Post-Fire Fuel and Vegetation Dynamics in an Ungrazed Phryganic Community of Crete, Greece

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Abstract

The effects of overgrazing and frequent burnings on phrygana are relatively known-by scientists, but limited attention has been paid to the functioning of these communities when grazing and fires are suppressed. The aim of this study is to investigate post-fire vegetation and fuel dynamics in an ungrazed S. spinosium dominated phrygana in northwestern Crete. Fuel was first analyzed according to shrub, herb, litter, and total load; then live and dead materials; and finally, 0-0.5 cm and 0.6-2.5 cm diameter classes. Vegetation was analyzed based on cover and life form composition and dynamics. Also, species richness, diversity, and dynamics were investigated. One-way ANOVA was used to test for fuel and vegetation differences among sites, and Shannon-Wiener and Equitability indices were used to assess both diversity and evenness. Results showed a rapid reestablishment of both the vegetation (cover, life form, species richness and diversity) and fuel, as early as the 3rd and the 6th post-fire year, respectively. Fuel and vegetation were tremendously dominated by unpalatable and highly flammable dwarf shrubs which smothered herbaceous plants. Species diversity was relatively low, indicating that few species crushingly structured the community by their high cover, while the remaining species were poorly abundant.

Keywords: Biomass, Phrygana, Post-Fire Dynamics, Species Diversity, Species Richness.

1. Introduction

Many, if not all, ecosystems of the world are known to undergo cyclic processes of disturbances and recovery, occurring at specific spatio-temporal scales. These natural phenomena allow ecosystems to maintain their ecological processes as well as their biological and ecological diversity in space and time (Naveh, 1994). As far as post-fire plant demography in phrygana is concerned, Arianoutsou (1998) documented a great deal of dwarf shrubs' seed germination and seedling recruitment during the first post-fire year, contrasting with the unburned phrygana. By far, the dominant seedlings were made up of *Cistus* spp. and *Sarcopoterium spinosum* (with numbers multiplied by 10 and 20 times). On the contrary, a low seed germination level portrayed dwarf shrubs in the 2nd post-fire year; 10 seeds per m^2 for Cistus spp. and 3 seeds per m^2 for *S. spinosum* were counted in winter. A similar demographic trend has also been reported for other phryganic communities by Naveh (1974), Papanastasis (1977), and Arianoutsou (1998), that is, a decrease in number of dwarf shrubs' seedlings during the first post-fire year, and no conspicuous seed germination during the 2nd post-fire year. It is worthwhile referring that two main hypotheses have been suggested to explain the aforementioned decrease in seedling density; either the negative effects of the hot and dry Mediterranean summer on dwarf shrub seedlings' survival (Ferran *et al*., 1998) or the strong inhibiting competition exerted by the massive herbaceous plants on the young dwarf shrubs' recruits (Henkin *et al*., 1999; Seligman and Henkin 2000) Studies (Naveh, 1994; Naveh and Whittaker, 2007) have reported that both high ecosystem diversity and landscape maintenance in the Mediterranean have been promoted and ensured by the cyclic disturbances properly induced by humans and their livestock. However, improper land use such as wildfires and overgrazing for decades has significantly altered the ecosystems, and more particularly rangelands, such as phrygana in the eastern Mediterranean. Therefore, the objectives of the current research are to investigate post-fire fuel and vegetation dynamics in an ungrazed *Sarcopoterium spinosum* dominated phryganic community in northwestern Crete (Greece) for a relatively short period; that is, between 3 and 12 years.

2. Materials and Methods

2.1. Study area general description

The study area is represented by the hills of Malaxa situated in north-western Crete. The Prefecture of Chania administratively manages this part of the island, and, more specifically, the municipality of Souda. The climate of Chania is typically Mediterranean, characterized by a long dry summer season with a monotone wind regime, and precipitations ranging from September to May (Elhag and Bahrawi 2016). The recent climatic data of Chania, for the last 20-year-period, indicated an annual precipitation

averaging 690.4 mm. The Bagnouls-Gaussen ombrothermic diagram, drawn from the abovementioned data, displays a longer dry summer period than the one mentioned by Elhag and Bahrawi (2016), beginning in April and ending in mid-September. The rainy period, ranging from October to March is characterized by an average precipitation of 615.65 mm, and the xerothermic period, extending from April to September, reaches 74.75 mm only. It is worth noting that January and February are the coldest months, with an average temperature of 10.6 °C, and July the hottest month with an average of 24.7 °C. Based on Emberger's pluviothermic quotient value (Q=86) calculated for Chania, Elhag and Bahrawi (2016) classified this region in the subhumid mediterranean bioclimate.

2.2 Sampling techniques and procedures

2.2.1. Fuel sampling and procedural steps

Sampling location was randomly selected in the central part of a physiognomically homogeneous vegetation, and line-transects were run in four directions from a central point. Each line- transect was 15 m long and one plot was taken at the end. The total number of plots per site was four. In each 1 m^2-plot, all the aboveground biomass was clipped and stored in a plastic bag. As regards the laboratory work, the first step consisted in biomass separation to shrub, herb, and litter. Shrub was then divided to live and dead parts. It is noteworthy that live material included green leaves and fresh twigs, whereas dead material all the parts devoid of living tissues. Afterwards, live and dead materials were separated to two diameter classes: 0-0.5 cm and 0.6-2.5 cm. Finally, the fuel was oven dried at a temperature of 105° C for 24 hours, then weighted with a digital balance according to the aforementioned categories.

2.2.2. Vegetation sampling and procedural steps

Vegetation sampling was carried out in the central part of a physiognomically homogeneous vegetation in order to ensure samples' representativeness and to avoid any edge effects. In each sampling location, four line-transects were run from a central point, following the scheme used in biomass sampling, but transect length was 20 m. Cover values of plants, litter, and bare ground were then recorded using Line Transect and Point Intercept methods combined (Bonham 1995); a 20 m measuring tape was stretched between two stakes along the line-transect, and a pin was dropped perpendicularly to the tape each 20 cm interval. Observations were recorded by reading the hits. The laboratory work was conducted in a herbarium: plant specimens were identified with the help of a stereoscope and the descriptive keys of Flora Europaea referential volumes (Tutin et al., 1980).

2.3. Analytical procedures and statistical treatments

2.3.1. Fuel analysis

Fuel was analyzed according to the several categorizations based on the biomass separation to shrub, herb, and litter, fuel separation to live and dead materials and fuel separation to diameter classes. Post-fire changes in fuel composition and dynamics were investigated at the abovementioned three category levels. Analysis of variance (one-way ANOVA) was used to test for biomass load differences among sites, and Duncan multiple range tests for mean pair's comparisons.

2.3.2. Species diversity

Post-fire species diversity dynamics was investigated using both heterogeneity and equitability (also referred as evenness) indices. Species diversity was calculated using the Shannon-Wiener heterogeneity index (H') which is based on the Information Theory (Naveh and Whittaker 2007; Magurran, 2013). The formula is the following:

$$H' = -\sum_{i=1}^{s}(P_i)(log_e P_i)$$

Where

H' = the Information content of sample (nits/individual).

s = Number of species.

Pi = Abundance of the i-th species expressed as a proportion of total cover.

Equitability which refers to the pattern of distribution of individuals among species was calculated using the following index proposed by (Kent, 2011) based on Shannon-Wiener diversity index:

$$J = \frac{H'}{H'_{max}}$$

Where

J = the Equitability index.

H' = Shannon-Wiener diversity index.

H' max = loge (s) = Maximum possible value of H'.

s = Number of species.

3. Results and Discussion

3.1. Post-fire fuel dynamics

In all sites, both shrub and litter accounted for about 97% of total fuel composition. By far, shrub's contribution was the most important (about 80%). The remaining fuel was represented by the herbaceous vegetation and counted about 3%. In addition, shrub, litter, and total fuel loads differed significantly (p=0.003, p=0.034, and p=0.002, respectively) among the sites, while herbaceous load did not (p=0.508). Live and dead shrub fuel loads measured at the four sites with different fire intervals are presented in table 1. The highest live material's contribution (about 80% of shrub fuel composition) was noted in the 3rd post-fire year. On the contrary, dead material was found highly accumulated (about 65% of shrub fuel composition) in the 12nd post-fire year. One must notice the similar proportions of both live and dead materials in the 6th post-fire year. Additionally, both live and dead fuel loads were found differing significantly (p=0.038 and p=0.002, respectively) among the sites and the following differences were highlighted in the multiple comparison test. Percentage of live and dead fuel load between parentheses. Comparisons among sites performed by conducting one-way ANOVA and Duncan's Multiple Range Test, both at p=0.05 level of significance. Values followed by the same letter are not statistically different. In all the sites, live fuel was almost entirely made up of material in the 0-0.5 cm diameter class.

Table 1. Live and dead shrub fuel loads (oven-dry weight) measured at the four sites with different fire intervals (kg/ha).

Site N° [Fire interval]	Live fuel	Dead fuel	Total fuel
Site 1 [3 years]	3092.3[a] (78.7%)	835.1[a] (21.3%)	3927.4[a] (100%)
Site 2 [6 years]	6097.5[c] (49.6%)	6191.1[b] (50.4%)	12288.6[b] (100%)
Site 3 [9 years]	5044.3b[c] (40.9%)	7284.9[b] (59.1%)	12329.2[b] (100%)
Site 4 [12 years]	3986.4[ab] (35.1%)	7380.6[b] (64.9%)	11367.0[b] (100%)

The latter size class material also dominated dead fuel composition (about 89%), while larger fuel in the 0.6-2.5 cm diameter class was poorly represented (about 11%). Additionally, live and dead fuel loads in the 0-0.5 cm diameter class differed significantly (p=0.046 and p=0.001, respectively) among the sites. On the contrary, dead fuel load in the 0.6-2.5 cm diameter class did not (p=0.143). During the post-fire dynamic process, the fuel accumulated in the community was chiefly issued from shrubs, mainly made up of *Sarcopoterium spinosum* and *Cistus creticus*, and litter. Litter was enough accumulated as early as the 3rd post-fire year. In comparison with the results of Arianoutsou-Faraggitaki (1984) in a phrygana of Attica, there is an agreement about shrub dominance as soon as the 3rd post-fire year onwards. However, the community of Malaxa had almost double the shrub fuel load (3927.4 kg/ha vs. 1950.0 kg/ha) three years after the fire. Additionally, total fuel load of the Malaxa phrygana in comparison with a *Sarcopoterium spinosum* dominated phrygana in Thessaloniki showed that the former had almost double fuel load (4673.9 kg/ha) than the latter (2800.0 kg/ha). Thus, the Malaxa phryganic community is characterized by a higher fuel production than the two other communities. These differences in biomass production may be attributed to differences in the prevailing environmental conditions or to the management practices (e.g., grazing), or even both.

3.2. Post-fire vegetation dynamics

In all sites, shrubs composed about 73% of the vegetation cover, whereas herbs and grasses contributed to about 27% only. With respect to the herbaceous component, it is worth noting that the most contributing species to total vegetation was the perennial grass *Brachypodium retusum* with an average cover amounting to about 3%. Additionally, both shrub and herbaceous covers did not differ significantly (p=0.269 and p=0.087, respectively) among the sites. The above results show that the vegetation was overwhelmingly structured by shrubs, whereas herbaceous contribution was not substantial. Overall vegetation cover stabilization was also detected as early as the 3rd post-fire year onwards. A total of 114 species belonging to 23 families were recorded in the community using the line transect and point intercept methods combined. The floristic composition based on life form richness in the four sites with different fire intervals is summarized in table 2.

Table 4. Life form richness of the four sites with different fire intervals.

Life forms	Site 1 [3 years]	Site 2 [6 years]	Site 3 [9 years]	Site 4 [12 years]
Phanerophytes	4 (9.8%)	3 (5.4%)	4 (6.6%)	4 (5.9%)
Chamaephytes	5 (12.2%)	7 (12.5%)	8 (13.1%)	7 (10.3%)
Geophytes	3 (7.3%)	2 (3.6%)	3 (4.9%)	2 (2.9%)
Hemicryptophytes	11 (26.8%)	19 (33.9%)	14 (22.9%)	17 (25.0%)
Therophytes	18 (43.9%)	25 (44.6%)	32 (52.5%)	38 (55.9%)
Total	41 (100%)	56 (100%)	61 (100%)	68 (100%)

Percentage of total life form groups for each site is given between parentheses.

In all the sites, therophytes and hemicryptophytes were the most dominant life forms, both contributing to about 76% of the floristic composition. It is worthwhile mentioning that therophytes were, by far, the most represented life form (about 49%), followed by hemicryptophytes (about 27%). The remaining forms, in decreasing richness, were the chamaephytes (about 12%), phanerophytes (about 7%), and geophytes (about 5%). The hemicryptophyte richness differed significantly (p=0.002) among the sites, whereas the other life forms did not (p=0.208, p=0.144, p=0.554, and p=0.255 for phanerophytes, chamaephytes, geophytes, and therophytes, respectively). In other respects, the statistical analyses revealed that species richness of phanerophytes, chamaephytes, geophytes, and therophytes did not differ significantly in all the studied post-fire stages, suggesting a stabilization process as early as the 3rd post-fire year onwards. On the other hand, it was noted a substantial increase of hemicryptophyte richness until the 6th post-fire year, and a decrease thereafter. The similar richness values obtained for the latter life form in the two oldest post-fire stages seemed to indicate a stabilization process since the 9th post-fire-year onwards. However, the study of a longer chronosequence is needed to confirm this latter suggestion. In table 3, the number of species increased from site 1 (S=44) to site 4 (S=74). On the contrary, species richness was similar (s comprised between 16.75 and 22.75): no significant differences were detected among sites (p=0.075). Based on the latter ecological parameter which allows a subtle appreciation of the differences among sites, the results indicated that in all

sites, an average of 21 species were collected in the covered transects. This average species number can be considered as representative of the community in each site (Blondel and Aronson, 1995; Magurran, 2013). Moreover, the species richness assigns to each species a weight that is proportional to its appearance probability along the sequence of transects; consequently, the less abundant species will be attributed a small weight (Blondel and Aronson, 1995; Magurran, 2013). On the other hand, it was noted that 70.4%, 70.2%, 85.1%, and 85.1% of the species occurring in site l, site 2, site 3, and site 4, respectively, were recorded in one transect only and with a minimal cover value.

Table 3. Number of species and richness in the four sites with different fire intervals.

Site N° [Fire interval]	Site 1 [3 years]	Site 2 [6 years]	Site 3 [9 years]	Site 4 [12 years]
Number of species	44	57	67	74
Species richness	16.75 (±1.25)	21.50 (±0.29)	22.75 (±1.25)	22.50 (±2.72)

Standard error between parentheses.

Within the frame of the studied chronosequence, plant species dynamics was outlined as follow: Three years after fire passage, *Sarcopoterium spinosum* and *Cistus creticus* structured 61.9% of the vegetation cover. S. spinosum was the dominant species with a contribution of 47.3%, while *Cistus creticus* totaled 14.6%. Other species were less abundant, but enough represented: such was the case for *Satureja thymbra*, *Brachypodium retusum*, *Trifolium campestre*, *Asphodelus aestivus*, *Lotus angustissimus*, *Atractylis gummifera*, and *Gastridium ventricosum*, characterized by cover values comprised between 2% and 6%. Also present but poorly abundant were *Linum corymbulosum, Pidicaria dysenterica, Rhamnus lycioides,* and *Blackstonia perfoliata*, with values ranging from 0.5% to less than 2%. The remaining species were represented by a minimal cover of 0.3%. Six years after fire passage, both *Sarcopoterium spinosum* and *Cistus creticus* totaled 68.4% of the vegetation cover; *S. spinosum* being more represented than *C. creticus* (54.9% vs. 13.5%). A cover decrease affected some species which were enough represented at the 3rd post-fire year; it was the case of *Brachypodium retusum* (3.2%), *Asphodelus aestivus* (0.5%), *Satureja thymbra* (0.3%), *Trifolium campestre* (0.3%), and *Gastridium ventricosum* (0.3%). Also decreased each of *Pidicaria dysenterica* (0.8%), *Blackstonia perfoliata* (0.3%), and *Linum corymbulosuin* (0.3%). On the contrary, other species increased; it was the case of *Atractylis gummifera* (3.2%), *Asparagus aphyllus* (1.1%), and *Drimia maritima* (1.1%). Furthermore, *Tolpis virgata* was enough represented (2.1%), while *Dactylis glomerata*, *Knautia integrifolia*, *Ononis spinosa*, and *Trifolium physodes* were poorly present with covers ranging from 0.5% to less than 2%. The remaining species occurred with a minimal cover of 0.3%. Nine years after fire, *Sarcopoterium spinosum* and *Cistus creticus* dominated the vegetation with a total contribution of 56.5%. However, *C. creticus* cover was higher than that of *S. spinosum*: 32.1% vs. 24.4%, respectively. A substantial cover increase of *Calicotome villosa* (11.4% vs. 0.3% in the 6th post-fire year) was noted. *Hypericum empetrifolium* also increased (5.1%). On the other hand, a decrease affected *Dactylis glomerata* (0.6%), *Knautia integrifolia* (0.3%), and *Pulicaria dysenterica* (0.3%). In addition, it is noteworthy that three species seemed to be characterized by a stable cover: *Brachypodium retusum* (3.4%), *Trifolium campestre* (0.3%), and *Linum corymbulosum* (0.3%). All the remaining species were characterized by a minimal abundance of 0.3%. Twelve years after fire passage, both *Sarcopoterium spinosum* and *Cistus creticus*

covered 66.2% of the vegetation; the dominance being reverted to *S. spinosum* (42.2% vs. 24%, respectively). A substantial increase characterized *Piptatherum miliaceum* cover (7.1% vs. 0.3% at the previous fire intervals). On the other hand, a decrease affected *Calicotome villosa* (2.2%), *Dactylis glomerata* (0.3%), and *Hypericum empetrifolium* (0.3%). A relatively stable cover seemed to characterize *Brachypodium retusum* (3%), *Knautia integrifolia* (0.3%), *Linum corymbulosum* (0.3%), *Origanum vulgare* (0.5%), and *Trifolium campestre* (0.5%). Also relatively stable were *Atractylis gimmifera* (0.3%), *Drimia maritima* (0.3%), and *Pulicaria dysenterica* (0.3%), which decreased after the 6th post-fire year. The remaining species were lowly represented by a cover of 0.3%. The richness values recorded in the studied phrygana cannot be fairly compared with the results obtained by other authors like Ish-Shalom-Gordon (1993) and (Bergmeier 1997) who also investigated species richness in phrygana owing to the different methods used for data collection, and the management- types. For information, Ish-Shalom-Gordon (1993) found a total of 199 species in a grazed community of Ariel (Israel), using a 100 x 100 m plot; and Bergmeier (1997) counted a total of 91 and 86 species (and an average species number of 15.3 and 19.5) in grazed and non-grazed 20 x 30 microplots, respectively, in a phrygana of Sfakia (Crete). Nonetheless, the use of species richness as well as diversity indices provided a good insight into the organization of the community and the number of the more representative species at each post-fire stage. The final interesting finding of the study is the similar stable species richness, heterogeneity, and equitability characterizing the community of Malaxa as early as the 3rd post-fire year onwards. These results are in line with other studies which indicated, that burned Mediterranean plant communities reestablish rapidly by auto succession process (Naveh, 1974; Trabaud and Lepart 1980; Christensen, 1985; Trabaud, 1994; Arianoutsou, 1998; Henkin *et al.* 1999; Allen, 2014. Similar conclusions have also been drawn for Califomian chaparrals (Trabaud and Lepart 1980). However, the relatively low diversity characterizing the community of Malaxa, as compared to other more diversified phrygana, is in all likelihood due to both fire suppression and non-grazing.

4. Conclusions

The unburned and ungrazed phrygana is characterized by a rapid reestablishment of both vegetation cover and overall aboveground biomass. These two latter's are

overwhelmingly dominated by highly flammable dwarf shrubs, chiefly *Sarcopoterium spinosum*. The cover tends to close and stabilize as early as the 3rd post-fire year with little or no risk of soil erosion, whereas the overall aboveground biomass needs a bit longer time to do so: that is, at the 6th post-fire year. In such a community, the herbaceous component is not substantially represented with respect to cover and aerial biomass (excepting during the first two post-fire years). This may be ascribed to the combination of both the high inhibiting competition pressure exerted by shrubs and the accumulation of litter which restrict the spreading and the development of herbaceous plants to few openings which are temporarily free from competition. Furthermore, the rapid reestablishment and stabilization of the representative species as well as the overall plant diversity as early as the 3rd post-fire year is in keeping with the general pattern of auto-succession and resilience characterizing Mediterranean-type communities which undergo cyclic fires. Phryganic communities recover faster than more advanced Mediterranean type shrublands. However, when the phrygana is ungrazed and unburned for a period, say 12 years as it is exemplified by the community of Malaxa, the overall plant diversity becomes relatively low, probably after reaching its highest values during the first two post-fire years. Such a community may be characterized by a "dictatorial-type" organization (in which few species (chiefly dwarf shrubs in the present case), dominate by their abundances and broaden their niches to the detriment of the remaining species which are poorly represented. In other respects, the conservation of the traditional practices, such as rotational burning and grazing, respectful of the diversity and the functioning of phryganic ecosystems may have positive socioeconomic repercussions. As previously seen, non-grazing situation associated with fire suppression for a period, both favor a rough encroachment of unpalatable dwarf shrubs such as *Sarcopoterium spinosum* and *Cistus creticus* which heavily smother the herbaceous plants. These are mainly annual legumes and grasses of high palatability and nutritive values. As a consequence, the amount of pasture is reduced and livestock production is lessened, affecting negatively the economy at both local and national levels. To optimize the benefits that can be gained from phryganic communities, both grazing and fire should be incorporated in the management plan. To be beneficial, grazing management should observe a stocking rate equivalent to the grazing capacity of the rangeland, combine grazer and browser animals for a better control of plants, and respect the season and duration of grazing. Also, prescribed or controlled fires improve the grazing capacity of phryganic communities.

Finally, tourism, as an additional source of income, can also be promoted by maintaining the biological and landscape diversity and attractiveness made up of mosaics of phrygana, maquis, and forests.

Acknowledgment

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