Diversity and Distributions, (Diversity Distrib.) (2004) **10**, 99–103

BIODIVERSITY RESEARCH

Impact of the invasive alien grass *Melinis minutiflora* at the savanna-forest ecotone in the Brazilian Cerrado

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ABSTRACT

Exotic grasses are a serious threat to biodiversity in the cerrado savannas of central Brazil. Of particular concern is the possible role they may have in impeding tree regeneration at gallery (riverine) forest edges and increasing fire intensity, thereby driving gallery forest retreat. Here we quantify the effect of roads and distance from gallery forests on the abundance of the African grass *Melinis minutiflora* Beauv. and test for an effect of this species on woody plant regeneration and leaf area index. *Melinis* was present at approximately 70% of the sites near gallery forest edges, with its frequency declining sharply at greater distances from the edge. *Melinis* frequency was 2.8 times greater where roads were present nearby. Leaf area index (LAI) of the ground layer was 38% higher where *Melinis* was present than where it was absent. LAI was strongly correlated to fine fuel mass ($r^2 = 0.80$), indicating higher fuel loads where *Melinis* was present. The abundance of tree and shrub species in the ground layer was negatively related to LAI and to the presence of *Melinis*. The greater fuel accumulation and reduced tree regeneration caused by *Melinis* may cause a net reduction in forest area by increasing fire intensity at the gallery forest edge and slowing the rate of forest expansion.

Keywords

Alien species, biological invasions, exotic species, fire, savanna, tropical gallery forest.

INTRODUCTION

Worldwide, exotic plants are one of the primary threats to biodiversity, primarily because invasive species exclude native species through competition. Invasive grasses can additionally increase fuel loads, and consequently increase fire frequency and intensity (D'Antonio & Vitousek, 1992; Platt & Gottschalk, 2001; Rossiter *et al.*, 2003), thereby reducing fire-sensitive native species. Fire often increases the abundance and diversity of exotics (Hughes *et al.*, 1991; Milberg & Lamont, 1995; D'Antonio *et al.*, 2000), resulting in a positive feedback enhancing the dominance of the exotic grasses and more intense fires (D'Antonio & Vitousek, 1992).

The Cerrado of Brazil is a region of approximately $2.0 \cdot 10^6$ km^2 originally covered predominantly by savanna vegetation. Savanna formations range from open grassland (campo limpo) and open shrub savanna (campo sujo) through tree dominated savanna (cerrado *sensu stricto*) to closed canopy woodland (cerradão, Oliveira-Filho & Ratter, 2002). These savanna formations are typically encountered on acidic soils with low availability of P, Ca, and Mg (Lopes & Cox, 1977). A number of forest types occur within the Cerrado region, including gallery (riparian or riverine) forests that form corridors along streams and dry forests ranging from deciduous to evergreen (Oliveira-Filho & Ratter, 2002)

One of the most problematic exotics in the cerrado region is *Melinis minutiflora* Beauv. (molassas grass or capim gordura). This perennial species is native to Africa, but now occurs widely throughout the tropics, often increasing fire intensity and frequency (D'Antonio & Vitousek, 1992). In the Cerrado, *Melinis* was previously planted as a pasture grass, but more productive exotics are now preferred (Klink & Moreira, 2002). It is already widely established within the Cerrado region, and has become a common problem in conservation areas (Pivello *et al.*, 1999a; Pivello *et al.*, 1999b). *Melinis* can form dense mats that exclude many other herbaceous species (Pivello *et al.*, 1999a; Pivello *et al.*, 1999b), so invaded areas have considerably lower richness and diversity of herbaceous species (Berardi, 1994). *Melinis* has been shown to cause large reductions in growth of the gallery (riverine) forest pioneer tree, *Cecropia* (Morosini & Klink, 1997), so forest regeneration may also be impeded. Furthermore, *Melinis*-dominated sites can result in greater fire temperatures than in natural cerrado, presumably due to greater fuel loads (Berardi, 1994).

The competitive effect of *Melinis*, together with the resulting increase in fire intensity may affect the dynamics of savanna-gallery forest boundaries. The dynamics of savanna-forest boundaries has been described as consisting of gradual forest expansion punctuated by occasional forest retreat due to fire or other disturbance (Hopkins, 1992). If *Melinis* reduces forest tree establishment and increases fire intensity, then this species should reduce the rate of forest expansion while increasing the risk of forest retreat, thereby causing a net reduction in forest area. Since gallery forest soils typically have greater nutrient (Furley, 1992; Haridasan, 1998) and water availability (Askew *et al*., 1970) than savanna, sites near gallery forest edges may be particularly prone to invasion by *Melinis*, which reaches dominance in more productive sites such as those where there is greater nutrient availability (D'Antonio *et al*., 2001; Barger *et al*., 2003). Furthermore, this species was found to be more sensitive to water stress than other grasses of the savannas (llanos) of Venezuela (Baruch *et al*., 1985) and appears to be associated with sites with greater water availability (Pivello *et al*., 1999b), though it is capable of occupying dry sites such as granite outcrops (Killeen & Hinz, 1992).

To demonstrate whether *Melinis* is likely to affect the dynamics of the savanna–forest boundary, we test the hypotheses that *Melinis* abundance is greater near gallery forests, that invasion by *Melinis* results in higher ground-layer leaf area index (LAI) and lower abundance of tree and shrub saplings. Because establishment of exotic species is often enhanced by the presence of roads (Milberg & Lamont, 1995; Gelbard & Belnap, 2003; Gelbard & Harrison, 2003), we test whether *Melinis* invasion is greater near roads.

METHODS

This study was conducted within the experimental station *Fazenda Água Limpa* (FAL) of the University of Brasília and the adjacent Ecological Reserve of the Brazilian Institute of Geography and Statistics (Instituto Brazileiro de Geografia e Estatística — IBGE). Fire has been actively suppressed at IBGE for approximately 25 years, but burned in 1994. Fire suppression has been more recent at FAL, but had not burned for several years prior to the study. These sites occur at 15°46′ S, 47°57′ W at an elevation of approximately 1100 m. Mean annual rainfall at the meteorological station in IBGE was 1426 mm for 1993–2002, with a distinct dry season from May to September Mean temperature was 22.5 °C with Mean annual minimum and maximum temperatures of 6.0 °C and 34.0 °C.

Within these two reserves, three gallery forests were chosen, known locally as the Taquara (IBGE), Monjolo (IBGE), and Onça (FAL) forests. These forests were chosen because each has a road running along one side but not along the other. Transects extending 100 m into the savanna were established perpendicular to the forest edge (Fig. 1). Four transects were established along each of the two edges (i.e. with and without a road) of all three forests, with the exception of the Monjolo forest for which only two transects were established on the side closest to the road, giving a total of 22 transects. All transects began at the savanna–forest boundary, which we define here as the limit of distribution of savanna grasses at the forest edge. The transects were distributed along the length of the gallery forest, with at least 100 m between transect. All sampling was done at the end of the wet season, from April to June 2003.

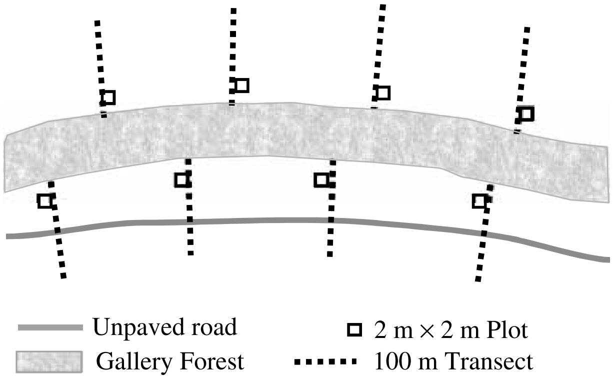

Figure 1 Schematic diagram showing the distribution of plots and transects relative to gallery forest and roads. This experimental design was repeated at three gallery forests.

The presence or absence of *M. minutiflora* was recorded at 1 m intervals along each transect. Presence was defined as the occurrence of the species within a 25 cm radius of the sample point. Additionally, ground-layer leaf area index (LAI) was estimated at each sample point using a LAI-2000 Plant Canopy Analyser (LI-COR, Inc., Lincoln, NE, USA). The LAI-2000 estimates LAI by comparing light intensity at various angles for measurements performed above and below the canopy (LI-COR, 1992). To estimate ground-layer LAI, the above-canopy measurement was performed above the ground layer but under tree cover, when present, as described by LI-COR (1992). For logistical reasons, the LAI measurements were not obtained for six of the 22 transects, but LAI was measured on at least four transects for each gallery forest. The LAI-2000 does not distinguish between living and dead leaf area, so it yields an estimate of green plus brown leaf area of all species in the ground layer, which we use as a proxy for fine fuel load.

To confirm that ground layer LAI is an appropriate surrogate for fine fuel load, we compared LAI with fuel dry mass at 10 locations chosen to represent a range of LAI values. At each location, 10 replicate estimates of LAI were performed using the methodology described above. Subsequently all fine fuels within a 0.5 m × 0.5 m quadrat was harvested, dried to constant mass at 70 °C and weighed.

To evaluate the effect of *M. minutiflora* on woody plant density, a 2 m × 2 m quadrat was centred 5 m from the forest edge for each transect. This distance was chosen so that the plot would be close to the forest, yet guarantee being in savanna vegetation. All individuals of tree and shrub species (subshrubs excluded) within the plots were identified and their heights measured. To test for an effect of *Melinis* on abundance of recruits, linear regression was used to test for a relationship between *Melinis* frequency and density of woody plants with height ≤ 2 m.

Logistic regression was used to test for the effects of roads and distance from the forest edge on the frequency of *Melinis* using SPSS 7.5. The likelihood ratio test was used to test for significance of these two factors and their interaction.

RESULTS

Melinis frequency was greatest at approximately 10 m from the gallery forest edge, declining sharply at greater distances until approximately 50 m from the forest edge, regardless of whether or not a road was present (Fig. 2). Frequency also declined somewhat at distances shorter than 10 m from the forest edge (Fig. 2), though the logistic regression does not capture this level of detail. When the logistic regression was performed with only the data for the first 10 m from the forest edge, there was an increase in *Melinis* frequency with increasing distance ($-2\,L = 4.895$, $P = 0.027$).

Along forest edges where a road is present, *Melinis* was more frequent than along sides without a nearby road (Fig. 2, $-2\,L = 304.6$, $P << 0.001$). In sites without roads, *Melinis* frequency declined more rapidly with distance from the forest edge than in sites with roads (Fig. 2; distance–road interaction: $\times 2\,L = 86.28$, $P << 0.001$). In the 20 m nearest the gallery forest, *Melinis* occurred in 75.4% of the sample sites where a road was present nearby, compared to 46.8% where no road was present. At distances of 80–100 m from the forest edge, *Melinis* was present in 28.9% of the sample sites near roads, but in only 1.2% of the roadless sites.

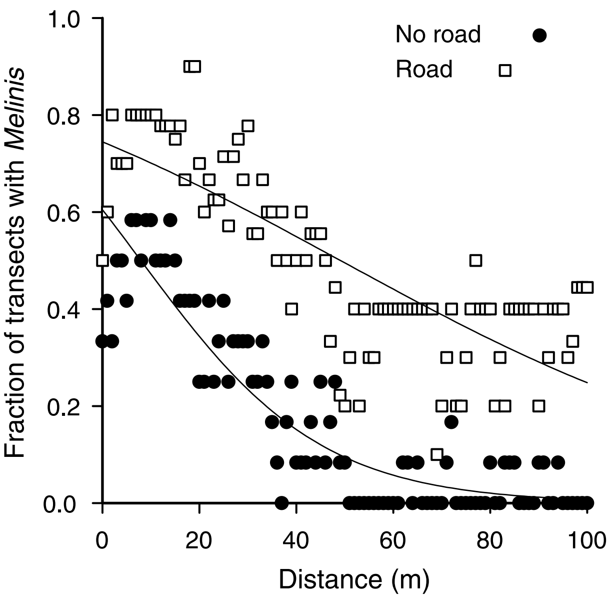

Figure 2 Frequency of *Melinis* in savanna as a function of distance from gallery forest edge. The curves were fitted by logistic regression. The frequency of *Melinis* was significantly affected by distance from the forest edge ($-2\,L = 298.0$, $P << 0.001$) and by the presence of roads ($-2\,L = 304.6$, $P << 0.001$).

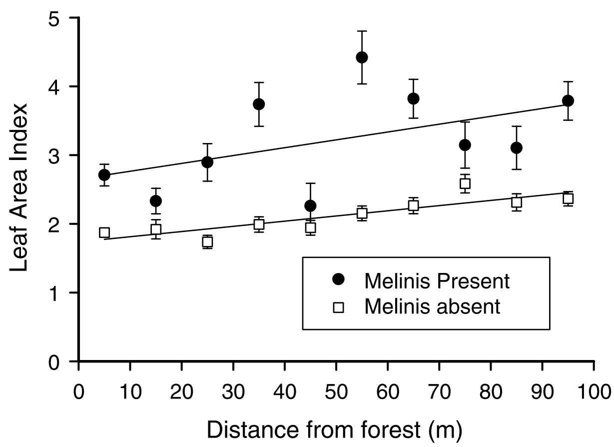

Figure 3 Leaf area index (LAI) ± SE of sites with and without *Melinis*. LAI averaged 38% greater where *Melinis* was present than where it was absent ($F_{1,1349} = 136.0$, $P << 0.001$). LAI includes both green and dead leaf area of all species in the ground layer. LAI measurements were performed at 1 m intervals but were grouped into 10 m intervals for presentation.

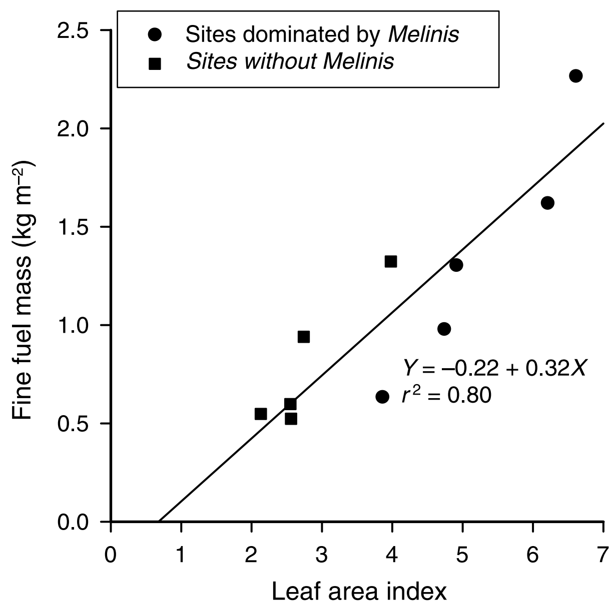

Figure 4 Relationship between LAI and fine fuel loads.

In sites where *Melinis* was present, total LAI (green + dead LAI of all species) averaged 37.8% higher than in sites where *Melinis* was absent (Fig. 3, $F_{1,1349} = 136.0$, $P << 0.001$). There was a tendency for LAI to increase with distance from the forest edge, both for sites where *Melinis* was present ($F_{1,995} = 30.14$, $P << 0.001$) or absent ($F_{1,353} = 87.84$, $P << 0.001$). Because of the greater LAI of *Melinis*, combined with its greater abundance near the gallery forest, the increase in LAI with distance from the forest was weaker when all sites were pooled, but still significant ($F_{1,1350} = 13.36$, $P << 0.001$). There was a strong relationship between LAI and fine fuel loads (Fig. 4, $r^2 = 0.80$, $P = 0.0005$).

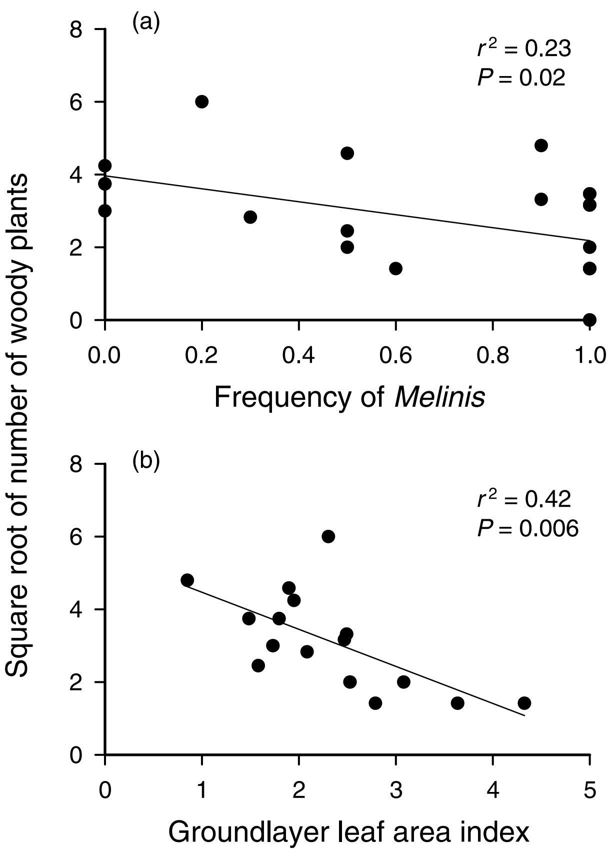

Figure 5 (a) Relationship between frequency of *Melinis* in the 10 m nearest the forest edge and the number of recruits (individuals with height ≤ 2 m) of tree and shrub species per 4 m^2 plot. (b) Relationship between ground-layer LAI in the first 10 m and the number of recruits.

Density of tree and shrub saplings (height ≤ 2 m) at 5 m from the forest edge was negatively correlated to the frequency of *Melinis* (Fig. 5, $r^2 = 0.23$, $P = 0.02$), but the number of species of saplings was unrelated to the frequency of *Melinis* ($r^2 = 0.13$, $P = 0.09$). Density of saplings was negatively correlated with total ground-layer LAI (Fig. 5, $r^2 = 0.42$, $P = 0.006$).

DISCUSSION

The dynamics of savanna-forest boundaries has been described as a balance between gradual forest advance during fire-free intervals and occasional forest retreat due to savanna fires or other disturbances that degrade the forest edge (Hopkins, 1992). The exotic species *Melinis*, which was shown here to be particularly abundant near gallery forest edges, is likely to affect the balance between forest advance and retreat. The greater frequency of *Melinis* near gallery forest edges is probably due to greater availability of nutrients (D'Antonio *et al.*, 2001; Barger *et al.*, 2003) or water (Baruch, 1985) although we observed that it was not common in sites with waterlogged soils.

Melinis dominance permits more intense fires due to greater fuel loads than native cerrado (Berardi, 1994). Total green and dead LAI, which includes all species in the ground layer, was 38% greater where *Melinis* was present (Fig. 3), indicating greater fuel loads (Fig. 4). More intense fires following *Melinis* invasion will tend to cause more damage to gallery forest trees at the forest edge, which are more sensitive to fire than savanna species (Hoffmann *et al.*, 2003). Furthermore, the reduced number of tree and shrub recruits where *Melinis* is present will slow forest advance. Where *Melinis* is present, we expect increased forest retreat when fire is frequent and reduced forest expansion during fire-free intervals, thereby increasing the likelihood of net gallery forest retreat over long periods.

In private lands, grazing may help reduce the threat caused by *Melinis*, as grazing animals appear to preferentially graze *Melinis* relative to native grasses (Lima *et al.*, 1998). In fact, where *Melinis* is present, light gazing can improve forest tree regeneration (Posada *et al.*, 2000), while greatly reducing fuel loads.

In the present study, *Melinis* was present at many points without forming the dense mats typical of the species. Here we only scored sites based on the presence or absence of *Melinis* so we did not distinguish between sites where *Melinis* was merely present and sites where it was truly dominant. As a result we surely underestimate the capacity for *Melinis* to impact LAI and woody plant recruitment, since where these dense mats were found, LAI was typically > 4 and tree and shrub saplings were scarce.

Melinis was much more frequent where a road was present nearby. *Melinis* establishment is favoured by disturbances (Barger *et al.*, 2003) such as that caused by road construction. The unpaved roads typical of these and other conservation areas in the Cerrado require frequent grading, leaving disturbed soil at the roadside. While roads cannot be avoided altogether in ecological reserves, their need and placement must be considered carefully. In particular, roads should be avoided near gallery forests where there is a greater propensity for invasion by *Melinis*.

In the two reserves where this study was conducted, fire is suppressed with considerable success, so fire frequency is much lower than for typical cerrado sites. As a result the forest edge has ample time to recover between infrequent fire events. In fact, forest expansion into cerrado in these two reserves has been observed over the last couple of decades (Ratter, 1992; M.C. Silva Junior, pers. comm.). As a result the gallery forest edge in many of the locations studied here were rather diffuse, in contrast to the sharp savanna-gallery forest boundaries that are typical where savanna fires are common.

In contrast, in unprotected areas, the extent of these forests has declined in recent decades, despite being protected by the Brazilian Forest Code. For example, in the Federal District, the area of these forests declined by 47% from 1954 to 1998 (UNESCO, 2000). Even where illegal cutting had been eliminated, it is unclear whether these forests will be able to recover their original area, as fire and alien grasses such as *Melinis* will undoubtedly reduce the capacity for these forests to regenerate naturally.

ACKNOWLEDGEMENTS

We thank Manoel Claudio da Silva Junior for help with plant identification and three anonymous referees for helpful comments.

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