa (Cowling 1991).

CITY SITES

City site information is from McDowell & Low (1990) unless otherwise stated.

Kenilworth R.C.

Vegetation type: Fynbos on sands overlying granite with localised seasonal flooding

Conservation status: Currently none

Species richness: very high

Comments: Kenilworth R.C. has a very high conservation value as it supports a number of rare and endangered endemics. A recent impact assessment has approved development on the outskirts of the natural area and a proposal has been put forward to afford the natural area official conservation status (D. Jeffery pers. comm.). The area chosen for sampling was moderately wet, with damper and dryer sections being incorporated into the sampling. The sampling area (as for most of the surrounding area) was densely covered with Buffalo grass (*Stenotaphrum secundatum*). Some disturbance was evident; a number of *Psoralea's* had been chopped down and an old footpath passed through the area.

Durbanville R.C

Vegetation: fynbos on deep acid sands
Conservation status: none
Species richness: very high
Comments: Most of the natural vegetation in the central island of the race-course has been cleared and replaced with grass, so that only a small area of fynbos remains. A number of exotic grass species are invading including *Stenotaphrum* and in one corner, apparently a dumping site, Kikuyu (*Pennisetum clandestinum*). A few myrtles (*Leptospermum laevigatum*) are also present in the area.

Milnerton R.C.

Vegetation: Fynbos on acid sands near the border with strandveld
Conservation status: none
Species richness: very high
Comments: Like Kenilworth and Durbanville, Milnerton race course is extremely species rich. Substrate and vegetation is very heterogeneous, and sampling was done in an area of fairly deep white sands, dominated by restios. The race course is no longer operational and has recently been sold. Development is proposed for some of the badly disturbed areas but it is likely that most of the remaining natural vegetation will be afforded official conservation status in the near future (D. Jeffery pers. comm.). An impact assesment of the area is currently under way.

Eskom Powerline reserve
Vegetation: fynbos on deep white acid sands
Conservation status: natural heritage site
Species richness: very high
Comments: Plant diversity varies widely over the reserve, mainly as a result of differences in the severity of past disturbance (McDowell 1991). Parts of the area that have been highly disturbed are dominated almost completely by grass. Other areas were previously infested with alien acacias which have long since been removed. Sampling was conducted in what appeared to be a relatively undisturbed patch of fynbos. However, sources of disturbance in the reserve are many e.g. people walking their dogs, littering etc. by vagrants who inhabit the reserve, refuse deposition.

Rondebosch Common
Vegetation: fynbos on acid sands overlying laterite hard pan
Conservation status: National monument and commonage
Species richness: very high

Comments: Rondebosch common has a long history of fairly severe disturbance. At present, the site is a popular area for walking dogs, is inhabited by vagrants. and is burned frequently (approximately annually). Despite this, the site still preserves a remarkable diversity of species, although proteoids and restioids have long been absent. Grass invasion is rife with *Pennisetum clandestinum* probably the biggest threat.

Sampling was done in the south west corner where sands are fairly deep and shrub cover is still present.

Rondebosch East Common

Vegetation: previously fynbos on acid sands but now almost completely dominated by grass

Conservation status: none

Species richness: low

Comments: Rondebosch East Common is a small patch of land off Kromboom road in RE, that has been severely disturbed in the past by activities such as vegetation removal and mowing, and no shrubs remain. However, a variety of indigenous species (particularly geophytes) still survive including the red data book species *Hessea cinnamomea* and *Chondropetalum rectum*. The area was included in the analysis as a highly disturbed site.

N1/N7 interchange

Vegetation: fynbos on deep yellowish acid sands

Conservation status: none

Species richness: very high

Comments: The area is rather small and is surrounded on all sides by busy roads. Vegetation is closely allied to that at Eskom PLR. Some planting of exotic trees and *Protea spp.* which do not occur naturally in the area, has occurred around the fringes.