FIRE INTENSITY AND SEVERITY IN BRAZILIAN *CAMPOS* GRASSLANDS

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SUMMARY

Brazilian Campos grasslands are rich in species and the maintenance of its diversity and physiognomy is dependent on disturbance (e.g. fire and grazing). Nevertheless, studies about fire intensity and severity are inexistent. The present paper describes fire parameters, using 14 experimental burn plots in southern Brazil (30º02' to 30º04'S, and 51º06' to 51º09'W, 311masl). Two sites under different fire histories were chosen: frequently burned and excluded since six years. Experimental burning was performed during summer (2006-2007), when most burning takes place in these grasslands. The following parameters were measured: air temperature and moisture, vegetation height, wind speed, fuel (fine, coarse), fuel moisture, fire temperatures (soil level and at 50cm), ash, residuals, flame height, fire duration; burning efficiency and fire intensity were later calculated. Fuel load varied from 0.39 to 1.44kg·m^{-2}*, and correlated positively with both fire temperature and fire intensity. Fire temperatures ranged 47 to 537.5°C, being higher in the excluded site. Fire intensity was low compared to grassland elsewhere (36.5-319.5kW·m*$^{-1}$*), differing significantly between sites. Fine fuel was the variable that best explained fire intensity. The results on fire intensity and severity in Campos grasslands can be considered a pilot study, since plots were very small. However, the data provided can help other researchers to get permission for experimentation using larger plots. The results provide support for further studies about the effects of fire on grassland vegetation and for studies involving fire models and fire risk prediction.*

Subtropical grasslands (also known as *Campos)* in southern Brazil are one of the less known ecosystems worldwide, covering ~13.7×10^{6}ha, and their conservation has been neglected (Overbeck *et al.*, 2007). Although its flora is very rich in species (~3000 plant species are estimated; Boldrini, 1997), only <1% of the total area is under legal conservation. Moreover, the legal protected areas adopted a management strategy that is not the most effective. Areas are fenced and totally excluded from any kind of disturbance, leading to shrub encroachment (Oliveira and Pillar, 2004) and, thus, loss of both plant species diversity and physiognomy.

Disturbance is a major factor influencing *Campos* grassland dynamics. Both grazing and fire maintain grasslands' diversity and physiognomy by removal of aboveground biomass and, consequently, opening gaps in the vegetation, which allows other species to establish. According to Bond *et al.* (2005) savannas and grasslands are fire-dependent

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ecosystems, since the dominance of grasses and shrubs are dependent on burnings. Additionally, these authors argued that such fire-dependent ecosystems are not a result of only recent anthropogenic burnings, but have existed for a long time.

In *Campos* grasslands of southern Brazil, fire has been present since the beginning of the Holocene, likely due to the use of fire by indigenous populations coupled with a seasonal climate, as supported by abundance of charcoal particles in peat profiles (Behling *et al*., 2004; Behling and Pillar, 2007). Nowadays, fire is lit by farmers to eliminate accumulated dead grass biomass and unwanted species (mostly shrubs) and, thus, to increase forage quality. Burning is carried out usually at the end of winter, which enhances re-sprouting of many species, but decreases C_3 grasses (Nabinger *et al.,* 2000; Llorens and Frank, 2004). The combination of these two practices (fire and grazing) is very common in Brazilian *Campos* grasslands, despite fire being prohibited as a management tool by federal and state environmental legislation (Código Florestal, lei 4.771/65 from 09/15/1965).

Fire affects plant population and community in several ways. Vegetative reproduction is mostly stimulated by fire events (Whelan, 1995; Pfab and Witkowski,1999) and plays an important role on plant population dynamics. Germination rates of seratinous seeders are probably increased by fire (Stokes *et al.,* 2004). However, the effect on seedling recruitment has been shown to be either positive (Satterthwaite *et al*., 2002) or negative (Hoffmann, 1996). Although recent ecological studies on Brazilian *Campos* grasslands have confirmed the positive effect of fire on plant diversity (Overbeck *et al*., 2005) and in impeding the establishment of woody species (Müller *et al*., 2007), nothing is known about fire intensity and severity (temperature, residence time, etc.) for these ecosystems and, consequently, their effects on plant communities.

Peak fire temperatures and duration are important variables for survival of plant tissues (Whelan, 1995). Most studies adopt temperatures >60°C as lethal for plant tissues (Whelan, 1995; Bilbao *et al*., 2006). The longer plants are exposed to temperatures >60°C, the more detrimental are the effects of fire. Bova and Dickinson (2005) stated that flame residence time was a better variable than fire intensity to predict tissue necrosis in oaks and chestnuts, demonstrating the importance of heat flux duration for plant survival. On the other hand, seed dormancy in many plant species (especially legumes) is broken by high temperature exposures (Martin *et al*., 1975; Tarrega *et al*., 1992; Herranz *et al*., 1998; Williams *et al*., 2003, 2004; Auld and Denham, 2006; Rivas *et al*., 2006).

Though fire temperatures may influence plant mortality and germination, fire intensity is the most important variable to analyze fire effects on plant community (Stocks *et al.,* 1997) and plant population dynamics (Whelan, 1995). According to Trollope *et al.* (2002), fire intensity was shown to correlate with other fire parameters (rate of spread, temperature, and flame height) and is easily measured. Other variables can also influence fire behavior, such as fire frequency, season, climate, wind speed and direction, slope and fuel. Fuel load is the total amount of dry biomass; that means, the total amount of heat energy available for release during fires (Whelan, 1995), and is considered one of the most important parameters influencing fire behavior (Trollope *et al*,. 2002).

The aim of in this study, based on experimental burning carried out in natural grassland in Porto Alegre, southern Brazil, is to evaluate and describe fire parameters (fire intensity, fuel load, rates of fire spread, burning efficiency, consumed fuel, fire peak temperatures and duration) using small plots, due to difficulties to obtain permissions from environmental authorities. These parameters are important to determine fire behavior and to infer its effects on the ecosystem. No similar studies have been carried out for *Campos* grasslands in Brazil so far. The study can be considered as a pilot study, and the results can be used to convince authorities to give permissions for further studies using larger plots.

Study Area

The experimental burnings were carried out on a natural grassland located at Morro Santana (near Porto Alegre, 30º02' to 30º04'S, and 51º06' to 51º09'W, 311masl). The climate in this region is subtropical humid (Köppen classification Cfa), with a mean temperature of 22°C (Livi, 1999). Soils are characterized by an A horizon rich in clay; Acrisol being the predominant soil type (Streck *et al.,* 2002). Grasslands undergo frequent anthropogenic fires occurring in intervals of three to five years in small patches, and a mosaic is produced with patches burned in different years. These grasslands are very rich in species (450 to 500 plant species in an area of 220ha), with high fine-scale diversity (Overbeck *et al*., 2005, 2006a). The vegetation is composed of a matrix of caespitose grasses (e.g. *Elionurus muticus*, *Aristida flaccida* and *Andropogon lateralis*) and a large number of small forbs (mainly Asteraceae, Leguminosae and Rubiaceae; Overbeck *et al*., 2006a). When fire is excluded there is an increase in shrub cover, some species being fire sensitive and obligate seeders (Müller *et al*., 2007).

Two sites on Morro Santana were chosen for this study: FB: frequently burned grassland (last fire occurrence in summer 2005), and E: excluded from fire the last six years. The latter site is characterized by the dominance of two shrubs (obligate seeders belonging to Asteraceae): *Baccharis leucopappa* and *Heterothalamus psiadioides.* The frequently burned site (FB) shows a higher cover of forbs and the presence of small shrubs. Grass cover is high at both sites, although higher on FB. In *Campos* grasslands, six years of exclusion already lead to shrub encroachment and loss of grassland species.

Methods

Seven plots ($25m^2$) were randomly established in each site. To avoid fire spread into the vegetation outside plots, firebreaks (2m width) around each plot were set up. Since these grasslands usually burn during the summer, fire experiments were carried out in December 2006 and January 2007, with assistance of a local fire brigade. Due to logistic problems and climate factors, the experimental burnings were performed in two different days (three weeks of difference between sites): plots in site FB were burnt in December 2006 and plots in site E were burnt in January 2007. Fires were ignited with a torch, always set to spread with the wind direction (head fire). Since fire is a very polemic issue in Brazil and forbidden by law, it was difficult to get permissions for carrying out the experiments. Therefore, it was decided to establish this pilot study using small plots, in order to provide data to convince authorities to give permission for further experiments using larger plots.

Air temperature and relative air moisture were measured before and during fire experiments using two TinyTag data loggers (Gemini data loggers, TGP-4500, every 5s), ~2m away from the plots. In addition, wind speed ($m{\cdot}s^{-1}$) and number of dry days before the experiment were also registered.

In order to estimate fuel load ($kg{\cdot}m^{-2}$), aboveground biomass in all plots was sampled immediately before burns in three quadrats of $0.04m^2$ per plot. The biomass was separated as coarse (stems and crowns) and fine (leaves and culms). Fuel moisture (expressed on a dry weight basis) was determined after samples were oven dried at 70°C during 72h. After fire, ashes and residual non-combusted materials were sampled (three quadrats of $0.04m^2$ per plot), dried and weighted.

TABLE I
WEATHER CONDITIONS BEFORE FIRE EXPERIMENTS IN DIFFERENT SITES AT MORRO SANTANA, SOUTHERN BRAZIL

Site	Air temperature (°C)	Relative air moisture (%)	Wind speed (m/s)
FB	32.43 ±0.74	47.18 ±2.2	0.98 ±0.22
E	34.9 ±1.36	54.8 ±3.2	0.55 ±0.08

FB: frequently burned, and E: excluded from fire since six years. Means and standard errors are presented.

Fire measurements

To measure fire temperatures, high temperature chromel-alumel thermocouples (unshielded head, type K, stainless steel sheath, 150×3mm) were used. Cables were placed inside aluminum tubes and additionally wrapped in aluminum foil and anti-fire tape to reduce heat absorption and conduction. Thermocouples were calibrated to measure over the 0-1100°C range. Sensors were placed in two different positions: soil surface (0cm) and shrubs crown height (50cm). They were positioned in the middle of the plot and connected to a DL2 Data logger (Delta-T). Two thermocouples were used per height. Temperatures were recorded every 2s.

Other fire parameters were also evaluated: rate of spread (m·s^{-1}), flame height (m), residence time of fire (s), burning efficiency (%), and Byram´s fire line intensity (kW·m^{-1}). Fire intensity was calculated using the equation $I= h\times w\times r$, where h: heat yield of fuel, w: consumed fuel load, and r: rate of fire spread. Since heat yield of fuel was not measured for *Campos* grasslands in southern Brazil, a value of 15500J·g^{-1} was used, as found in Australia by Griffin and Friedel (1984) and also used for the Brazilian Cerrado (Heloísa Miranda, personal communication). Experiments were carried out between 10:00 and 15:00.

Statistical analysis

To evaluate differences between the two sites in terms of the measured variables, variance analysis was performed using randomization tests (10000 iterations; Manly, 2007). For a better visualization of the results, principal components analysis (PCA; for details on the method see Podani, 2000) based on correlations was used to reveal the main trends of variation of sampling units (in both FB and E sites) and the measured variables (fire intensity, fuel load, fine fuel, coarse fuel, combustion, temperature at soil level, temperature at 50cm above soil level, flame height, tussock height, shrub height, air temperature, relative air moisture, ash, and residuals). The stability of axes was tested with bootstrap re-sampling (1000 iterations; Pillar, 1999). General linear modeling techniques were used to determine which variable (the same 14 measured parameters used in the ordination analysis) influenced fire intensity the most and to provide the simplest model. The significance of the model was examined by randomization tests (1000). Since experiments were carried out on different dates, environmental conditions may not have been the same and this could have influenced fire intensity. In order to analyze if such possible biases were relevant, it was evaluated, among the weather related variables, which ones differed statistically between treatments; if none of these variables were among the ones that most influenced the fire parameter in the final linear models, the models were deemed unbiased by weather conditions during burnings. All statistical analyses used the software MULTIV (Pillar, 2005).

Results

Weather conditions

There was a period of 4-7 days whitout precipitation before fire was set. The highest air temperatures were obtained near midday (35-38°C), as well as the lowest air moisture content (38-45%). Wind speed varied from 0.37 to 2.0m·s^{-1}. As seen in Table I, air temperature and relative air moisture were almost the same for both sites, while wind speed was higher in site FB during the fire experiment.

Fuel load and fire temperatures

A continuous grass matrix, with some short shrubs, characterizes site FB, whilst site E shows an increased cover of shrubs. Tussock grasses (33.57 ±2.91cm, P=0.11) and shrubs (82 ±2.22cm, P=0.001) are taller in the excluded site than in the frequent burned site (tussock grasses 27.6 ±1.79cm, shrubs 65.2 ±1.98cm) (Figure 1a).

Fine fuel ranged from 0.27 to 1.01kg·m^{-2} and coarse fuel from 0.05 to 0.43kg·m^{-2}. Fuel load varied 0.39-1.44kg·m^{-2}. The excluded site also had the highest values of fine, coarse and fuel load in comparison to the frequently burned site (Figure 1b). In addition, both sites showed a higher load of fine than coarse fuel.

Fire temperatures fluctuated from 47°C (50cm above soil surface) to 537.5°C (at soil surface). At the soil surface, fire temperatures tended to be higher in the excluded (P=0.11), as did temperatures measured at 50cm above soil surface (P=0.12, Figure 1c).

Temperatures at soil surface correlated positively to fine fuel (r= 0.53). Fire temperatures at 50cm showed a strong positive correlation to fire intensity (r= 0.82), fine fuel (r= 0.68), flame height (r= 0.70), and fuel load (r= 0.66).

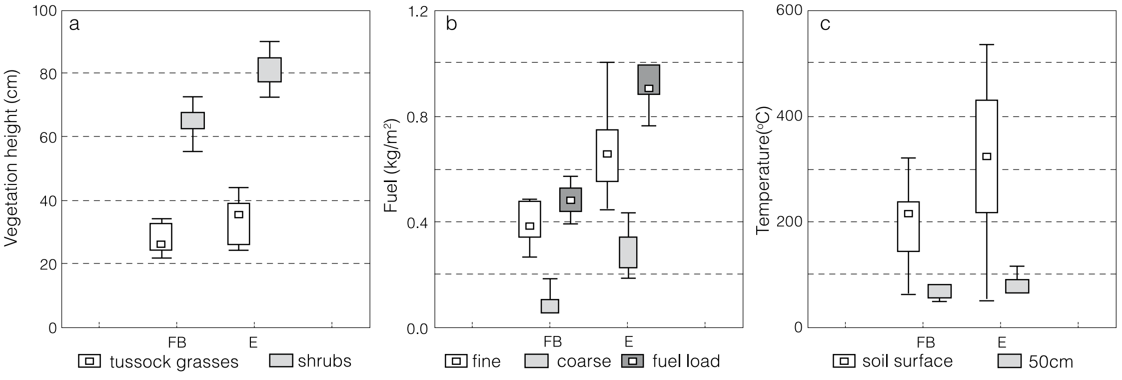

Figure 1. a: Tussock and shrub heights (cm), b: fine and coarse fuel, as well as fuel load (kg m^{-2}), and c: fire temperatures at the soil surface and 50cm above surface in sites frequently burned (FB) and excluded from fire since six years (E) on Morro Santana, southern Brazil.
Asterisks mean significant differences between sites (p≤0.05), based on randomization testing. Points between the boxes represent the median, boxes 25%-interquartils, and the t-shaped lines the maximum and minimum values among seven experimentally burned plots

TABLE II
MEANS AND STANDARD ERRORS OF VARIABLES MEASURED IN EXPERIMENTAL BURNINGS IN DIFFERENT SITES AT MORRO SANTANA, SOUTHERN BRAZIL

Variables	FB	E
Ashes (kg·m^{-2})	0.02 ±0.003	0.05 ±0.01*
Residuals (kg·m^{-2})	0.06 ±0.01	0.08 ±0.02
Fine fuel moisture (%)	44.49 ±1.46	37.84 ±4.23
Coarse fuel moisture (%)	49.44 ±3.72	36.21 ±3.71*
Burn efficiency (%)	93.8 ±0.84	95.07 ±0.9
Flame height (cm)	36.43 ±3.96	64.52 ±5.7***
Rate of spread (m·s^{-1})	0.015 ±0.002	0.013 ±0.001
Fire intensity (kW·m^{-1})	93.52 ±19.6	179.04 ±27.5*

FB: frequently burned, E: excluded, seven plots each. Fuel moisture was expressed on a dry mass basis. Probabilities were generated by randomization testing (10000 interactions). Asterisks mean significant differences between sites: *: p≤0.05, **: p≤0.01, ***: p≤0.001.

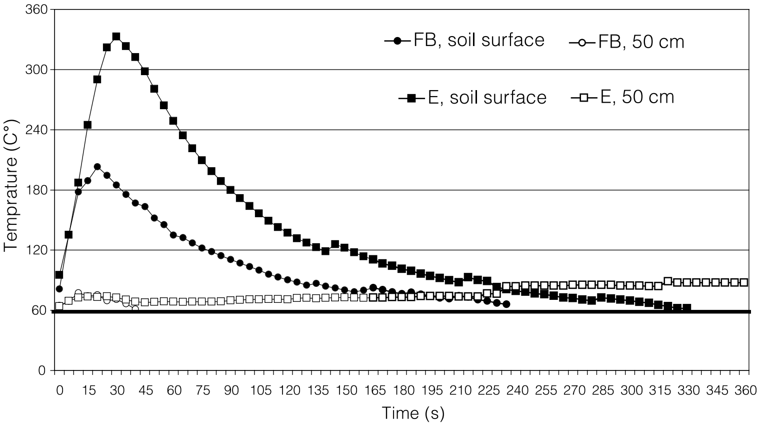

Figure 2. Maximum temperatures (°C) and residence times (s) above 60°C of fire experiments in different areas sites (FB: frequently burned and E: grasslands excluded from fire since six years) and different heights (at soil surface and 50cm above soil surface) in *Campos* grasslands in southern Brazil. Each point on the curve is the average of seven experimentally burned plots.

Plots in the excluded site burned longer over temperatures of 60°C at both soil surface and at 50cm (Figure 2). The highest value of residence time (360s) was reached at 50cm. At soil surface, residence time was much higher (140-330 s) than in the frequently burned site (15-235s). Residence time was very low (5-40s) at 50cm above soil surface in the FB site.

Fire intensity

Fire intensity presented significant differences (P=0.02) between sites, as shown in Table II. Values ranged 36.5-319.5kW·m^{-1}. Fine fuel showed the highest correlation to fire intensity (r= 0.86). Other variables also strongly correlated to fire intensity, temperatures at 50cm above soil surface (r= 0.82), flame height (r= 0.81), and shrub heights (r= 0.59), and coarse fuel (r= 0.62).

Table II also shows other variables measured during and after fire experiments. Ashes (P=0.02) and flame height (P=0.0006) were higher in the E site, while coarse fuel moisture (P=0.03) was higher in the FB site. Fine fuel moisture showed no significant differences between sites (P>0.05), as well as residuals, burn efficiency and rate of fire spread.

According to the PCA, the two sites were clearly separated (Figure 3). Almost all measured variables correlated with one of the two axes (r≥ 0.5), except for temperatures at soil level, air temperature and relative air moisture. Fuel load, fine fuel, and fire intensity highly correlated to Axis 1 (r= 0.98, 0.94, and 0.89, respectively), showing that plots of the E site had higher values of these variables in comparison to the ones of the FB site. Other variables also showed high correlation to Axis 1, such as flame height (r= 0.9), coarse biomass (r= 0.83), shrub cover (r= 0.77), temperature at 50cm above soil level (r= 0.75), and ash and residual weight (r= 0.57 and 0.5, respectively). Air temperature and relative air moisture correlated with Axis 2 (r= -0.88 and 0.76, respectively).

After testing all possibilities with the 14 measured variables, the model that best fitted resulted in only one variable, fine fuel, influencing fire intensity. The following equation was found:

Fire intensity= -36.49 + 324.02 (fine fuel)

which can be represented by a linear regression (Figure 4). The β coefficient was found to be significant (P=0.003), as well as the linear model (R^2= 0.71, P=0.0009).

Discussion

Maximum fire temperatures (both at soil level and at 50cm) found in this study were similar to those found for Australian grasslands (98-458°C; Morgan,1999) and shrub-woodlands (150°C; Bradstock and Auld 1995), open savannas in Venezuela (198-232°C; Silva *et al*., 1990), heathlands in Scotland (140-840°C; Hobbs and Gimingham, 1984), mixed prairie in USA (83.3-682.2°C; Stinson and Wright, 1969), and Brazilian cerrados (83-330°C; Miranda *et al.,* 1993). Bilbao *et al.* (2006) stated that, in savanna areas, surface fires are very common and under these conditions, the highest temperatures would be recorded at soil level.

In the present study, soil surface temperatures were always higher than that at 50cm. Temperatures measured at both levels correlated positively with fine fuel, corroborating its importance. There is a great accumulation of fine fuel near soil surface due to the high cover of tussock grasses and forbs. Grasses build up a great amount of biomass, both live and dead. After fire, most forbs were completely consumed, remaining only shrub stems and grass crowns (un-combusted residuals), re-

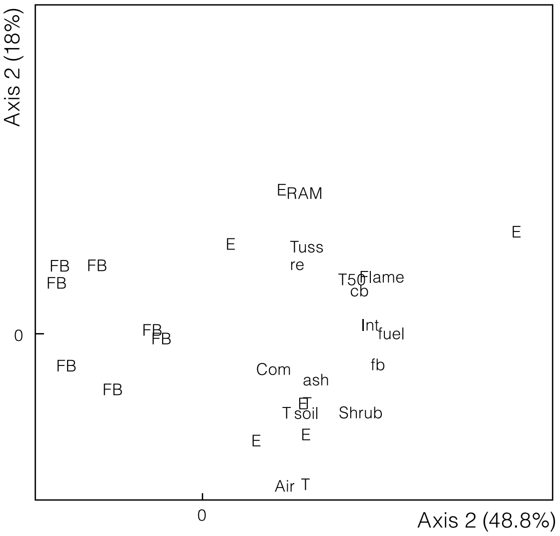

Figure 3. Ordination of plots in frequently burned grasslands (FB) and excluded sites (E) and measured variables (fb: fine fuel, cb: coarse fuel, fuel: fuel load, Int: fire intensity, Tsoil: temperature at soil level, T50: temperature at 50cm above soil level, Tuss: tussock height, Shrub: shrub height, ash: ash weight, re: residual weight, Flame: flame height, Com: combustion, AirT: air temperature, and RAM: relative air moisture). The ordination method is principal components analysis (PCA), applied to correlations between variables. Bootstrap resampling (1000 iterations) indicated significance of axis 1 only (P(ro° ≥ro)= 0.047). Only parameters that correlated (r ≥0.5) with one of the axes are showed.

TABLE III
COMPARISON OF FIRE INTENSITY AND TEMPERATURE DATA BETWEEN DIFFERENT LOCALITIES AND VEGETATION TYPES

Local	Vegetation type	Fire intensity ($kW·m^{-1}$)	Temperature at soil level (°C)	Reference
Africa	Savanna	28-17905	no data	Trollope *et al*., 1996, 2002 Gambiza *et al.,* 2005 Govender *et al*., 2006
Australia	Savanna	151-9214	150	Bradstock and Audl, 1995
Australia	Grassland	99-1147	98-458	Morgan, 1999
USA	Prairie	31-11788	83-682	Stinson and Wright, 1969 Bidwell and Engle, 1992 Trollope *et al.,* 2002
Scotland	Heathland	43-1112	140-840	Hobbs and Giminghan, 1984
Venezuela	Savanna	398-472	no data	Bilbao and Medina, 1996
Venezuela	Upland savanna	293-2253	48-571	Bilbao *et al*., 2006
Brazil	Cerrado	2842-16394	83-330	Miranda *et al*., 1993 Kaufmann *et al*., 1994
Brazil	*Campos* grasslands	36-319	48-537	Present study

sprouting after one week (Fidelis, 2008). Some forbs, such as *Eryngium horridum* and *E. pristis* (spiny rosette forbs, Apiaceae) were not totally consumed by fire, with their basis remaining and also re-sprouting very quickly after fire (more details in Fidelis *et al*., 2008). Burn efficiency in both sites was very high (~90%), confirming the high flammability of these grasslands, even only two years after the last fire (site FB).

Differences in vertical temperature are determined by the spatial distribution of vegetation (Bilbao and Medina, 1996). In the present study, temperatures (both at soil level and 50cm above) tended to be higher in the E site, where there was higher accumulation of biomass (both dead and live) from tussock grasses, and almost no bare soil. Fuel load was higher, and although this site showed a higher cover of shrub species, fine fuel was the most important component increasing fire temperature.

High temperatures can cause tissue necrosis at different depths (Bova and Dickinson, 2005). High temperatures (up to 530°C) were reached in the present study, mostly in areas excluded since six years. However, according to Bova and Dickinson (2005) the most important factors affecting tissue death are fire intensity and residence time. Present results showed that plants were exposed to temperatures >60°C for an average of 23-247s, similar to the residence time found by Bilbao *et al.* (2006) for the Gran Sabana in Venezuela. Short exposure to high temperatures may have positive effects on vegetation dynamics, mostly on germination of some species. As reported by several studies (Auld and O´Connell, 1991; Tarrega *et al.,* 1992; Herranz *et al.*,1998; Rivas *et al.,* 2006), some species, mostly legumes, need short exposures to high temperatures (>70°C) to break their dormancy. In southern Brazilian grasslands, no relation between high temperatures and increase in germination viability could be found so far (Overbeck *et al*., 2006b; Fidelis *et al*., 2007), but experiments were conducted mostly with Poaceae, Apiaceae and Asteraceae species, and not with hard seeded species, as legumes are.

Fire intensity was very low compared to other vegetation types (Table III). Small plots had to be used in order to facilitate the experiment authorization by environmental control agencies, and therefore the results should be considered preliminary and, thus, analyzed carefully. The small size of the plots may have lead to lower values of fire intensity. Additionally, experiments were performed during the growing season (summer), when most fires take place in *Campos* grasslands, set mostly by local people. During this period, dead biomass levels are lower than in in winter (Heringer and Jacques, 2002a) leading to fires with lower intensities, and consequently less damage to the vegetation. As showed by the regression model, fine fuel highly influenced fire intensity, showing the importance of accumulated biomass. Further studies using controlled fire experiments during winter and on larger plots should be performed so as to confirm or not these low values of fire intensity for the Brazilian *Campos* grasslands.

Nevertheless, fire intensity tended to be higher in the excluded (E) site, where fine and coarse fuels, as well as height of flames and shrub heights were also higher. In this site, there was a dominance of small shrubs (~0.5-1m) but, still, the lower stratum was continuous, with a high cover of tussock grasses and small shrubs and forbs. Accumulation of dead biomass in this site was higher than in the FB site, contributing to the high burning efficiency and fire intensity. Moreover, fine fuel was the best variable in the regression model for predicting fire intensity. Fine fuel is easy to measure in the field and can be used in models to simulate fire intensity. Since the experiments were carried out on different dates, the influence of environmental parameters on fire intensity could not be evaluated to find a relationship. Only relative air moisture had a marginal significance in linear models; however, this parameter was not significantly different between dates and probably did not influence fire intensity.

In Brazilian *Campos* grasslands, cattle raising is one of the most important economical activities, and fire is used to “improve” forage quality (Pillar *et al*., 2006; Overbeck *et al*., 2007). Generally, these fires occur at the end of the winter season, in order to decrease the accumulated dead biomass produced by grasses and to enhance re-sprouting. In winter, live biomass accumulation reaches the lowest values, whilst dead biomass accumulation is nearly the same in summer (Heringer and Jacques, 2002a). Unfortunately, this continuous and intense use of fire (almost every year) may lead to soil erosion and a decrease in C_3 grass cover, the latter including several good forage species (Nabinger et al., 2000; Llorens and Frank, 2004).

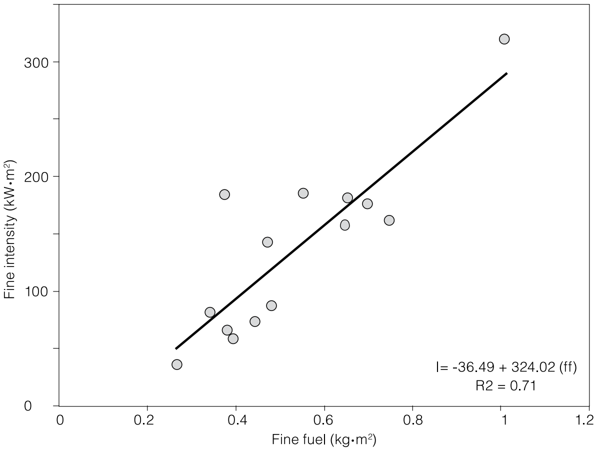

Figure 4. Regression model of fire intensity (I) on fine fuel (ff) for *Campos* grasslands in southern Brazil (R^2= 0.71, P=0.0009).

Fire as a management tool is still very controversial in Brazil. Its prohibition by state and federal environmental legislation should be reviewed (lei 4.771/1965; Behling and Pillar, 2007). Fire intensity and temperatures reached during experimental burns were not as high as those found in the literature, and vegetation responded fast to fire: after less than one month after fire experiment, some species were flowering, most grasses presented new green leaves and many forb and shrub species showed new sprouts (Fidelis, 2008). However, as already mentioned above, such facts must be carefully considered, since many farmers burn during winter, almost annually, and in combination with grazing. Such practice lead to species richness decrease and changes in vegetation structure (Heringer and Jacques, 2002b).

Because of this, further studies on fire intensity and severity (also during winter), as well as the effects of fire on vegetation regeneration and diversity, should be carried out in order to provide further support for future management practices for both farmers and environmental authorities, to maintain the biodiversity of *Campos* grasslands in southern Brazil. Moreover, more studies on fire intensity would offer support for the elaboration of fire risk prediction systems to help authorities to avoid wild fires of high intensity in conservation areas with *Campos* grassland vegetation.

Implications

Although small plots were used and generalizations about fire intensities and temperatures should be carefully considered, the present study is the first one to evaluate fire parameters, which are important tools for the elaboration of models about effects of fire on vegetation and about fire risks. This pilot study can offer support for other researches to convince environmental authorities about the importance of such studies to obtain reliable data to be used for the elaboration of fire risk models, as well as models about the effect of fire on vegetation dynamics. Fires in Brazilian *Campos* grasslands are of low intensity, spread rapidly and have a short residence time. Temperatures are not very high and therefore, belowground organs are protected from fire damage, assuring regeneration of the vegetation.

Further studies using larger plots, as well as in different seasons are of crucial importance in order to fill in the gaps about the ecological role of fire in these grasslands. For fire to be used as a management tool, more studies on its intensity and severity are needed.

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INTENSIDAD Y SEVERIDAD DEL FUEGO EN LOS PASTIZALES O CAMPOS SULINOS DE BRAZIL

Alessandra Fidelis, Maria Dolores Delgado-Cartay, Carolina C. Blanco, Sandra C. Müller, Valério D. Pillar y Jörg Pfadenhauer

RESUMEN

Los pastizales o Campos Sulinos del Brasil se caracterizan por gran riqueza de especies, y el mantenimiento de su diversidad y fisonomía depende de perturbaciones como fuego y pastoreo; sin embargo, no hay estudios sobre intensidad y severidad de fuegos. Se describen parámetros del fuego, usando 14 parcelas de quemas experimentales en el sur de Brasil (30º02'-30º04'S, y 51º06'-51º09'O, 311msnm). Se eligieron dos sitios con diferentes historias de quemas: una frecuentemente quemada y otra con seis años de exclusión de quemas. Se realizaron quemas experimentales durante el verano (2006-2007), cuando ocurre la mayor parte de los incendios. Se midieron temperatura y humedad del aire, altura de la vegetación, velocidad del viento, acumulación de material combustible (fino y grueso), humedad del material combustible, temperatura del fuego (a nivel del suelo y a 50cm), cantidad de cenizas y residuos, altura de la llama y duración del fuego. Se calcularon la eficiencia de quema e intensidad de fuego. Las temperaturas de fuego (47-537,5°C) fueron mayores en el sitio con historia de exclusión de fuego. Las intensidades de fuego fueron bajas (36,5-319,5kW·m^{-1}) comparadas con otros pastizales, difiriendo entre las dos localidades. La acumulación de material combustible fino es la variable que mejor explicó la intensidad de fuego. Los resultados presentados son preliminares, debido al tamaño pequeño de las parcelas. Sin embargo, pueden servir de base para la obtención de permisos para realizar quemas experimentales en parcelas mayores, y proveen respaldo a estudios sobre los efectos del fuego en el pastizal y de modelado y predicción de riesgo.

INTENSIDADE E SEVERIDADE DO FOGO NOS PASTIÇAIS OU CAMPOS SULINOS DO BRASIL

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RESUMO

Os pastiçais ou Campos Sulinos do Brasil se caracterizam pela grande riqueza de espécies, e a manutenção de sua diversidade e fisonomia depende de perturbações como fogo e pastoreio; no entanto, não existe estudos sobre intensidade e severidade de fogos. Descrevem-se parâmetros do fogo, usando 14 parcelas de queimadas experimentais no sul do Brasil (30º02'-30º04'S, e 51º06'-51º09'O, 311msnm). Elegeram-se dois locais com diferentes histórias de queimadas: uma frequentemente queimada e outra com seis anos de exclusão de queimadas. Realizaram-se queimadas experimentais durante o verão (2006-2007), quando ocorre a maior parte dos incêndios. Mediram-se temperatura e umidade do ar, altura da vegetação, velocidade do vento, acumulação de material combustível (fino e grosso), umidade do material combustível, temperatura do fogo (a nível do solo e a 50cm), quantidade de cinzas e resíduos, altura da chama e duração do fogo. Calcularam-se a eficiência de queimada e intensidade do fogo. As temperaturas do fogo (47-537,5°C) foram maiores no sítio com historia de exclusão de fogo. As intensidades do fogo foram baixas (36,5-319,5kW·m^{-1}) comparadas com outros pastiçais, diferindo entre as duas localidades. A acumulação de material combustível fino é a variável que melhor explicou a intensidade do fogo. Os resultados apresentados são preliminares, devido ao tamanho pequeno das parcelas. No entanto, podem servir de base para a obtenção de licença para realizar quemadas experimentais em parcelas maiores, e proporcionam apoio a estudos sobre os efeitos do fogo no pastiçal e de modelagem e predição de risco.