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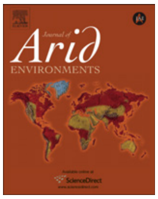

Fire patterns in central semiarid Argentina

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ABSTRACT

Wildfires can cause severe impacts on the terrestrial ecosystems depending on their frequency and behavior. We studied the environmental factors influencing the spatial and temporal distribution of fires, their size and duration in the central semiarid Argentina. We identified fires using MODIS satellite data and we analyzed their association with climate and land cover/use patterns. Spatial and temporal fire patterns varied between eastern, central and western regions according to the presence of agriculture, shrublands and water deficits, respectively. The frequency and behavior of fires also varied temporally with water conditions. Years with low effective precipitations were characterized by an important hotspot density and fire number, as well as the months preceded by two months with low effective precipitation (r^2: 0.42; $p < 0.0001$). We observed a spatial delay of fires in a northeast–southwest sense, related to the delay of the spring beginning (r^2: 0.7594; $p < 0.0001$). The mean fire sizes and duration varied significantly among vegetation types (F: 10.76, $p < 0.0001$ and F: 3.703, $p < 0.01$). Fires were bigger in shrublands and longer in shrublands or forests regarding agricultural areas or degraded areas (F: 16.0, $p < 0.0001$). The results obtained would be useful to prevent/control fires and to preserve natural resources and human communities.

1. Introduction

Wildfires are powerful phenomena that can modify ecosystems in positive or negative ways. Fires that maintain natural features (*e.g.*, frequency, intensity, duration, spatial distribution) are considered an important evolutionary force (*e.g.*, Mueller-Dombois and Goldammer, 1990). However, when these features are altered, fires can cause severe damage on the environment. The human arrival, the population growth and the intensification of their activities have altered the fires frequency and density, as well as their spatial and temporal distribution. Humans have changed environments producing high frequency of fires, as well as environments producing low fires frequency. For instance, tropical regions where fires were not very frequent originally, showed an increase of fire frequency because they were used to clear forested areas and change land use (*e.g.*, Di Bella et al., 2006). In the contrary, the onset and dryland agriculture in semiarid/arid areas reduced the natural fire frequency in these regions, where fire was part of the system (*e.g.*, Di Bella et al., 2006). As a result of these changes, the study of spatial and temporal patterns of fires is essential to create early warning systems and thus, reduce the negative effects of fires on the environment.

In the last two decades, remote sensing has become a valuable tool to study fires at different spatial and temporal scales (*e.g.*, Chuvieco & Kasischke, 2007; Dwyer et al., 2000). Using the spectral data captured by remote sensors it is possible to obtain information about: the surface temperature which allows the detection of fires (*e.g.*, Chuvieco, 1990; Giglio et al. 1999, 2003), the total radiative power of fires (megawatts) (*e.g.*, Kaufman et al., 1996, 1998; Wooster et al., 2005), the reliability of the fire detection, the fuel load (Brandis and Jacobson, 2003; Roff et al., 2005), the fuel moisture content (*e.g.*, Carter 1991; Chuvieco, 1990; Yebra et al., 2008), the burned area (*e.g.*, Chuvieco et al., 2008; Roy et al., 2008), and the vegetation status after fire occurrence, among others. Particularly, the hotspots product, for instance, allow the localization of potential areas affected by fires with different reliability. Currently, there are numerous institutions that provide free databases of hotspots detected around the world (*e.g.*, FIRMS, INPE, INTA, CONAE).

Argentina is a country severely affected by fires, in particular in its semiarid region. In 2007, around 47% of the total burned area of the country (120,000 ha) was registered in such environments, specifically in the Chaco region (PNMF, 2007). Despite the large surface burned every year, there is little understanding of fires,

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their patterns and behavior, hindering the implementation of appropriate prevention and control practices. In this paper we study fires patterns and behavior using satellite data (spatial and temporal distribution, frequency, spread, duration and advance direction), and we associate them with vegetation characteristics, climate and land use across a 530,000 km^2 in central Argentina. We hypothesized that these factors will influence the occurrence and behavior of fires, being shrublands and grasslands the most affected vegetation types because of their fuel accumulation and grazing use. Grazing will favor fires, since the use of fires is a common practice in foraging systems in order to eliminate senescent plant biomass and promote the vegetation re-growth. We also expect that water deficit will lead to an increase of fires. Finally, mean fire size and duration will vary depending on the vegetation types. Large fires will occur in grasslands, characterized by their horizontal continuity, while fires of long duration will be detected in forests, where the accumulation of biomass is higher. In addition, fire direction will be influenced by winds, due to the large surfaces without physical barriers in fields.

2. Materials and methods

2.1. Study area

The study area, located in the central semiarid belt of Argentina, extends over 530,000 km^2, and includes the provinces of Cordoba (CO), La Pampa (LP), Mendoza (ME) and San Luis (SL) (Fig. 1). According to national statistics, from 2003 to 2006, around 0.6 million ha (half of the burned area registered for the whole country) were affected by fires in the area (PNMF 2003-06). Across the region, mean annual precipitation declines from east to west from 1000 to 200 mm, while mean annual temperature decreases from north to south from 18 to 15 °C. The topography varies from sedimentary plains to mountain areas, including the *Sierras Pampeanas* and the *Andes*. Three different areas can be recognized: western, central and eastern. The western area (between 67°W – 69°W) is characterized by an arid/semiarid climate with poorly developed soils. This area is also characterized by sparse evergreen shrublands. Above 2800 m, grasslands replace shrublands, and above 3900 m the vegetation is sparse. As a result of the unfavorable climatic and ecological conditions limiting land uses, the extensive livestock prevails, although the intensive agriculture can be observed in areas under irrigation. The central area (between 65°W and 67°W) is characterized by semiarid climate and middle developed soils. Shrublands, forests and grasslands with xerophytes characteristics coexist in this area (Burkart, 1999; Cabrera and Willink, 1973; Paruelo et al., 2001). The main land use is grazing. In the eastern area (61°W–65°W), the subhumid climate and well developed soils favor the wide extension establishment of dryland agriculture.

2.2. Fire hotspot data

We used daily hotspots generated by the National Commission on Space Activities (Comisión Nacional de Actividades Espaciales, CONAE, 2004–2007). This product is developed from spectral

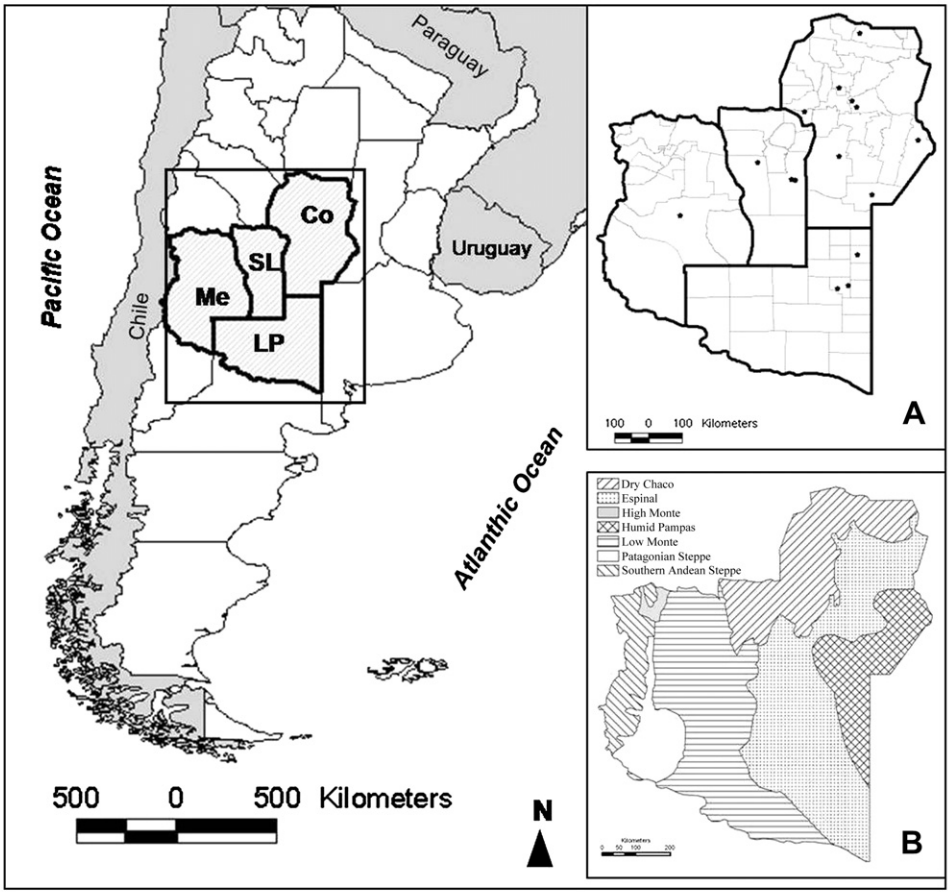

Fig. 1. Study Area location, including the Argentinean provinces of Cordoba (Co), San Luis (SL), Mendoza (Me) and La Pampa (LP), in South America. A) Points inside the zoom area represent the location of meteorological stations used to obtain the weather data; B) Spatial distribution of seven ecological regions described by Olson et al. (2001): Humid Pampa, Espinal, Dry Chaco, Low Monte, High Monte, Patagonian Steppe, Southern Andean Stepe.

data captured by MODIS sensor, aboard Terra and Aqua satellite platforms, applying different algorithms for day and night, and taking into account the energy emitted by surface at 4 μm (T_4) and 11 μm (T_{11}) (Dozier, 1981; Giglio et al., 2003; Justice et al., 2002). This product presents a spatial resolution of 1 km^2. A total of 7500 files, from September 2003 to May 2006, were analyzed. This period of study was selected because of the high fire density and frequency detected in this area. A database of hotspots was created including information of latitude, longitude, day, month and year, and detector satellite. Through the use of such database we could associate the hotspots data with other geographically referenced data layers (land cover/use and climate).

2.3. Land cover/use data

We used the Global Land Cover 2000 -GLC 2000- map (Eva et al., 2004; Mayaux et al., 2006) to obtain information about the extension and distribution of the land cover classes in the Semiarid Region of Argentina. This product provides information about the land cover types with 1 km^2 of spatial resolution (the same resolution that the MODIS hotspots products provide). This global product of land cover presents 22 classes, which we divided into 7 groups: agricultural crops, degraded vegetation, savannas, shrublands, grasslands, steppes and mountain forests.

Land use data was mainly obtained from national census at the county level (Censo Nacional Agropecuario, 2002 -CNA, 2002-). We extracted data from three variables: the total cultivated area (including annual/evergreen crops, annual/evergreen forage and deciduous/evergreen forests), the natural areas (including grasslands, shrublands, and spontaneous forests), and the unused/marginal areas.

2.4. Meteorological data

We obtained daily precipitation data -PP- (mm) and daily potential evapotranspiration -ETP- (mm) for the period 2003–2006 from 15 meteorological stations of the official Meteorological National Network, located in the study region (Fig. 1). The ETP values were calculated with Penmann-Monteith methodology (Monteith, 1965). From the PP and ETP values, we calculated the effective precipitation -EP-, as the difference between PP and ETP (EP = PP−ETP). We have generated, monthly, seasonally (weather seasons, growing/rest season) and annually, databases of EP. This variable is considered as a reliable indicator of water balance or drought index at regional scale. Previous studies have shown that EP is associated to the occurrence of fires and consequently, would be a good indicator of the wildfire risk (Dwyer et al., 2000; Price and Rind, 1994). The meteorological data were averaged and then analyzed temporarily with fire data. The meteorological data were not spatially interpolated due to the uncertainty of this process taking into account the number and spatial distribution of the stations evaluated.

2.5. Extraction and analysis of data

2.5.1. Fire events product

We considered that two or more hotspots can be part of the same 'fire event' if they present spatial and temporal association. The temporal and spatial window considered for the clustering process was two days and 2 km^2, to avoid omission errors related to undetected hotspots. We created a fire events database from the MODIS hotspots file previously generated. For each fire event, the following characteristics were extracted: a) occurrence date, b) potential size (number of pixels detected as hotspot), c) duration (days), d) orientation: main advance sense of fire events (NS, SN, WE, EW), e) extension rate: relationship between size and duration (pixels/day), and f) geographic location (central Lat/Long of the fire event). Although the estimation of fire size is unspecific from the hotspots databases, we considered that the fire size obtained from fire event data is the potential size of each fire. In this sense, we only considered the number of pixels detected as hotspots as the unit of fire event size.

Using a Geographic Information System -GIS- (©ArcView GIS 3.3, ©ERDAS IMAGINE 8.4) we compiled fire event data and additional information of land use/cover (point 2.3) and climate (point 2.4). From this utility it was possible to associate spatial and temporal fire patterns and their behavior, with the factors that influence them.

2.5.2. Data analysis

Firstly, we carried out a general descriptive analysis (Tukey, 1977) and we analyzed possible correlations between the variables applying the Pearson's correlation coefficient (r). We also analyzed simple linear regressions between variables (for example, the total burned surface and proportion of lands occupied by croplands by county). Dependent variables were associated to number, size, duration of fire events, or burned area. Independent variables were associated to climate, land cover or land use.

To analyze the spatial patterns of fire events, we used correlation functions of pairs, uni and bi-varied at different spatial scales 'r' (Stoyan and Stoyan, 1994). From these analyses it was possible to test the existence of spatial randomness or aggregation/regularity of fire events. We applied the O-ring statistics, which evaluate the number of points within a ring area at distance 'r' from an arbitrary point, divided by the intensity λ of the pattern (Wiegand and Moloney, 2004). In order to analyze the spatial distribution of all fire events in the study region we applied a univariate function, establishing as null model their complete spatial randomness (CSR). For CSR $O(r) = \lambda$, $O(r) > \lambda$ indicates aggregation of the patterns at distance r, and $O(r) < \lambda$ regularity (Wiegand and Moloney, 2004). Significance was evaluated by comparing the observed data with Monte Carlos envelopes from analysis of multiple simulations of the null model. We established a test with 99 samples and a ring radius of 20 km. We also applied this analysis for three different areas within the study area: *eastern, central* and *western*. In addition, from bi-variate tests we evaluate the distribution of early fire events initiated in late winter or early spring (August, September, October) in comparison with late fire events, occurred in late summer or early autumn (November, December, January). This function (O_{12}) can be defined as the expected number of points of pattern 2 (late fire events) within a ring at distance 'r' from an arbitrary point pattern 1 (early fire events) (Ripley, 1977):

$O_{12}(r) = \sum$[# (points of pattern 2 at distance r from an arbitrary point of pattern 1)]

All tests were done with the '*Programita*' software developed by Wiegand and Moloney (2004), with the spatial resolution of the grid greater than the measurement error but also fine enough to capture the scales of interest with sufficient resolution.

3. Results

From September 2003 to May 2006, around 1000 fire events affected 4450 pixels every year, which is equivalent to a potential burned area of 445,000 hectares. This area is three times bigger than the area burned in Spain every year in the same period (source: European Forest Fire Information System). In the study region, the period 2005–2006 was the most affected by monthly frequency of fires, 9% and 7% higher than the 2003–2004 period and 2004–2005 period, respectively (Table 1). On the other hand, the period 2003–2004 presented the largest burned area and

Table 1
Fire events -FE- patterns per campaign: Mean surface burned per month (hectares), mean number of FE detected by month, and mean FE size (pixels), mean FE duration (days) and mean effective precipitation -EP- (millimeters) per campaign.

Year	Burned surface	FE number	FE size	FE duration	EP
2003–04	42,305.79	99.1	4.27	1.13	−49.49
2004–05	25,169.28	96	2.62	1.04	−32.52
2005–06	31,217.7	118.64	2.63	1.04	−43.78

concentrated fires of large extension and long duration. Also, this campaign showed the lowest values of effective precipitation (EP).

Fire events were mainly detected in late winter and early spring (Fig. 2A). In fact, 67% of fire events and 68% of potential burned area were concentrated from August to November. This season is commonly affected by significant water stress. We even observed an exponential relationship between monthly frequency of fires and mean EP registered for two previous months (Fig. 2B). This trend was also observed with the monthly burned area. Both, fire frequency and burned area increased with EP decreases (r: 0.64, $p < 0.001$; and r: 0.76, $p < 0.001$, respectively). The fire frequency registered in August and September 2004, and August, September and October 2005 presented singular highest values (Fig. 2B). In this period, August presented the lowest variability in years (Fig. 2A).

Mean fires size indicated an upward trend from June to December and a downward trend from January to May (Fig. 3A). On the other hand, mean fire duration increased from July to November, when it reached the maximum, and then showed a considerable variability. Climatic conditions explained this pattern. Mean fire size was strongly and directly associated with the potential evapotranspiration registered per month ($r = 0.72$, $p < 0.0001$, $y = 43.78 + 18.39*x$). However, the increase in mean fire duration from July to November was directly and significantly associated with the mean monthly temperature ($r = 0.73$, $p < 0.01$, $y = -36.18 + 48.37*x$). In the following months, the average duration of the fire was controlled by another unanalyzed factor, causing its temporal variability.

Shrublands were the land cover that was most affected by fire events. About 48% of fire events affected shrublands, 65% of burned area was registered in this vegetation type and, fires were of larger extension than in the rest of land covers. Although the size and duration of fires are related, *i.e.*, large fires are also durable; it was observed that the mean duration of fire events was higher in forest (Table 2).

In addition, we observed that about 43.5% of fire events showed a north–south direction (N–S), 30.5% south–north (S–N), while 10% and 9.5% of the fires showed west–east (W–E) and east–west (E–W), respectively. We also noted that the geographical orientation of fires varied between seasons. During spring and summer, fires showed mainly N–S direction, while in autumn and winter, they mainly evidenced W–E direction (Fig. 3B).

Spatial distribution of fire events indicated a strong aggregation of fire events at scales smaller than 8 km, a segregation of fire events between 9 and 17 km, and a random distribution of them at larger scales ($p = 0.01$) (Wiegand and Moloney, 2004). In addition, spatial fire patterns varied among western, central and eastern areas. Central area showed the strongest aggregation of fires, associated to the surface occupied by shrublands and woodlands. This area presents the 26% and 23% of surface covered by shrubs and woodlands, respectively. In the eastern area, the low frequency of fires was related to the dominance of agricultural lands. About 95% of surface presents agricultural use. We detected a negative relationship between the fraction of burned area and the fraction of agricultural surface per county (Fig. 4). In this relationship, counties were grouped in ten groups according to the agricultural surface: 0–10%, 10–20%, 20–30% … 90–100% (r^2: 0.33, r: −0.58, p: 0.08, n: 10; Fig. 4). The response of two county groups reduced the analysis fit (30–40 and 40–50% of Agriculture Surface). Both groups were represented only by one county each (*Chacabuco* and *Guatraché* respectively). Excluding these two groups, the relationship gets stronger (r^2: 0.66, r: −0.81, p: 0.01, n: 8). *Chacabuco* is located in the northeast of *San Luis*, where the precipitation varies from 600 to 800 mm annually. Such county showed high values of fires. As a result of the water availability, areas covered by natural vegetation (64.7%) accumulate high quantity of biomass during the growing season, which leads to a high fuel quantity at the beginning of the fire season. On the other hand, *Guatraché*, located in the west zone of *La Pampa*, has an extensive area protected by law, thus reducing the available effective surface to be burned. Finally, in the western area, the low density of fires was associated to the quantity of fuel available. This area showed the most negative effective precipitation -EP-, causing a decline of vegetation growth and then, a smaller fuel quantity available for the ignition. Also, western area showed the biggest concentration of unused lands (around 10%), probably associated with the water deficits and soil characteristics.

We also observed that the occurrence date of fire events showed a spatial gradient (NE–SE sense). Fires occurred at the end of winter or early spring (August, September, October) were concentrated mainly in the northeast region, while these phenomena showed a delay to late spring- early summer (November, December, January) in the Southwest (Fig. 5).

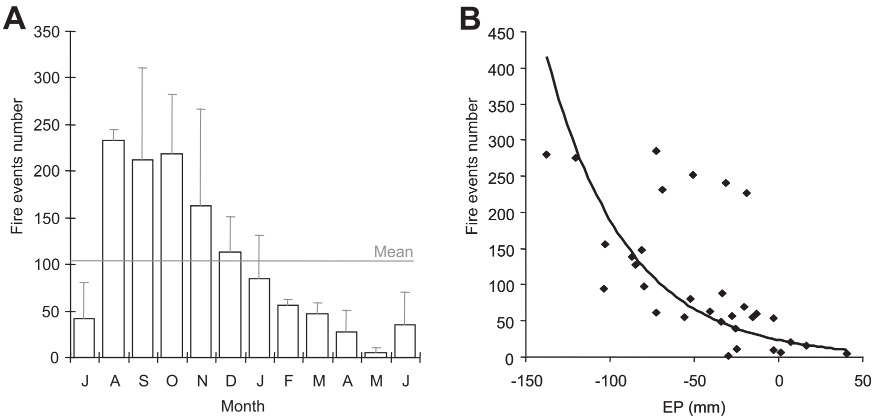

Fig. 2. A) Mean number of Fire Events -NFE- detected per month. B) Relationship between mean effective precipitations -EP- of two months (millimeters) and the number of fire events detected in the second month, exponential function ($R = 0.65$; $R^2 = 0.42$; $F(1;30) = 21.86$; $p < 0.0001$; $y = 23.48*\exp(-0.021*x)$).

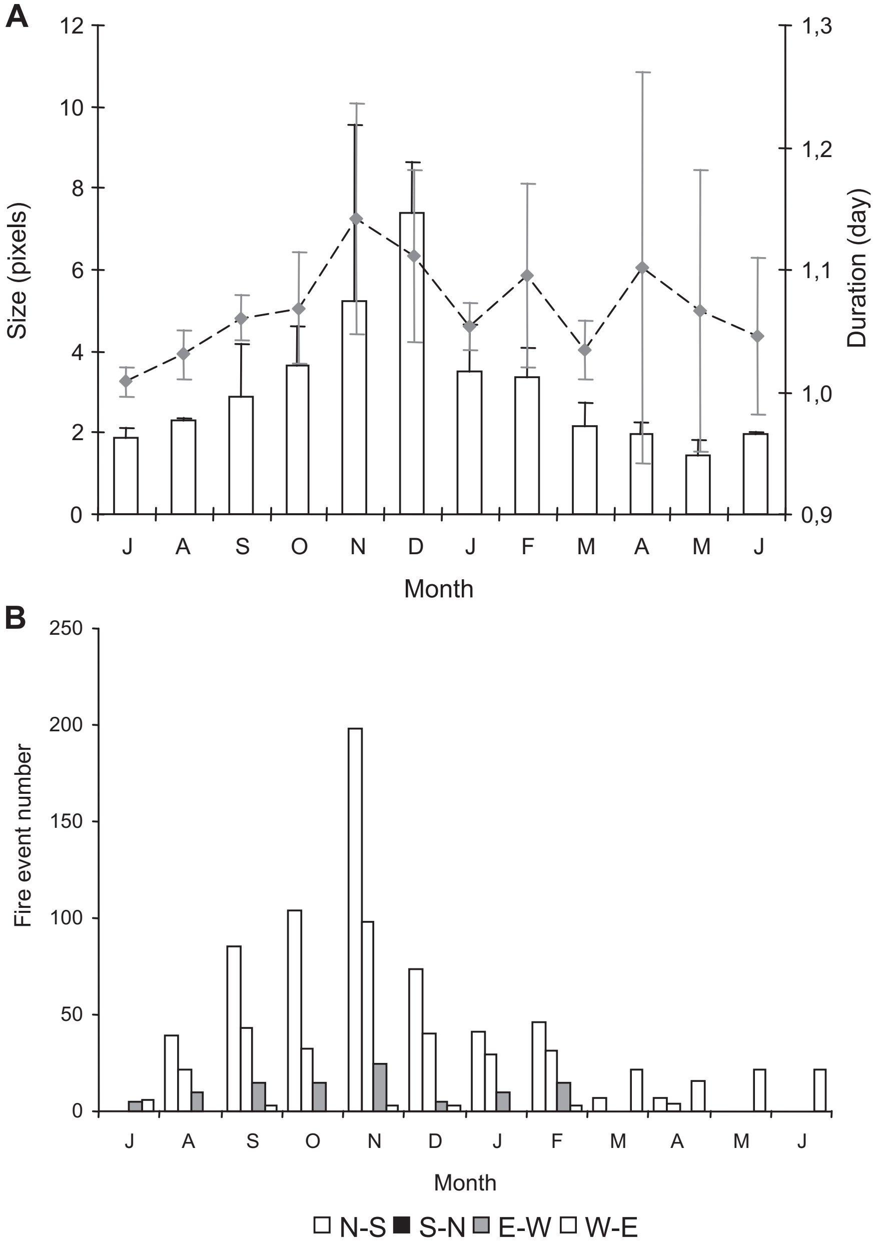

Fig. 3. A) Monthly distributions of size (bars) and duration (line) of fire events. B) Monthly distributions of fire events with N–S (NE–SW, NW–SE), S–N (SW–NE, SE–NW), E–W and W–E direction.

4. Discussion

There is a wide background on the influence of weather, fuel and ignition factors on the spatial and temporal patterns of fires (*e.g.*, Archibald et al., 2008; Chuvieco et al., 2002; Di Bella et al., 2006; Dwyer et al., 2000; Gisborne 1933; Price and Rind, 1994). However, in the central region of Argentina there are few studies that demonstrate the importance of each one considering the

Table 2
Annual characteristics of fire events -FE- by vegetation covers: number of fire events (NFE), burned surface (BS), size of FE (SFE), duration of FE (DFE), advance Speed (AS) per year.

Land Cover/Use	NFE	BS (hectares)	SFE (pixel)	DFE (days)	AS (pixel/day)
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean
Agriculture	140.7 ± 32.9	81,200 ± 10,551	1.90 ± 0.38	1.03 ± 0	1.84
Degraded Vegetation	52.3 ± 15.5	36,100 ± 2051.7	2.11 ± 0.90	1.06 ± 0.2	2
Savanna	19.3 ± 8.4	10,500 ± 1664.3	1.79 ± 0.13	1.02 ± 0	1.76
Shrublands	238.8 ± 72.9	428,300 ± 78,242.2	5.91 ± 2.97	1.03 ± 0.1	5.75
Grasslands	37.5 ± 4.4	33,275 ± 53,35.1	2.09 ± 0.93	1.03 ± 0.1	2.02
Steppes	19.7 ± 4.2	16,700 ± 25,10.6	2.72 ± 0.77	1.11 ± 0.1	2.45
Mountain Forest	22.9 ± 10.1	18,850 ± 4373.7	2.75 ± 2.15	1.14 ± 0.2	2.41

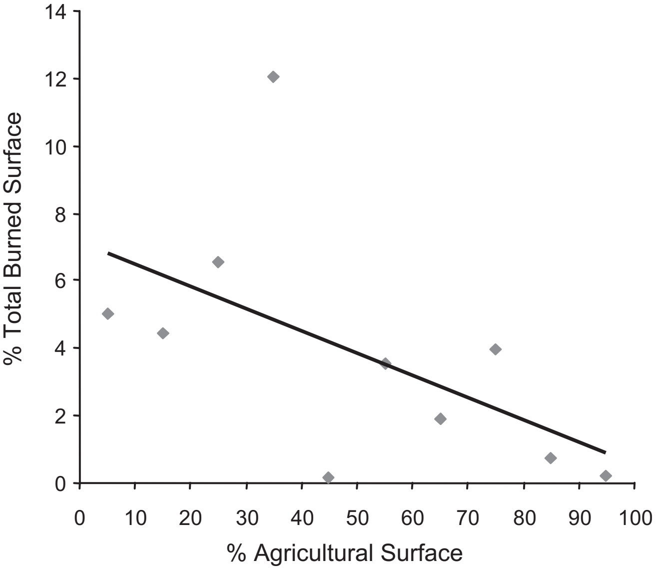

Fig. 4. Relationship between %Burned Surface and %Agricultural Surface for ten groups of counties clustered at 10% of agricultural surface (0–10, 10–20…90–100%) (r^2: 0.33, r: −0.58, p: 0.08, n: 10, %Burned Surface = 7.207–0.0674*x).

beginning and development of fire events. Our study was based on the importance of analyzing the spatial patterns of fire in this region and the influence of factors such as climate, vegetation cover and triggers of ignition. Our results showed that the season most affected by fires was late winter and early spring, period affected by an important water deficit caused by the temperature increase and the summer rains delay. The level of water deficit and the length of dry season are important to define the quantity and the status of fuel available to ignition. For instance, Stott (2000) suggests that a dry season as little as 2.5 months is enough to provide dry fuels for burning. In our study area, not only fire season is characterized by water deficit but also this time is preceded by a period of three months of low precipitations values (*i.e.*, autumn–winter months: May, June, July). In addition, during late winter and early spring farmers increase anthropogenic fire utilization in order to reduce senescent biomass and to promote forages re-growth. Optimal weather conditions for fuel combined with the high frequency of ignitions caused by humans determined the high frequency of fires in August, September and October observed in the results. However, only August showed lowest inter-annual variability. This result could be related to the higher frequency of droughts in August in comparison with September or October. These two months did not show dissimilar behavior among years taking into account burned area, probably because the burned area is strongly linked to climatic factors and weakly linked to human factors. Furthermore, the magnitude of fires grew during spring and summer. Main conditions of climate during these seasons could influence fire magnitude. However, the influence of climatic conditions on the fire size was stronger than the influence on the fires duration, this last variable was strongly related to the type and amount of fuel available.

In addition, our results show the important influence of fuel type over the spatial distribution of fires. Two factors could be affecting the highest frequency of fires detected in shrublands: their dominant land use and their vegetation composition and structure. This land cover is usually intended for livestock grazing, with addition of fires to improve forage quality and quantity. Also, the presence of fine and medium fuels (grasses and shrubs, respectively) in shrublands make them vulnerable to high fire sizes, as seen in results. In contrast, forests were vulnerable to a higher duration, associated to the presence of thicker fuels, which can promote the permanency of flames (*e.g.*, Kunst et al., 2003). Also, the spatial pattern of fires observed in this paper was defined by the presence of shrublands in the central region, determining two regions with low fire density. The eastern and western regions were characterized by the presence of agriculture and unused areas, respectively. Di Bella et al. (2006) observed that the agriculture addition in arid or semiarid environments reduces fire density due to the addition of irrigation and fuel reduction practices. Meanwhile, low fire density in western area was associated to the low fuel quantity available and the scarce productive land use. Baldi and Paruelo (2008) found historical low values of vegetation index (NDVI) in the western area, indicating low vegetation accumulation and growth. In turn, this region is characterized by having a mean annual precipitation from 200 to 300 mm. Previous studies showed that annual rainfall lower than 300 mm does not produce the necessary quantity of fuel for spreading of fires (Archibald et al., 2008; Tropolle et al., 2002). Also, the highest concentration of unused lands as a result of climatic and soil characteristics implied less human intervention, thus reducing the main fire trigger.

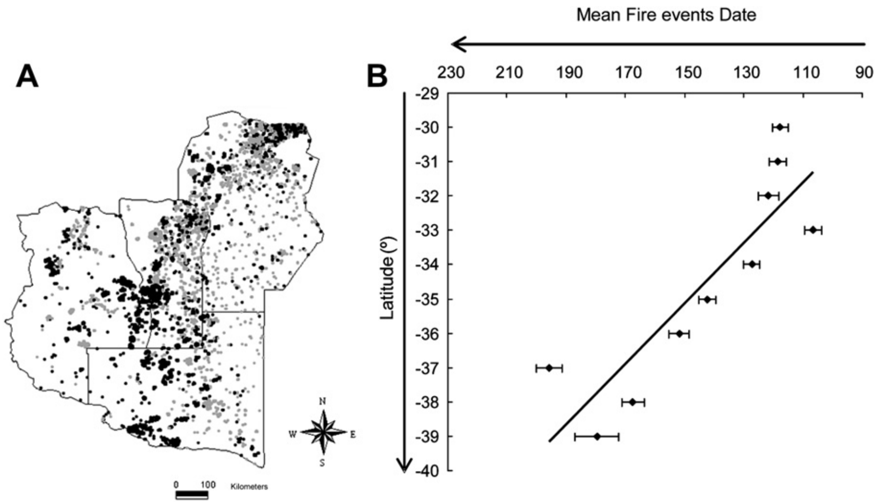

Fig. 5. A) Spatial distribution of winter-spring fires (grey: august, September, October) and spring–summer fires (black: November, December, January). B) Relationship between mean fire date and latitude (r: 0.8; $p < 0.01$; n: 10). Fires were enumerated from 0 to 365, according to the detection date, from July 1to June 30.

Although previous studies described that the geographical orientation of fires is strongly influenced by physical boundaries and microclimate conditions (Lacroix et al., 2006; Porterie et al., 2007; Tropolle et al., 2002), in our results the prevailing seasonal orientation of fires could be explained by the general winds direction registered by seasons (Snaider, 2004). The few physical barriers (perimeter edges, internal roads, corridors without fuel) as a result of the extensive grazing, allowed free propagation of fires mostly influenced by weather conditions.

Finally, the spatial pattern of ignition dates agrees with the results observed by Di Bella et al. (2006) between 1999 and 2001 for South America. The fire density peak varied with the beginning of the temperature increase and the delayed beginning of the rainy season. In the study area the NE–SW pattern would be determined by the climate and the warm air front coming from Brazil to Argentina in the spring–summer season (Snaider, 2004).

5. Conclusions

This paper describes the most important environmental factors influencing the spatial and temporal distribution of fire events and their behavior in a large area of the central region of Argentina. While the spatial-temporal patterns of hotspots are easier to describe, this work emphasized the importance of detecting fire events in order to characterize fire activity and behavior. In addition, the physical and biological diversity of the study area makes this an ideal region for studying the relations between climate, land cover, land use, and fires. The study of these interactions at regional level highlights the spatial and temporal variability, making it possible to obtain useful information to inform land managers.

Spatial distribution of fire events was influenced by the predominant vegetation type, climate and land use in different magnitudes depending on the three different areas. In the eastern area, the agricultural practices excluded fire as a management practice. The central area concentrated the highest density of fires as a result of grazing uses which include the use of fire to improve forage quality and quantity. The western area concentrated low fire density because it is characterized by limiting climatic conditions which reduce the amount of biomass accumulated in surface, and thus reduce the fuel available for fire ignition. Temporal patterns of fires were strongly influenced by the environmental conditions of humidity and by the frequency of ignition factors. Fire activity fluctuated not only annually in terms of number of fires, area burned, severity and duration of fire season, but also in a monthly basis. A period of sixty days was enough to generate appropriate conditions of fuels for fire ignition and burning. The beginning of fire season also varied with the beginning of the spring season and the increase of temperatures; resulting in a spatial delay of fire ignition dates in the northeast–southwest sense. Also, the association between the fire advance direction and the prevailing wind direction is an indicative of the lack of physical barriers (large farms) and, consequently, the freedom of propagation of fires in different directions, making them more unpredictable. Furthermore, in this paper we observed that the size and duration of fires vary among vegetation types, indicating a high frequency of large and severe fires in covers such as shrublands and woodlands, respectively.

Despite some limitations, the remote sensing data let us know where and when fires are more frequent and the characteristics of the places affected by severe fires. In the future, this information will be adequate to integrate more complex analysis which would lead to the creation of fire risk indexes at regional level with an operative cost and speed. These data will be useful in order to manage the systems appropriately before the fire occurrences and also to take correct decisions so as to control fires and apply rehabilitation measures in areas affected by them.

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