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Procedia Environmental Sciences 19 (2013) 856 – 864

Procedia
Environmental Sciences

Four Decades of Progress in Monitoring and Modeling of Processes in the Soil-Plant-Atmosphere System: Applications and Challenges

Spatio-temporal vegetation recuperation after a grassland fire in Lithuania

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Abstract

The aim of this work is to study the spatio-temporal effects of a grassland fire in Lithuania. Immediately after the fire, a experimental plot was designed in a east-faced slope. Vegetation cover and height were measured 10, 17, 31 and 46 days after the fire (vegetation cover was only measured until 31 days after the fire because in the last measurement campaign the plot was completely covered). The results showed that vegetation recovered very fast. Ten days after the fire vegetation cover and height distribution were heterogeneous, decreasing with the time due to vegetation spread. Vegetation recovered was specially observed between 17 and 31 days after the fire due vegetation recuperation. This increase might reduce the soil vulnerability to erosion However, the spatial structure of this recuperation was different in both variables, and spatial autocorrelation was higher in vegetation cover than vegetation in height in all measurements. Despite these differences, vegetation cover and height values were higher in the bottom part of the plot that was attributed to lower fire severity and ash and nutrient transport.

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doi:10.1016/j.proenv.2013.06.095

Keywords: Type your keywords here, separated by semicolons ; Grassland fire; Lithuania; Vegetation cover and height; Vegetation recuperation; spatial autocorrelation

1. Introduction

Fire is a global phenomenon with important implications in many earth ecosystems. It is considered as a “global herbivore” and, with exception to polar environments, it is difficult to find a place not visited by fire. In addition, fire is linked to many ecosystems life history and evolution. Fire is an ecological factor [1,2]. Traditionally, research on forest fires effects on ecosystems has been carried out in Mediterranean environments due the impact of summer wildfires [3,4,5,6]. These fires are considered catastrophic for human goods [7,8]. Often, boreal ecosystem receive the visit of fire, and it is considered an important disturbance [9] especially in the recent years due climate warming [10,11]. Several studies about fire effects on boreal vegetation recover were carried out in Eurasia [12,13,14] and North America [15,16,17]. Spatio-temporal variability of fire severity in boreal ecosystems depends on biophysical environment (e.g. slope, aspect, elevation, fuel characteristics as type, distribution, connectivity, density, package and meteorological variables as moisture and wind). Fire is a process that changes with time and trigger different impacts in the boreal area [18]. Most of the research about fire impacts in vegetation recover in boreal ecosystems was carried out in the forests. Little is known about the effects of fire in boreal grasslands vegetation recuperation, especially in the immediate period after the fire, where the major changes occur (e.g ash and sediment transport), with implication on nutrients distribution and plant recuperation [19, 20, 21].

Mapping spatial distribution of variables is important to be able to understand how processes change in space and time [22]. This is especially relevant in burned areas, because they are subjected to important changes in ash transport, soil protection [19, 20, 23] or in soil physical and chemical properties [24, 25]. Some works have been carried out in mapping vegetation recover after fire using remote sensing techniques, in a small scale resolution [26, 27]. However, little information is available in international literature about vegetation recuperation in small plots, where important processes occur and are ignored in small scale studies [19].

Vegetation recovery spatial assessment is a crucial study in recent burned areas. Vegetation response it is a good indicator of ecosystem resilience and soil protection, minimizing the effect of erosion agents in soil [28]. In addition, the great majority of the studies do not consider short-term changes and studies in burned areas are carried out considering large time intervals (e.g. months or years) [29, 30], ignoring the impacts occurred in the immediate period after. The aim of this work is to study the spatio-temporal vegetation recovery in the immediate period after a spring grassland fire.

2. Materials and methods

2.1. Study area

The studied area is located near Vilnius urban area (Lithuania) at 54° 42’ N, 25° 08’ E, 158 m.a.s.l. where grassland fires are common after the winter, to remove old grass and dead material so fields are clean for spring and summer cultivations. This low severity fire occurred in April 15th of 2011 affecting an area of 20-25 ha. Soils are classified as *Eutric podzoluviols* [31] and the vegetation was majorly composed by *Leontodon autumnalis and Anthoxanthum odaratum*, characteristics of semi-cultivated grasslands of *Cynosurion cristati*. The research was carried out in an experimental plot designed in an east-faced slope with 15% of inclination. Four parallel transects of 1m distance and 20 m of length were vegetation cover was measured with small plots of 0.25 x 0.25 m, adjacent along the transects [32].

Vegetation cover was assessed visually. The height of the dominant species (*Leontodon autumnalis and Anthoxanthum odaratum*) was assessed in four individuals in each sampling point and the average of it was assigned to the point inside the small plots. The vegetation recover assessment was carried until vegetation showed strong signs of recuperation. Measurements for vegetation height were taken 10, 17, 31 and 46 days after the fire. For vegetation cover, the assessment was only carried out in the first three periods. Forty six days after the fire the plot was reached a 100 % cover. In each period we measured both variables in 164 sampling points.

2.2. Statistical and spatial analysis

We applied statistical analysis of vegetation cover and height, specifically mean, standard deviation (SD), coefficient of variation (CV%), minimum (Min), maximum (Max), skewness (skew) and kurtosis (kur) in order to analyze data distribution. Prior to data treatment, the normal distribution was assessed with the Kolmogorov-Smirnov test (K-S). In this study, vegetation cover data only respected the Gaussian distribution after a neperian logarithm transformation (ln) and vegetation height after a box-cox (B-C) transformation. Comparisons among periods were carried out with an Anova repeated measures test, using the transformed data. If significant differences were founded (at a $p<0.05$) a post-hoc Fisher LSD test was applied. The correlation between vegetation cover and height was carried out with the non-parametric Spearman correlation coefficient. For spatial modeling proposes, data were transformed to minimize the effects of the outliers and back-transformed in order to observe the spatial distribution of the real values. This procedure is commonly used when original data in severely skewed [33].

Data spatial correlation was assessed with the Moran's *I* index. This index was used to identify the spatial changes of vegetation cover and height among the neighboring points using the Euclidian distance. With this information we can observe if the data it is spatially correlated. Moran's *I* index is a measure similar to Pearson correlation coefficient, +1.0 means strong positive spatial autocorrelation (clustered), 0 it is a random distribution and -1.0 is a strong negative autocorrelation (dispersion) [19].

Data spatial variability was assessed with a semi-variogram that identifies the spatial continuity of vegetation cover and height. It is obtained calculating the semi-variogram values at different lags. These values are fitted with different theoretical models. The most common are the spherical, exponential and Gaussian. These models give an idea about the spatial structure of Kriging interpolation [34]. In the present study the omni-directional semi-variogram was assessed, it assumes that the variability of the variable is equal in all directions. The amount of sampling points is higher than the minimum required to have a stable variogram (100-150) [19, 35]. The variable spatial dependency was assessed with the nugget/sill ratio. If the ratio is <25% the spatial dependency is high. Between 25% and 75% the spatial dependency is moderate and >75% the spatial dependency is weak [36].

Spatial estimation was carried out with Kriging method that provides a considerable number of methods for estimate values in unsampled points [37]. The great advantage of Kriging in relation to other methods is the estimation of the spatial correlation among sampling points [38]. In this work for spatial interpolation we used the ordinary Kriging method. Statistical analysis was carried out with Statistica 7.0 (Statsoft) and spatial analysis and interpolation with ArcGis version 10.1 (ESRI) for windows.

3. Results and discussions

3.1. Descriptive parameters

The results show significant differences in vegetation cover (F=1277.50, p<0.0001) and vegetation height (F= 1727.67, p<0.0001). Vegetation recuperation increased with the time and, especially, in the period between 17 and 31 days after the fire. In opposition, the CV% decreased with the time in both variables (Table 1a and b). The correlation vegetation cover *vs* vegetation height was 0.15, p>0.05, 10 days after the fire, 0.82, p<0.0001, 17 days after the fire and 0.89, p<0.0001, 31 days after the fire. This rapid vegetation recuperation was attributed to the low fire severity that did not have direct implications on soil properties (e.g soil moisture and organic matter) [39, 40], the great amount of nutrients available in ash [41] and the rainfall pattern after the fire.

Table 1. Descriptive statistics of a) vegetation cover (%) and b) vegetation height (mm) and results of Fisher LSD test. Different letters represent significant differences at a $p<0.05$. Neperian logarithm transformation (ln) and box-cox transformation (BC) data**.**

a)	10	10(ln)	17	17(ln)	31	31(ln)
Mean	15.79	2.64**a**	27.26	3.21**b**	67.74	4.18**c**
SD	7.99	0.48	11.89	0.43	15.70	0.23
CV%	50.61	18.18	43.61	13.39	23.17	5.50
Min	5	1.60	10	2.30	40	3.68
Max	45	3.80	56	4.02	95	4.55
Skew	1.25	-0.002	0.72	0.07	0.32	-0.004
Kur	1.38	-0.05	-0.47	-0.90	-1.01	-0.98

b)	10	10(ln)	10(BC)	17	17(ln)	17(BC)	31	31(ln)	31(BC)	46	46(ln)	46(BC)
Mean	117.79	4.69	12.51**a**	148.78	4.96	13.39**b**	288.94	5.62	16.44**c**	488.73	61.17	19.34**d**
SD	45.01	0.43	1.57	44.01	0.30	1.22	86.49	0.30	1.52	110.89	0.22	1.32
CV%	38.21	9.16	12.54	28.58	6.04	9.11	29.93	5.33	9.24	22.68	0.35	6.82
Min	10.40	2.34	5.82	69.80	4.25	10.78	150.80	5.02	13.69	265	5.58	16.27
Max	232.15	5.45	15.63	267	5.59	16.31	462	6.14	19.26	772.20	6.65	22.48
Skew	0.51	-1.21	-0.475	0.57	-0.02	0.15	0.341	-0.005	0.09	0.51	0.07	0.20
Kur	-0.043	4.58	1.23	-0.36	-0.52	-0.57	-1.13	-1.21	-1.21	-0.48	-0.60	-0.46

The major precipitation occurred between 17 and 31 days after the fire triggering rapid vegetation recover [39]. The decrease of CV% with the time is due to the rapid spread of vegetation cover and increase of vegetation height that reduced the differences between the measured values. The small-scale variability in the immediate period after the fire was higher due to the heterogeneous effects of fire in soil and ash properties. Over the time, these differences were reduced and the ash redistribution allocated the nutrients in specific part of the plot [42] that will be analysed further in this paper. These results showed that vegetation rapidly covered the soil minimizing the effects of the studied fire and the potential exposition to sediment transport, especially between 17 and 31 days after the fire. Comparing with other environments (e.g Mediterranean) [21], the vegetation recuperation was faster, suggesting that the studied grassland have strong resilience to these spring fires that are very common in Lithuania [39].

3.2. Spatial analyses

The results shown that vegetation cover and height spatial distribution were significantly clustered (positive and significant Morans *I* index) ten days after the fire, and increased with the time. The same situation was observed in vegetation height (Table 2). The existence of spatial autocorrelation suggests that after the fire, plant recuperation responds to processes that occur in the area of interest. This pattern was more observable in vegetation cover than in height (higher coefficient of correlation) until 31 days after the fire.

Table 3 shows the results of the semi-variogram modeling. Among other models, the spherical was the best-fitted in all measurement periods for vegetation cover (Table 3a) and the Gaussian the most accurate to explain the vegetation height variability (Table 3b). These results suggest that the spatial structure of vegetation cover and height recover was different across the studied plot. In both variables the nugget effect was small showing that the measurement error and the small scale variability was reduced, and the number of samples was enough to represent the spatial variability of the variables [19] (Table 3a and b). The nugget/sill ratio results showed that vegetation cover has a strong spatial dependence in all measurement periods (<25%). Ten days after the fire, the vegetation height has a moderate spatial dependence, 33.33%, decreasing in the following measurements to very low values, 31 and 46 days after the fire, suggesting that vegetation grew in height faster in specific(s) area(s) of the plot (Table 3a and b). In order to compare the range of Gaussian and Spherical model, we calculated the “effective” range of the Gausian model. The “effective” range it is the distance at which the variogram reaches 95% of its sill [43]. The range was always higher in vegetation cover than in vegetation height, suggesting that the spatial correlation of the first variable was higher than the second, supporting the results observed with Moran’s *I* index. The semi-variogram range was higher than the sample density (0.5 m) in all sampling periods, which shows that the sampling design was adequate to measure the variability of the vegetation cover and height.

Table 2. Results of the Moran *I* index for vegetation cover. Significant differences at a $p<0.05$.

	Vegetation cover (%)		Vegetation height (mm)	
Day	Moran's Index	p-value	Moran's Index	p-value
10	0.672931	0.000000	0.506652	0.000000
17	0.872059	0.000000	0.742019	0.000000
31	0.905002	0.000000	0.876701	0.000000
46	-	-	0.919814	0.000000

3.3. Spatial distribution of vegetation cover and vegetation height

Ten days after the fire the vegetation cover and height did not had a clear spatial pattern in the top and middle of the slope. Nevertheless some majour values were observed in the botom of the slope (Figure 1a and 2a). These differences in spatial vegetation recuperation across the slope can be atributed to the fire severity. After the fire the majority of the ash was black, suggesting that fire had a low severity. However grey and white ash was also identified, especially in the middle and top slope positions [42]. This can explain the differences in plant recuperation 10 days after the fire. In addition, fire is more severe in slope top positions were vegetation moisture is lower in comparision with flat areas and the fuel vulnerability to the flammes is higher, as observed in previous studies [20; 44; 45]. With the time, the faster recuperation of the vegetation in cover and height in the bottom of the area of interest was atributed to the accumulation of ash and nutrients. Previous studies observed that plant recuperation is fast in the areas where ash is accumulated [41] .

Table 3. Results of the semi-variogram modelling for a) vegetation cover and b) vegetation height.

a)	Model	Nugget effect	Partial sill	Sill	Nug/sill ratio (%)	Range (cm)
10	Spherical	0.2	1.5	1.8	11.11	1320
17	Spherical	0.09	0.82	0.91	9.89	2980
31	Spherical	0.21	1.6	1.81	11.60	2990

b)	Model	Nugget effect	Partial sill	Sill	Nug/sill ratio (%)	"Effective" Range (cm)
10	Gaussian	0.57	1.14	1.71	33.33	1214
17	Gaussian	0.51	2.61	3.12	16.34	1613
31	Gaussian	0.18	10.89	11.08	1.65	1639
46	Gaussian	0.37	23.65	24.02	1.54	1795

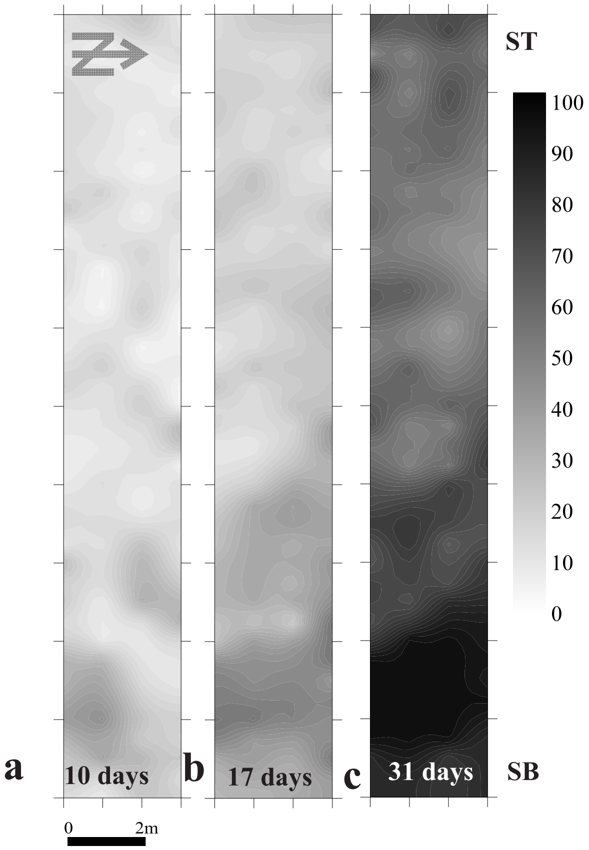

Fig. 1. Vegetation cover (a) 10; (b) 17 and (c) 31 days after the fire. Slope Top (ST) and Slope bottom (SB). Data in %.

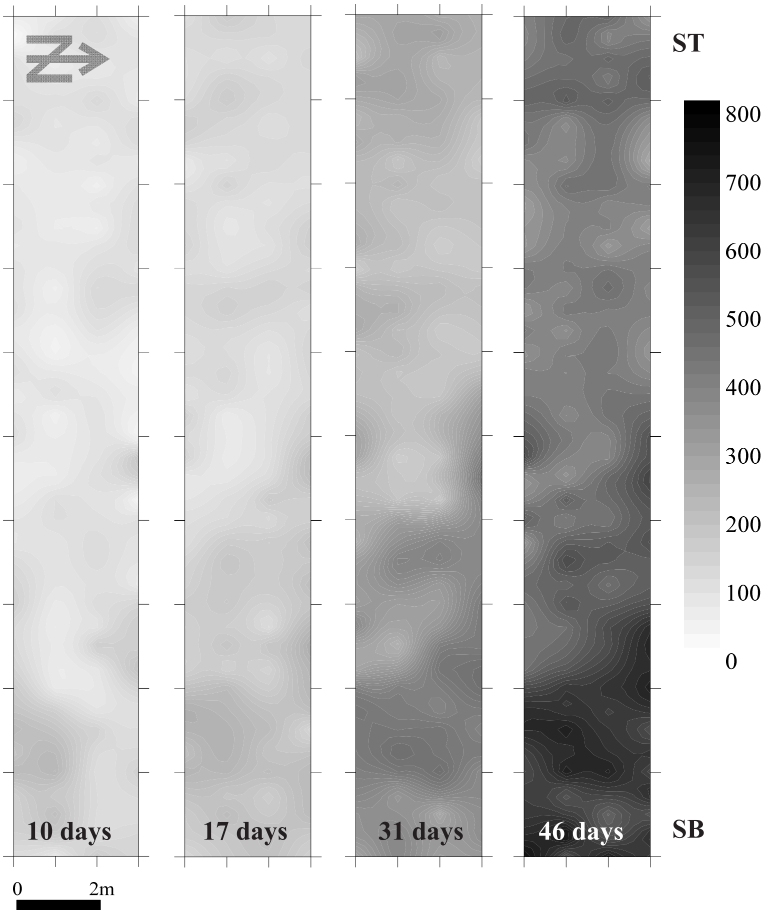

Fig. 2. Vegetation height 10; 17; 31 and 46 days after the fire.Slope Top (ST) and Slope bottom (SB). Data in mm.

4. Conclusions

This study showed that vegetation recuperation after a grassland fire was fast and the studied grassland had strong resililience to such distrurbance. This fast recovery might reduce the amount of sediment transport, minimizing the effects of vegetation removal induced by fire. Vegetation cover and height spatial autocorrelation increased with time, indicating that areas with bare soil or only covered by ash were reduced. This increase did not had the same spatial structure in vegetation cover height. Ten days after the fire the vegetation cover and height had an heterogenous distribution, reducing with the time. In the following measurments, cover and height increased especially in bottom area of the plot due lower fire severity and ash and nutrients accumulation.

Acknowledgements

The authors appreciated the support of the project 'Litfire', Fire effects in Lithuanian soils and ecosystems (MIP-048/ 2011) funded by the Lithuanian Research Council, Spanish Ministry of Science and Innovation for funding through the HYDFIRE project CGL2010-21670-C02-01, and to Comissionat per a Universitats i Recerca del DIUE de la Generalitat de Catalunya i Recerca del DIUE de la Generalitat de Catalunya. The authors appreciate the comments of one anonymous reviewer that improved substantially the quality of the manuscript and to Miss Maria Burguet for the English revision.

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