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Impact of invasion by molasses grass (*Melinis minutiflora* P. Beauv.) on native species and on fires in areas of *campo-cerrado* in Brazil

Rafael Drumond Rossi[1,5], Carlos Romero Martins[2], Pedro Lage Viana[3], Evandro Luís Rodrigues[4] and José Eugênio Côrtes Figueira[1]

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ABSTRACT

In the Cerrado Biome of Brazil, African grasses constitute a serious problem, occurring in virtually all protected areas. Molasses grass (*Melinis minutiflora* P. Beauv.) accumulates more biomass than do most other species of the herbaceous stratum vegetation native to the Cerrado. In this study, our aim was to determine the impact of *M. minutiflora* on native vegetation, as well as (using simulations of fire traits) on the characteristics of fires, in invaded areas of the Serra do Rola-Moça State Park (*Parque Estadual da Serra do Rola-Moça*, PESRM), a protected area where fires are frequent, in the state of Minas Gerais, Brazil. Our main results are that *M. minutiflora* considerably increases the amount of biomass, becoming the main combustible plant in the *campo-cerrado* (grassy-woody savanna) fires in the PESRM; that the native monocot biomass is inversely correlated with the *M. minutiflora* biomass, suggesting suppression of the native herbaceous stratum; that eudicots are diminished by *M. minutiflora*, both in number of individuals and number of species; and that fires are more severe in *M. minutiflora*-invaded areas.

Key-words: Cerrado, BehavePlus, biological invasion, fire intensity, savannah

Introduction

The most economically important cattle forage grass species in the Neotropics are those native to Africa (Parsons 1972). African grasses are also used for recovery of degraded areas and as slope cover along highway and railway embankments (Reis *et al.* 2003; Martins 2006). They are easily exportable due to their invasive characteristics (Foxcroft *et al.* 2010), causing a global problem (Hughes *et al.* 1991; Barger *et al.* 2003; Martins 2006; Dogra *et al.* 2010; Foxcroft *et al.* 2010) through biological contamination of natural ecosystems (Espíndola *et al.* 2005). In Brazil, African grasses were introduced during the colonization period of the 16th century (Diamond 1999; Zenni & Ziller 2011) and were commonly used for pasture after deforestation (Parsons 1972; Fearnside 2005). Owing to their great ability to invade open areas, they also became a serious problem in the Cerrado Biome (Pivello 2014), becoming common in several of its protected areas (Pivello *et al.* 1999a; 1999b). The African grass *Melinis minutiflora* P. Beauv. (molasses grass), widely distributed in South America, Hawaii, Australia, Central America, Asia and Oceania (Hughes *et al.* 1991; Barger *et al.* 2003; Martins 2006), is commonly found in Brazil (Pivello 2014), where it had been the most commonly used species for pastures until the beginning of the 1970s, when programs to replace it with more productive grasses began (Martins 2006). Its introduction into the state of Minas Gerais most likely dates back to the 18th century (Biodiversitas *et al.* 2006).

Although the genus *Melinis* P. Beauv. comprises 22 species (The Plant List, 2014), only *M. minutiflora* and *M. repens* (Willd.) C. E. Hubb. occur in Brazil (Biodiversitas *et al.* 2006; Filgueiras *et al.* 2010). Molasses grass grows vigorously in the nutrient-poor and aluminum-rich soils of the Cerrado Biome (Gonçalves & Borges 2006; Martins *et al.* 2011). It blooms at the beginning of the dry season, in mid-May, producing large amount of seeds with a germination rate of approximately 90% (Alcântara & Bufarah 1951; Martins 2006; Carmona & Martins 2009). Studies within different ecosystems around the world indicate that molasses grass can form dense cover in invaded areas, changing nutrient cycles, light availability and soil microclimate (Barger *et al.* 2003), thus slowly replacing native species of the herbaceous stratum (Martins *et al.* 2004; Martins *et al.* 2009). Because of its higher biomass accumulation

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[1] Universidade Federal de Minas Gerais, Instituto de Ciências Biológicas, Departamento de Biologia Geral, Avenida Antônio Carlos nº 6.627, Pampulha, Belo Horizonte, MG, Brasil – CEP: 31.270-901.

[2] IBAMA/DILIC, SCEN Trecho 2, Ed. Sede do IBAMA, Brasília, DF, Brasil – CEP: 70.818-900.

[3] Museu Paraense Emílio Goeldi. Avenida Magalhães Barata, 376, São Braz, Belém - PA, 66040-170, Brasil.

[4] Universidade Federal de Minas Gerais, Instituto de Geociências, Avenida Antônio Carlos n.º 6.627, Pampulha, Belo Horizonte, MG, Brasil – CEP: 31.270-901.

[5] Author for correspondence: rafeldr@gmail.com

rates, compared to those of the native herbaceous stratum (Berardi 1994; Silva & Haridasan 2007), and its abundant oil secretions (Prates *et al.* 1993), this grass can also change fire regimes in invaded areas, promoting its further expansion in a feedback mechanism known as the "grass-fire cycle" (Hughes *et al.* 1991; D'Antonio & Vitousek 1992).

In the Cerrado Biome, several important protected areas suffer from invasion by molasses grass. Some of these are the Brasília National Park, the world's largest natural conservation area in an urban environment (Martins 2006; Zanin 2009); the Emas National Park, an important reserve in the Central Plateau (França *et al.* 2007); and the Serra do Rola-Moça State Park (*Parque Estadual da Serra do Rola-Moça*, PESRM), which protects areas of the Cerrado in the iron-stone vegetation and areas of the Atlantic Forest (Biodiversitas *et al.* 2006). The PESRM is considered a priority area for biodiversity conservation in the state of Minas Gerais because of its high levels of biodiversity and endemism. Large patches of molasses grass in this park increase its vulnerability to fire, one of its main threats (Biodiversitas *et al.* 2006). However, the impact of molasses grass on native vegetation and its effects on fire properties have been largely unevaluated.

In an attempt to address parts of this knowledge gap, this study had the following goals: to determine whether native species are being suppressed due to invasion of molasses grass; to assess the magnitude of the increase in combustible plant biomass resulting from the molasses grass spread in an area of the grassy-woody savanna (*campo-cerrado*) vegetation; and to simulate and compare characteristics of fires in the *campo-cerrado* areas with different degrees of molasses grass invasion.

Material and Methods

Study area

The PESRM is located in the northwestern part of the region known as the Iron Quadrangle, a transition area between the Atlantic Forest and the Cerrado Biomes, in the metropolitan area of Belo Horizonte, the capital of Minas Gerais. The main vegetation formations found in the PESRM are the semideciduous forest; the woody savanna (*cerradão*); the grassy-woody savanna (*campo-cerrado*, or *cerrado sensu stricto*); and the sandstone and ironstone grasslands. Molasses grass is found in all of those formations, with the exception of the semideciduous forest. The climate of the region is mesothermal, characterized by an annual mean temperature of 25°C, high daily thermal variation, high winds, and a dry season from April to September (Biodiversitas *et al.* 2006). The molasses grass patches studied are located near the park headquarters (20º03'07.1"S; 44º00'00.0"W). The *campo-cerrado* vegetation is predominant in the study areas, with sparse trees embedded in an extensive matrix of grasslands.

Biomass increase and elimination of native monocots

Vegetation sampling was carried out in April and May 2009. Twenty plots of 0.5 × 0.5 m were randomly selected in a *campo-cerrado* field invaded by molasses grass and protected from fires for over 13 years. The vegetation within each square was cut at ground level, collected, bagged in 100-L plastic bags and taken to the laboratory. In the laboratory, the biomass was separated into live and dead fractions of its various components: molasses grass; native monocots; native eudicots; and litter (composed of dry fragments of grass blades, stems, etc.) The biomass components were then dried in an oven at temperatures of approximately 60°C to a constant weight, after which they were weighed with a precision balance. The monocot species of the study area were identified from the specialized literature and by comparison with specimens at the Herbarium of the Federal University of Minas Gerais, in Belo Horizonte (BHCB).

Linear regression, Pearson's correlation coefficient or both were used in order to test the hypotheses that molasses grass is the main component of the total biomass, leads to the biomass reduction of native monocots and is correlated with a large increase in the amount of litter found in the plots. To compare the standing dead biomass between the native grasses and molasses grass, we used ANCOVA. When necessary, log transformations were used in order to linearize the data or to homogenize variances and normalize residuals.

Elimination of eudicots

From June to August 2011, vegetation sampling was also carried out at other field patches that had been invaded, or not, by molasses grass and protected from fires for over fifteen years. Linear transects were set in invaded and non-invaded patches, and samples of all eudicots in 0.7 × 0.7 m plots, one meter apart, were collected. The size of the molasses grass patches limited the number of plots sampled in each area. There were 50 plots sampled for each condition (invaded vs. non-invaded) in area 1; 100 plots for each treatment in areas 2 and 3; and 70 plots for each treatment in area 4. All eudicots were identified, and the number of individuals of each species for each plot (sampling unit) were determined in order to estimate the species richness in the invaded and non-invaded areas, with the richness estimator index ACE (abundance-based coverage estimator). To compare the density of species in invaded and non-invaded transects, we used the Mann-Whitney U test.

Fire simulations

The BehavePlus Fire Modeling System is a collection of over 40 semi-physical models described in 58 reference papers that predict wildland fire behavior and its environmental effects. It is among the most widely used systems for wildland fire prediction. Planning prescribed fires, fuel hazard assessment, and training are among the BehavePlus applications (Andrews 2009; 2014). Using the BehavePlus, Mistry & Berardi (2005) obtained results substantiated by previous studies in the *cerrado* fires. Fernandes (2003) did simulation with BehavePlus in the PESRM and also obtained satisfactory results. The lowest relative air humidity (11%), and mean wind speeds (13.9±8.7 km/h) in August of the years 2011, 2012 and 2013 (data from the A555 Ibirité-Rola-Moça meteorological station: www.inmet.gov.br), were used for the input data in BehavePlus, in order to compare the expected fire behavior in the *campo-cerrado* fields without molasses grass (5.6 Mg/ha), with the intermediate invasion (14.0 Mg/ha) and the high invasion rate (18.4 Mg/ha). The biomass surface/volume ratio and biomass energy content were obtained from Mistry & Berardi (2005). Since dead biomass moisture and wind speeds depend on climate conditions, and the moisture of dead grasses and air can reach equilibrium in approximately one hour (Fernandes 2003), simulations were performed with mean wind speeds of 5, 10 and 15 km/h, and the dead biomass moisture ranged from 8 to 23%. These value ranges allow for a direct comparison with the findings of Mistry & Berardi (2005). For simplicity, the topography was considered plane.

Results

Biomass increase and elimination of monocots

Apart from molasses grass, seven native monocot species were found in the studied area: six species of Poaceae (*Andropogon* sp., *Anthaenantia lanata* (Kunth) Benth., *Aristida recurvata* Kunth, *Axonopus siccus* Kuhlm, *Paspalum* sp., and *Schizachyrium microstachyum* (Desv. ex Ham.) Roseng., B.R. Arrill. & Izag.); and one of Iridaceae (*Sisyrinchium vaginatum* Spreng.). No other invasive species were found.

The rate of accumulation of the standing dead biomass of native grasses was similar to that of molasses grass (Fig. 1). However, the combined live and standing dead biomasses of molasses grass were greater than were those of native grasses (Fig. 1), indicating a greater contribution of the former to the fine fuel accumulation. The maximum total biomass in the areas invaded by molasses grass was 18.4 Mg/ha, or 3.3 times greater than the 5.6 Mg/ha in the non-invaded areas. As can be seen in Fig. 2, molasses grass became the main biomass component in the areas it invaded, correlating strongly with the total biomass in the plots (r = 0.756). The native monocot biomass decreased in proportion to the increase in molasses grass (native monocot biomass = 69.70 − 0.30 molasses grass, r=−0.547, p<0.05). Litter, another important component of the total biomass, was strongly correlated with the molasses grass biomass in each plot (litter biomass = 36.98 + 0.66 molasses grass biomass, r=0.636, p<0.05).

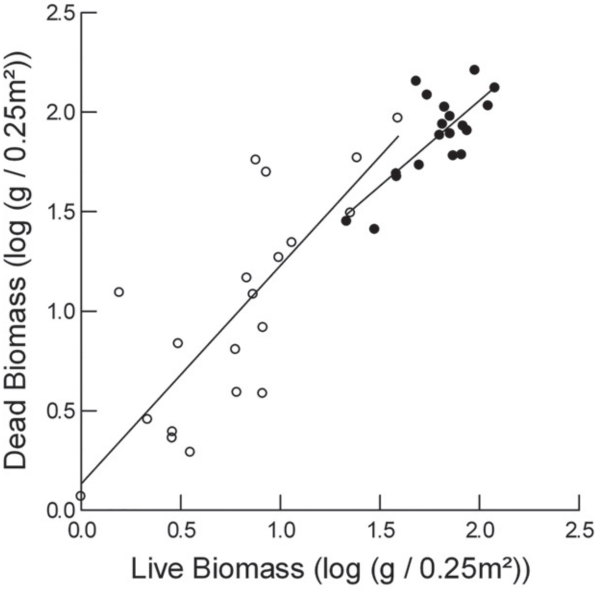

Figure 1. Relationships between standing dead and live biomasses of molasses grass (filled circles) and native grasses (open circles). ANCOVA: p=0.950 for the intercept, and p=0.887 for the angular coefficient.

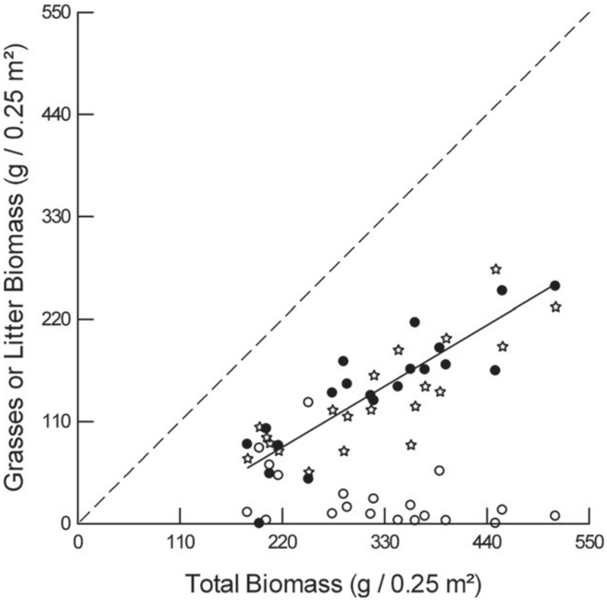

Figure 2. Contribution of molasses grass (filled circles, continuous line), native grasses (open circles) and litter (stars) to the biomass of the *campos-cerrado* grass layer (dashed line).

Elimination of eudicots

Taking into account all recorded species of eudicots, molasses grass reduced their individual numbers in the four invaded areas between 1.8 and 4.1 times (Tab. 1). The richness estimator index ACE (abundance-based coverage estimator) indicated a reduction in the number of species

Table 1. Comparison of eudicot counts in areas invaded (INV) and non-invaded (NAT) by molasses grass.

	INV 1	NAT 1	INV 2	NAT 2	INV 3	NAT 3	INV 4	NAT 4
Number of Squares	50		100		100		70	
Total Number of Individuals	129	322	55	209	145	591	224	407
Average Number of Individuals	2.58	6.44	0.55	2.09	1.45	5.91	3.20	5.81
Standard Deviation	1.46	2.03	0.86	1.52	1.42	2.70	2.10	2.98
Wilcoxon (Z)	5,889		6,753		8,497		5,533	
P-Valor	<0.001		<0.001		<0.001		<0.001	

in the four studied areas invaded by molasses grass (Fig. 3). The reduction was estimated to be between 16% (Area 2) and 43% (Area 4), with a mean of 33%. Species density was higher in non-invaded areas (6.3 species/m^2 vs. 2,6 species/m^2, Mann-Whitney U test: $p<0.001$). Species sensitivity to the molasses grass invasion is listed in Tab. 2.

Fire simulations

Simulations with the BehavePlus 5 indicated that fires would be more destructive in the fields invaded by molasses grass (Fig. 4 and 5). From 2010 to 2013, the relative air humidity was ≤ 18% on 13 days. Considering the more critical periods with 18% dead biomass moisture and 15 km/h winds, in areas with high invasion rates vs. non-invaded areas (Fig. 4 and 5), fire fronts would advance 2.5 times faster (9 m/min vs. 22.1 m/min), the fire intensity would be 17.3 times greater (569 KW/m vs. 9868 KW/m), the flame length would be 2.8 times greater (1.4 m vs. 5.3 m), and the heat per unit area (independent of wind velocity) would be 7.1 times higher (3792 Kj/m^2 vs. 26778 Kj/m^2).

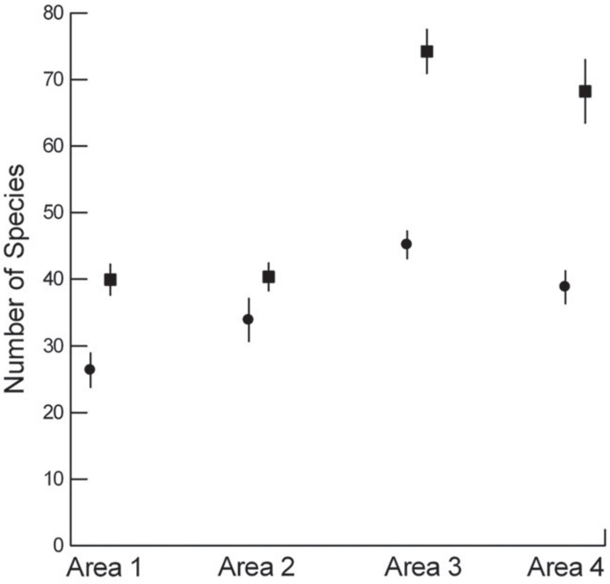

Figure 3. Comparison of species richness in non-invaded areas (circles) and areas invaded by molasses grass (squares). Richness was estimated using the abundance-based coverage estimator (ACE) index. t-test for all paired areas: $p<0.01$.

Discussion

Molasses grass greatly increased the fine fuel biomass in the *campo-cerrado* areas of the PESRM, potentially reaching values of up to 18 Mg/ha, similar to the 12.1-21.4 Mg/ha estimated for a *cerrado* area with high rates of invasion in Brasília (Martins *et al.*, 2011). The negative correlation between the biomasses of native monocots and those of molasses grass suggests that the former have been suppressed by the latter. This would also explain the reduction in the richness and abundance of eudicots, some of which are naturally rare. Conversely, eudicots persisted in small non-invaded patches within large areas invaded by molasses grass. Nitrogen use efficiency in molasses grass is known to be higher than is that of native South American C4 grasses (Lannes *et al.* 2012). Coutinho (2000) estimated that nearly 95% of nitrogen in burned *cerrado* plants is lost to the atmosphere as smoke. As a consequence, burned sites tend to be nitrogen deficient, with molasses grass often being the dominant species (Lannes *et al.* 2012). Furthermore, the competition for space and light, as well as allelopathy, changes in soil chemistry and accumulation of litter, are causal factors that affect smaller plants and seedlings (Corbin & D'Antonio 2004; D'Antonio & Vitousek 1992; Hamilton *et al.* 1999; Levine *et al.* 2003; Hoffmann *et al.* 2004; Hoffmann & Haridasan 2008).

In the Cerrado Biome, natural fires are caused by lightning strikes and may be extinguished by subsequent rains. However, human activities have increased the risk of out-of-control fires during the dry season in protected areas (França *et al.* 2007), as is the case at the PESRM. In addition, the invasion of exotic grasses potentiates the grass-fire cycle, characterized by more frequent and intense fires encompassing larger areas, due to the greater and faster accumulation of their biomass compared to that of the native species (D'Antonio & Vitousek 1992; Milton 2004).

The fire simulations for the *campo-cerrado* at the PESRM indicated potentially greater fire intensity and flame length, with the chance of the fire spreading from the low herbaceous strata to the treetops increasing. The fire properties

Table 2. Species sensitivity to molasses grass invasion.

Species	Individuals in Non-Invaded Areas	Individuals in Invaded Areas	Suggestion
Ageratum fastigiatum (Gardner) R.M.King & H.Rob.	58	12	Invasion sensibility study for molasses grass of those species
Aspilia sp.	72	13	
Baccharis retusa DC.	128	0	
Baccharis sp.	18	0	
Solanum sp.	17	0	
Peixotoa tomentosa A. Juss.	84	18	
Croton antisyphiliticus Mart.	47	27	Study of invasion sensibility and resistance study for molasses grass of that species
Baccharis dracucunlifolia DC.	6	13	Invasion resistance study for molasses grass of those species
Hyptis lippioides Pohl ex Benth.	25	22	
Lippia sp.	18	18	
Peltaea polymorpha (A. St.-Hil.) Krapov. & Cristóbal	1	19	
Periandra mediterranea (Vell.) Taub.	11	39	

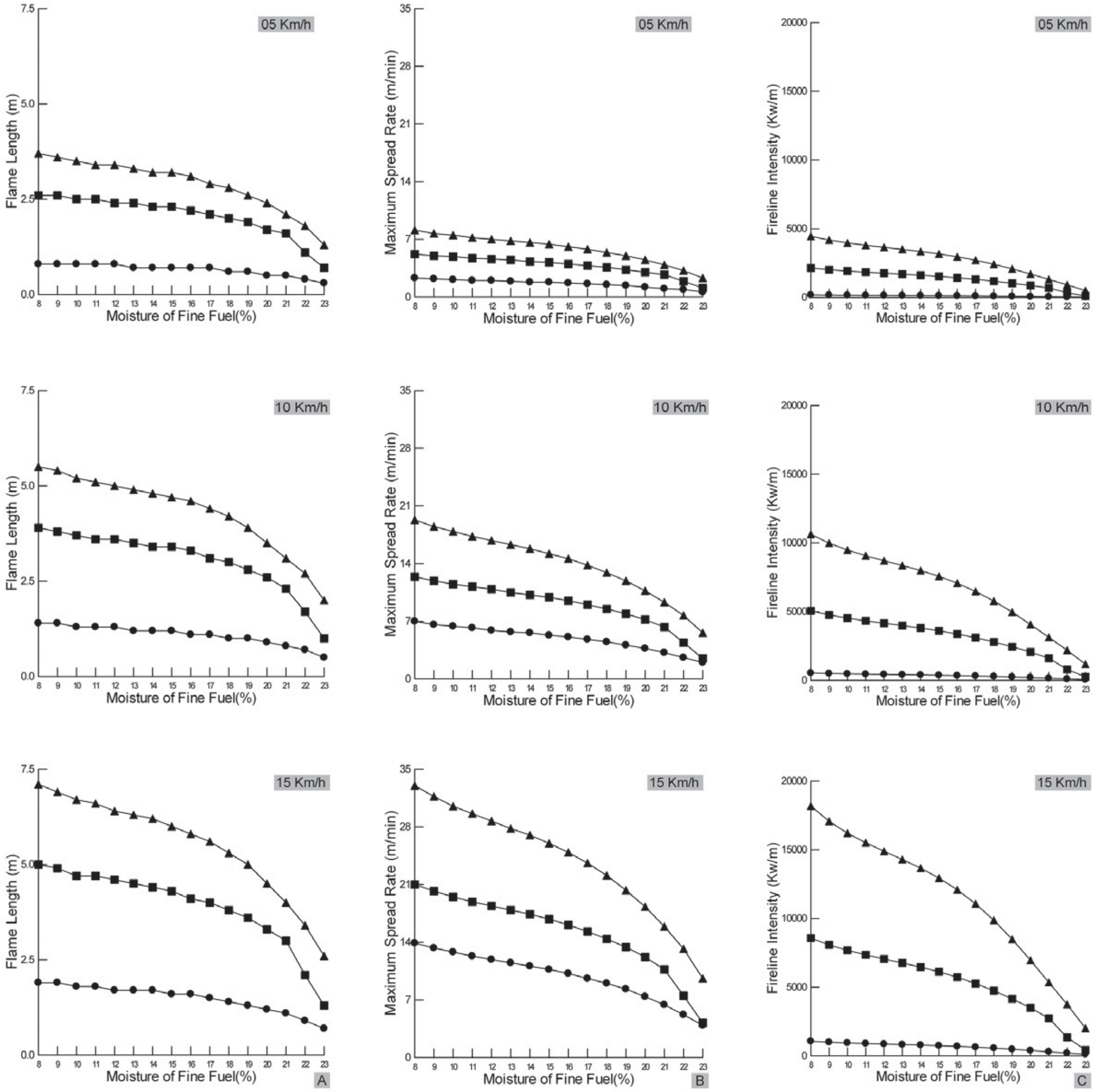

Figure 4. Flame length (a), maximum spread rate (b), and fire intensity (c) for different levels of invasion by molasses grass, with different levels of fine fuel moisture and at different wind speeds.
Triangles – high invasion rate; squares – intermediate invasion rate; circles – no invasion.

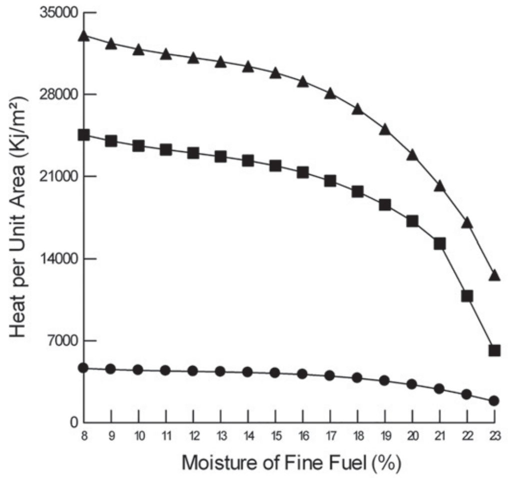

Figure 5. Heat per unit area for different levels of invasion by molasses grass, with different levels of fine fuel moisture.
Triangles – high invasion rate; squares – intermediate invasion rate; circles – no invasion.

previewed by BehavePlus are compatible with other studies of the Cerrado Biome (Kauffman *et al.* 1994; Castro-Neves 2000). Eye-witness accounts from firefighters and volunteers of a large nine-day fire in this park at the end of the 2011 dry season, when 1949 ha (≈60%) of the park area were burned, are impressive: flames 12 m high on the hilltops, invaded by molasses grass, had formed a huge fire front, and the heat could be felt from up to 200 m away. In the invaded valleys, the wind was channeled and the fire spread rapidly. Flame lengths surpassed 6 m (Rodrigo B. Belo, Director for Prevention and Control of Forest Fires and Critical Events, SEMAD). Charcoal marks on the valley trees showed signs of burning at a height > 5 m, and some *cerrado* trees, like the "barbatimão" (*Stryphnodendron adstringens* (Mart.) Coville), appeared to be dead.

The results of our study corroborate those of other studies describing a reduction of native species diversity in areas invaded by molasses grass or other exotic grasses (D'Antonio & Vitousek 1992; Hughes *et al.* 1991; Rahlao *et al.* 2009). Competition, changes in soil chemistry and fire can act synergistically, leading to a continuous species loss. Recurrent fires favor molasses grass at the expense of native monocots and eudicots that have less resistance to burning and less ability to regenerate (França *et al.* 2007). Control of molasses grass would be the only solution for a possible re-establishment of native vegetation in invaded preservation areas. At the Brasília National Park, such control was achieved by the combined use of controlled burning, herbicides and seedling removal (Martins *et al.* 2011). At the PESRM, the persistence of dense patches of molasses grass after decades of fire suppression demonstrates its ability to persist in the absence of such disturbance, as has been reported by other authors (Hughes *et al.* 1991; Berardi 1994).

The invasion of molasses grass in the *campo-cerrado* areas of the PESRM is increasing fire intensity, one of the major components of fire regimes (Brooks *et al.* 2004; Whelan 1995; Bond & Wilgen 1996). In addition, molasses grass invasion increases the risk of fire and the chance of fire spreading from the grass layer to the treetops. Hoffmann *et al.* (2004; 2009) predicted the retraction of gallery forests in the Cerrado Biome boundaries when fires are frequent. The increases in fire frequency and destructiveness associated with the invasion of molasses grass at the PESRM could reduce its gallery forests, bordered by the *campo-cerrado*, which sustain and protect one of the most important sources of fresh water for the metropolitan area (Euclydes 2011).

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