EFFECTS OF FIRE ON PLANT BIODIVERSITY IN A CORK OAK FOREST IN THE BLIDEAN ATLAS (ALGERIA)

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Abstract. Cork oak stands are the forest formation most affected by fire in Algeria. The objective of this study was to evaluate the diversity and structure of the vegetation of a cork oak stand in a part of the Blidean Atlas before and after fire by sampling three transects: an unburned control transect and two other burnt transects at different dates. The application of the method of frequency analysis by applying the Brillouin formula allowed us to show that during the first two years after the fire the local and spatial biodiversity have strongly changed; the richness, the six biodiversity indices calculated, the slope of the curve area-species and the floristic composition reached their maximum value due to the installation of heliophyte species, taking advantage of the opening of the environment and replacing the typical species of forest -the sciaphilous dryads-. These parameters decrease and tend to stabilize after seven years of fire. The change in vertical stratification results in a decrease in the tree stratum, allowing the development of lower strata. This method consists of a first evaluation of the response of the cork oak forest of the Blidean Atlas to fires by the statistical method of frequency analysis.
Keywords: *forests fires, Quercus suber, spatial and local biodiversity, biodiversity indices, vertical stratification*

Introduction

Fire is a global ecosystem process, and ecosystems in the Mediterranean basin are highly exposed to this type of disturbance (Keeley, 2012).

Fires are one of the main causes of the degradation of these forests and the erosion of their biodiversity (Kadik, 2012), with about 50,000 ha per year, i.e. twice as many as in the 1970s (Alexandrian et al., 1998).

This is mainly due to the hot and dry Mediterranean climate. A tendency for simultaneous drought in the extreme western (Spain, Morocco, Algeria, Tunisia) and eastern (Balkans, Greece, Turkey) ends of the basin is observed by (Cook et al., 2016). This suggests a degree of spatial coherency and synchrony during major drought events in the basin. Moreover, the Mediterranean basin can be considered a hotspot in future climatic conditions conducive to extreme fires, with significant potential impacts on human well-being (Bowman et al., 2017).

In addition, the preponderance of species with a high content of resins or essential oils makes Mediterranean vegetation highly flammable and combustible. Fire danger also varies with variations in fuel load and population density between regions (Keeley et al., 2012).

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But, today, fire is not a factor of change in the ecological systems of the Mediterranean basin. Most of the results of research carried out on the effect of fires on the regeneration of ecological systems in the Mediterranean region show that there is no profound modification of the communities currently in place. It returns to a specific structure and composition identical to the original one (Trabaud, 1991).

For example, in tropical and boreal zones, fire contributes to the maintenance of biodiversity by allowing the regeneration of pioneer species and heliophyte species necessary for the rapid healing of disturbed areas.

In the Mediterranean climate, the vegetation most often implicated in forest fires is the oak groves which appear in the sub-humid Mediterranean zones associated with other species such as *Arbutus unedo* and *Erica arborea* (Balzan and Hassoun, 2020).

In Europe as in North Africa, cork oak areas have considerably decreased in size and vitality due to strong climatic variations, fires, and clearings.

In Algeria, a total area of 33,200 ha of vegetation on an annual average was devastated by fires between 1963-2018 at the national level (General Directorate of Forests, 2018), of which a total cork oak area of around 200,000 ha was ravaged by forest fires between 1985 and 2012 (Bouhraoua, 2013).

Several works on the influence of fires on the ecosystems of the Mediterranean basin have been carried out such as (Naveh, 1974, 1975) and (Trabaud, 1983, 1989, 1991, 1992, 1995, 2004). In Algeria, among the most recent studies carried out on the effect of fires on vegetation and their response to this disturbance include those of Chouahda and Benyacoub (2014) in the northwest of the country; Bekdouche (2010) in Tizi-ouazou and (Melouani, 2014; Mekideche, 2019; Ouadah, 2019) in different regions of the Blidean Atlas.

This article aims to compare the local and spatial biodiversity, composition, and structure of the vegetation before and after the fire in a cork oak forest in the Blidean Atlas by answering the following questions:

Does biodiversity decrease after the passage of a fire? Is it the species that existed before a fire that will reoccupy the burned area or are species foreign to the community previously in place that will settle? How does the vertical structure of the vegetation change?

Materials and methods

Study zone

Our work was carried out in the Blidean Atlas, in a portion of the natural reserve of the Chréa National Park (El-Hamdania commune) (*Fig. 1*). The Blidean Atlas extends between 36°30’ and 36° north latitude and 3°20’ and 2°40’ longitude, to the north of Algeria, in the central part of the Tellien Atlas, on soils of schistose origin characterized by the importance of the coarse elements due essentially to a more intense action of erosion (Halimi, 1980).

The climate is humid Mediterranean, with mild, rainy winters and hot, dry summers (Ouadah, 2019). The annual rainfall ranges from 679 to 1019 mm, and the annual temperatures range from 14.5 to 19.2 °C (Mekideche et al., 2018).

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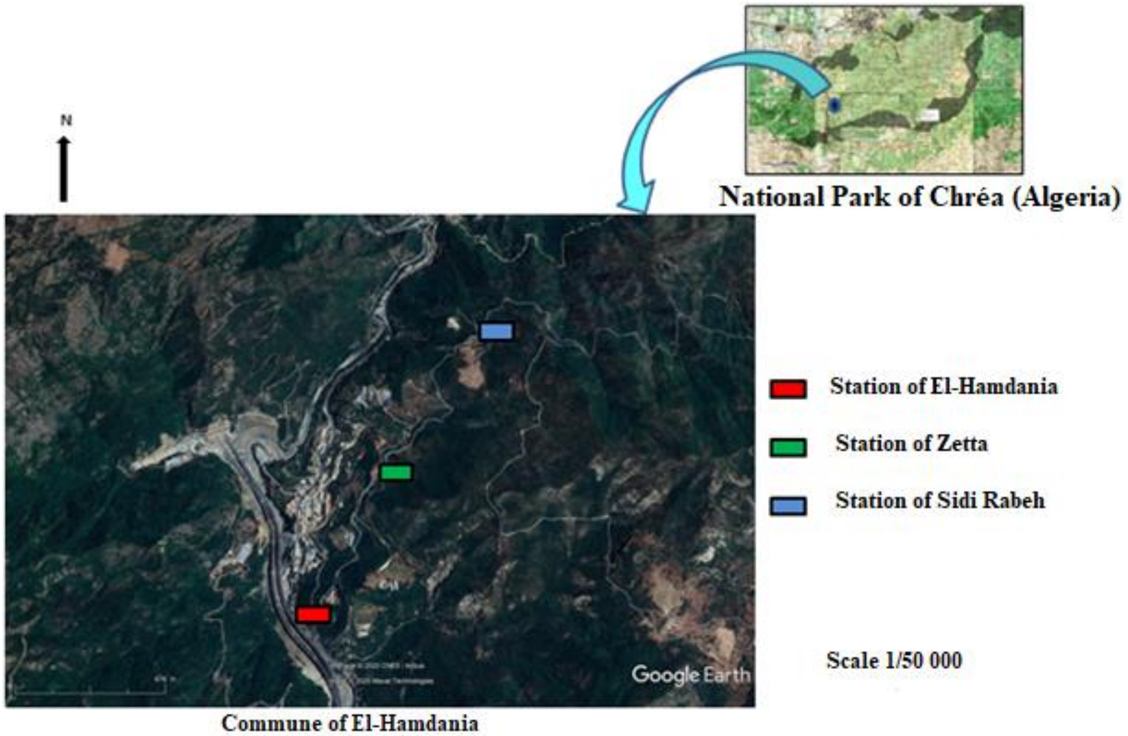

Figure 1. *Location of the study area in the National Park of Chréa (Blidean Atlas-Algeria). Unburned station of El-Hamdania, burned station of Zetta in 2012, burned station of Sidi Rabeh in 2017 (Source Google Earth)*

Vegetation sampling

Contrary to the diachronic method which lasts in time to be able to follow the evolution of an ecosystem, we compared synchronically in the National Park of Chréa three stations following a systematic sampling which makes possible to calculate many biodiversity indices and leaves controls in place that allow the observations to be repeated diachronically in exactly the same place (Godron, 2012).

Transect sampling was used as the sampling method. It has many advantages: speed, clarity, statistical efficiency and is particularly suited to the study of complex plant formations that combine herbaceous plants, low woody plants, and trees (Godron, 2012).

Three transects are sampled, the first being placed in a station that has not been burned for 50 years at El-Hamdania (x: 2°76’79.32 / y: 36°35’64’ / 480m) and the second at a station that was burned in 2012 at Zetta (x: 2°77’15.32 / y: 36°36’38.02 / 550 m). These two stations are 1.5 km apart and are located in the sclerophyllous forest of cork oak (*Quercus suber*) accompanied by holm oak (*Quercus ilex*) which are well represented in this national park (*Photo 1*).

Another transect was carried out at Sidi Rabeh station (x: 2°.77’15.32 / y: 36°. 36’38.02 / 678 m) which was burned in 2017 and is located at 2 km from Zetta station in a low matorral of *Quercus suber* in the Chréa National Park (*Photo 1*).

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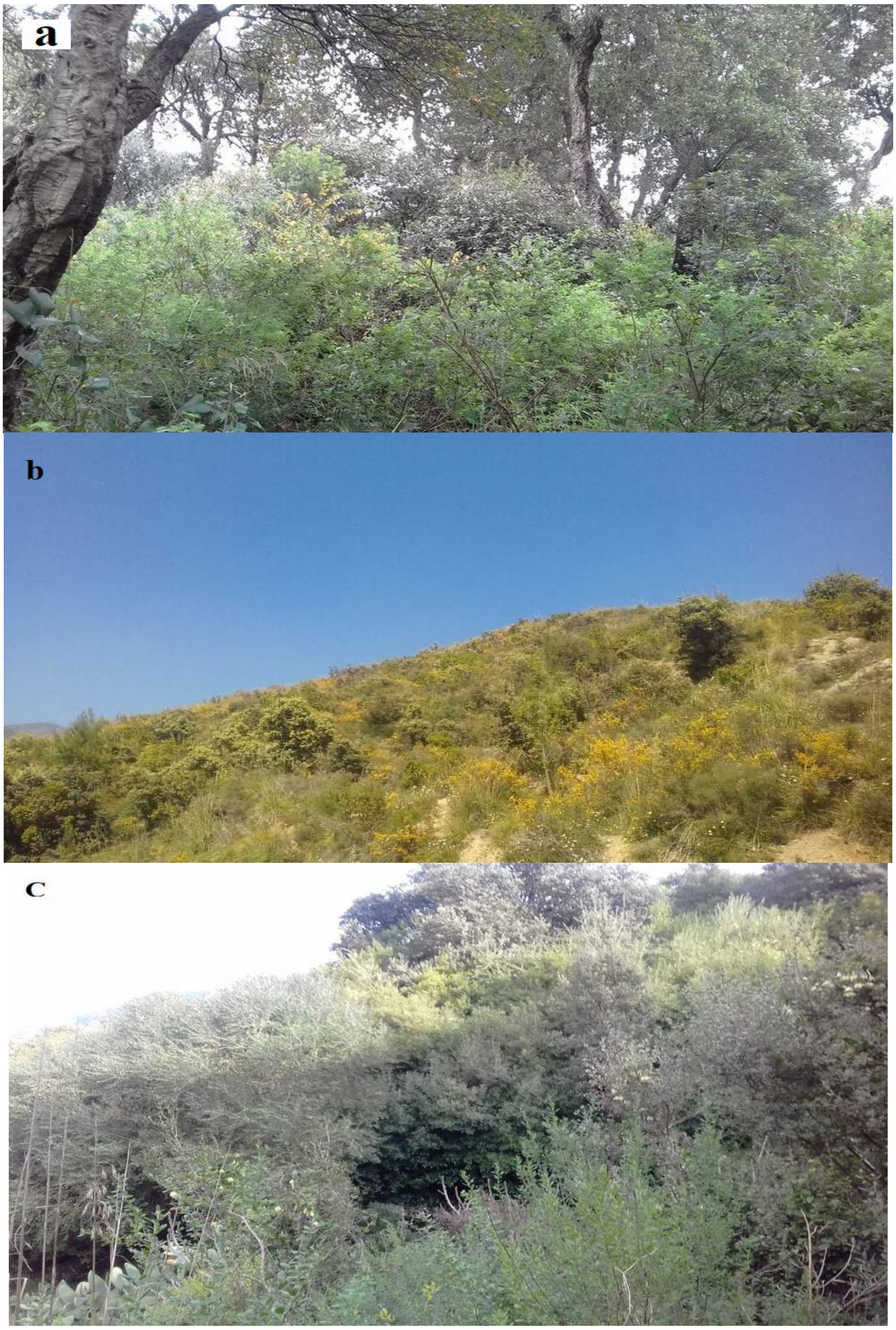

Photo 1. *Sampled stations in the Chréa National Park. (a) Unburned dense cork oak and holm oak forest of El-Hamdania (photo taken in April, 2018). (b) Low Quercus suber matorral of Sidi Rabeh burned in 2017 (photo taken in May, 2019). (c) Open Forest of cork oak and holm oak in Zetta station burned in 2012. (Photo taken in May, 2019)*

The dimensions of each transect were 50 m long and 20 cm wide, consisting of 50 segments of 100 cm × 20 cm. These dimensions are adequate for sampling the different vegetation strata (trees, shrubs, and herbaceous strata). For each species, the abundance-

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dominance of Braun-Blanquet (1952) and the vertical stratum occupied were noted by following the codification of the heights of the vertical strata of the vegetation (Kadik, 2005) and (Godron, 2012):

Strata I (0 m - 0.124 m) - Strata II (0.125 m - 0.24 m) - Strata III (0.25 m - 0.49 m) - Strata IV (0.50 m - 0.99 m) - Strata V (1 m - 1.99 m) - Strata VI (2 m - 3.99 m) - Strata VII (4 m - 7.99 m).

Due to difficulties in accessing the field during the first year of study, the sampling effort was focused on the observation of the unburned transect of El-Hamdania during the month of April 2018.

The second year of research focused on tracking the evolution of biodiversity after a fire, two years for the Sidi Rabeh station and seven years for the Zetta station. These two burnt stations were sampled in April and May of 2019.

The species are determined using the Algerian flora (Quézel and Santa, 1962-1963) and the Tela Botanica site (www.Tela-botanica.org). The abundance-dominance coefficient (Braun-Blanquet, 1952) was noted for each species in each segment.

All the data collected was processed using Dyalog software (www.dyalog.com), (Forman and Godron, 1986; Akodéwou, 2019).

The observations for each transect are represented in the form of a double-entry matrix, with each line corresponding to a species and the abundance dominance observed in a segment for this species is noted in the column of this segment.

In our study region, the pre-fire and post-fire surveys are only floristic surveys which give indications of the richness of the vegetation but not of the precisely measured biodiversity.

Our synchronic study then focuses on the analysis of the spatial variations of the structure and the floristic composition of the plant communities present at a given moment in a space having undergone a disturbance, while respecting the uniformity of the climate and the substrate of the sites studied.

Biodiversities

The term “biodiversity”, a contraction of “biological diversity” was proposed by Wilson and Peter (1988). It refers to the variety of living organisms whatever their environment of origin and includes intraspecific, interspecific, and functional biodiversities. In our study, it is the biodiversity of species and habitats that will be studied from several aspects.

Species richness

It is the simplest parameter to measure species biodiversity. Species richness is the number of different species represented in an ecological community, landscape or region (Blondel, 1995). It obviously depends on the extent of the territory where the species has been observed.

The increase in the number of species according to the area observed

In phytosociology, one of the most widely used methods for assessing vegetation heterogeneity is the area-species curve (Akodéwou, 2019). Since the number of species observed in a place depends directly on the extent of the territory considered, it is always necessary to take into account the surface on which the richness has been calculated and to make a critical evaluation of the result, as shown in the example of the article by

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Nusbaumer et al. (2005) which shows that a significant correlation exists between the area observed and the number of species found in eight botanical inventories in Côte d'Ivoire.

For the three transects, we calculated the slope of the area-species curve, the average number of species per segment, and the slope of the area-species curve in doubly logarithmic coordinates which is called the Arrhenius curve and it is the first approach of biodiversity.

The probabilistic area-species curve

When exploring a place, it is useful to regularly note the surface that has been prospected and to construct the area-species curve, i.e. the curve of the number of species found according to the surface prospected by reading the matrix left to right then right to left.

To overcome the arbitrary choice of the order of reading the presence of species in the places observed, it is possible to find a general method by reasoning from the "uniform" probabilistic model which is the most general in this domain.

The probability is calculated for each of the species of the three stations studied and the result is the curve which will be represented in red in the results section. It has been recognized by one of the most eminent phytosociologists, Guinochet (1973) that the calculation which has just been indicated gives a clear solution to the problem of the interpretation of the area-species curve which remains fundamental in phytosociology.

Frequency analysis and Biodiversity indices

The goal of frequency analysis is to find the observations that contain the most information (Daget and Godron, 1982; Barima et al., 2016; Godron, 2012, 2018) by applying the Brillouin formula.

In order to measure biodiversity, we used Brillouin's formula because it does not suffer from the bias of the Shannon's formula (Godron et Kadik, 2003; Wolff et Amandier, 2009; Godron, 2012, 2018). It is an important measure of local and spatial biodiversity. It directly concerns the entire observed distribution of abundances-dominances or presences of the observed objects in the considered sample. The observed distribution has a probability P:

$$P = n1 ! \, n2 ! \dots ni ! \dots ne ! / N ! = \Sigma \, ni ! / N \qquad \text{(Eq.1)}$$

with n1, n2, ... ni, ... ne, the species abundance-dominances (or their absolute frequencies) and N the total number of individuals.

Brillouin's formula (1962) then gives the information on biodiversity:

$$Ib = (\log 2 \, N! / \Sigma \, ni!) / N \qquad \text{(Eq.2)}$$

The unit of measurement of this information is the binon.

Biodiversity indices of the vegetation can be finely measured based on the Brillouin formula. This method was used by Amandier et al. (2012) in the forests of the Provence-Côte d'Azur region and Akodéwou (2019) in Togo.

We applied this formula using the two parameters of abundance dominance and presence of species, first to the columns of the matrix to calculate the two local

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biodiversities then to the rows of the matrix to calculate the biodiversities of each species and finally to the entire matrix to calculate the two global biodiversities.

The two spatial biodiversities

This type of diversity takes into account the differences between two places in a more precise way than that proposed by Whittaker for his beta biodiversity. It is also calculated with the Brillouin formula by comparing the total number of abundances-dominances (after the total number of presences) of each of the species observed.

For each species, for which the abundance-dominance scores are n1 and n2, the spatial biodiversity of the abundances-dominances is Dnot:

$$\text{Dnot} = (\log_2 (s1 + s2)!) \div (s1! \times s2!) - (\log_2 (n1 + n2)!) \div (n1! \times n2!) + (\log_2 ((s1-n1) + (s2-n2))!) \div ((s1-n1)! \times (s2-n2)!) \quad \text{(Eq.3)}$$

The Dnot distance indicates for each species the intensity of the difference between the abundance-dominance scores in the first place (s1) and the second place (s2), but it does not say whether the score in the second place is higher or lower than the note in the first place. We agree to assign the quantity Dnot the sign + when n2 is greater than n1 and the sign – otherwise.

The spatial biodiversity of presences is calculated in exactly the same way by replacing Dont with the distance between the total presences (Dpres) in the first and second places.

We calculated these two biodiversity indices between El-Hamdania and Sidi Rabeh, and El-Hamdania and Zetta to compare the floristic differences before and after the fire, and then between the two burnt stations Zetta and Sidi Rabeh to compare the floristic procession installed after two and seven years after the fire.

Vegetation strata

Vertical stratification of the vegetation is a complementary aspect to studying the structure of a plant formation. To characterize this stratification, the height of the species was noted in each transect according to the coding of (Kadik, 2005 and Godron, 2012) which takes into account the logarithmic distribution of the vegetation whose dynamic origin is the upward thrust that makes the vegetation rise towards the zenith thanks to the transpiration of the leaves (Godron, 2012), and then grouped them into different vegetation strata according to the proposal of Godron et al. (1968) to distinguish the following strata:

Tree strata: over 4 m, Shrub strata: 2 m-4 m, Under-shrub strata: 1 m-2 m, Herbaceous strata: 0 m-0.5 m.

Results and discussion

Measuring biodiversity and studying the structure of the vegetation in the cork oak formation of the Chréa National Park allowed us to answer the questions about our problematic and to note that the regeneration of the species is present after the fire and the vegetation continues to develop to constitute a forest atmosphere in a few years. But this development is different between the two burned sites due to the different dates of the fires they suffered.

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The floristic richness and ecological characteristics of species

The floristic richness of the recently burned Sidi Rabeh station (64 species) is significantly higher than that of El-Hamdania and Zetta (43 species and 42 species respectively). As a result, floristic richness increased following the fire. To explain these results, we have chosen to study the ecological characteristics of the identified species.

Ecological characteristics of species

Our results show that the most revealing ecological and bionomic character for all the species collected is the heliophyte-sciaphile distinction.

The species that arrived after the fire were heliophytes (89% in Sidi Rabeh) (*Fig. 2*), including in particular anemochorous therophyte herbaceous plants. The number of sciaphilous species typical of the forest - the dryads - which are no longer present after the fire is much lower than that of the newly arrived species that took advantage of the arrival of light to the ground where the litter has disappeared to establish themselves.

Then, the number of heliophytes decreases with time after the fire (68% at Zetta, 7 years after the fire) (*Fig. 2*) and the vegetation gradually returns to its initial state. We can thus affirm, that the floristic richness of the first stages of the recolonization of the environment is due to the large number of annual heliophyte species that disappear with the healing of the communities. Our results are in agreement with the model generally described in the successions after fire for Mediterranean ecosystems (Trabaud, 1987; Martinez-Sanchez et al., 1997; Guo, 2001; Capitano and Carcaillet, 2008; Bekdouche, 2010).

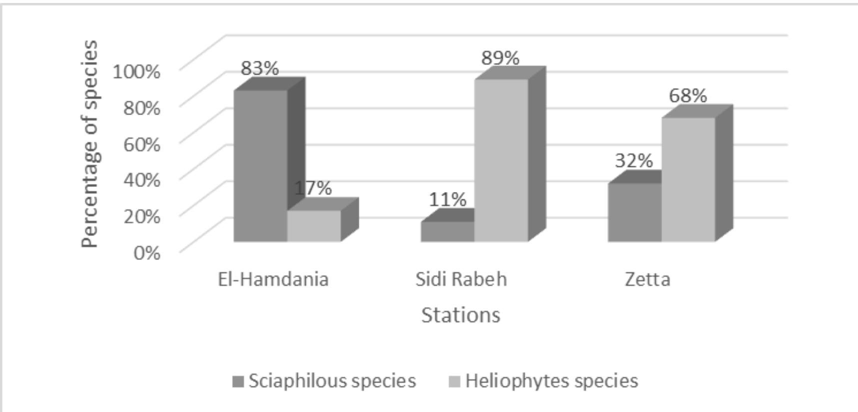

Figure 2. *Floristic richness by species category at the three study sites. Sciaphilous species = forest species, which accept shade; heliophyte species: which live in the light*

Probabilistic area-species curve

At El-Hamdania

Figure 3a shows that the 3 area-species curves are quite close to each other, which means that the distribution of species in the transect is quite regular.

At Sidi Rabeh

The curve from right to left (in blue) is above the probabilistic curve. This means that the number of species increases rapidly when we start to browse the matrix (and in

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particular in the field) from right to left, and therefore the distribution of species is not regular and the vegetation is rather heterogeneous (*Fig. 3b*).

At Zetta

Unlike Sidi Rabeh, the curve from left to right is significantly below the probabilistic curve (*Fig. 3c*). This means that the number of species found when starting to traverse Zetta's transect matrix from left to right slowly increases and the probabilistic curve is only reached at the 40th segment. This asymmetry is confirmed by the fact that the beginning of the curve in blue which corresponds to the reading from right to left is located below the probabilistic curve.

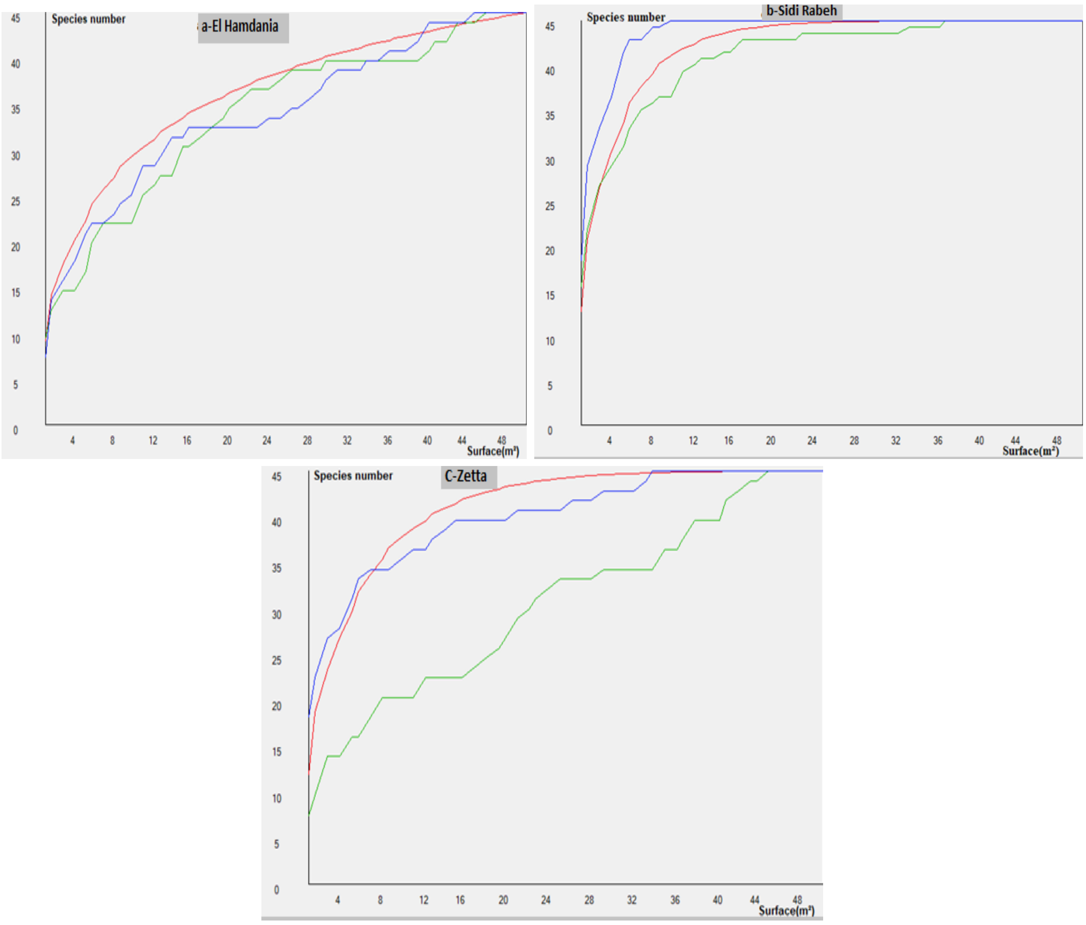

Figure 3. *The area-species curve of the three stations studied (by the Dyalog software). The probabilistic area-species curve is drawn in red, the curve for the reading from left to right of the transect matrix in green, and for the reading from right to left in blue*

Also, the area-species curves give three indices shown in *Table 1*. The slope of the Arrhenius curve equals 2.74 at El-Hamdania, 3.36 at Sidi Rabeh, and 3.23 at Zetta, indicating that the vegetation is more heterogeneous in the two burnt transects, particularly at Sidi Rabeh, where species are clustered in small "patches" that are distinctly different from one another. In landscape ecology, this means that the "grain" of the vegetation is small and well-contrasted (Godron, 2012) because the average size of individuals increases sharply during the evolution of the vegetation (Godron, 2012; Akodéwou, 2019).

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The average number of species present in each segment is the most obvious index. The Sidi Rabeh station confirms its uniqueness with an average of 17.9 species present in a 100 cm × 20 cm area (*Table 1*).

Table 1. *Increase in the number of species as a function of the area observed in the three study stations. For the three transects, we calculated the slope of the area-species curve: Number of species/Surface m², the average number of species per segment and the slope of the area-species curve in double logarithmic coordinates which is called Arrhenius curve*

Station	The slope of the area-species curve	The average number of species	The slope of the Arrhenius curve
El-Hamdania	0.86	8.8	2.74
Sidi Rabeh	1.1	17.9	3.36
Zetta	0.84	11.8	3.23

Biodiversities

Knowing the floristic richness of a community is insufficient to characterize its structure. The calculation of six biodiversity indices has been introduced for this purpose.

According to *Table 2*, we observe that floristic richness and diversity follow the same pattern. The biodiversity indices of the two burned transects (especially at Sidi Rabeh) are always higher than those of the unburned.

Table 2. *Results of the biodiversity index calculations for the three study stations. The first column gives the type of biodiversity index calculated, and the following are the averages of the biodiversity index calculated with the Brillouin formula*

Station	El- Hamdania	Sidi Rabeh	Zetta
Type of biodiversity	**Biodiversity index**	**Biodiversity index**	**Biodiversity index**
Local biodiversity of abundances	2.3	3.2	2.6
Local biodiversity of the presences	2.0	2.9	2.3
Biodiversity of species abundances	1.8	2.7	2.5
Biodiversity of species presences	1.6	2.4	2.2
Global biodiversity of abundances	7.3	8.7	7.7
Global presence biodiversity	7.8	8.4	8.1

The reasons for these results are the same as those mentioned previously for floristic richness. The increase in the number of herbaceous species, particularly therophytes, takes advantage of the richness of the surface layer of the soil in ashes and mineral elements. This coevolution of floristic richness and diversity is also found by Mazzoleni and Pizzolongo (1990) in south-central Italy, Bekdouche (2010) in the suberaies of Kabylie, and Melouani (2014); Mekideche (2019) in the suberaies of the Blidean Atlas.

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Spatial and temporal biodiversity

The flora

Let us analyze the results of the spatial biodiversity between the three sites studied represented in *Table 3*.

The two structural trees of the sclerophyllous forest (*Quercus suber* and *Quercus ilex*) are present in the two burnt areas. The cork oak and most of the woody species of the undergrowth emit shoots abundantly and very quickly, the first regrowths sometimes appear during the first month (Bekdouche, 2010). This facilitated the recovery of shade-tolerant species such as *Asparagus acutifolius, Geranium robertanium,* and *Rubia peregrina*.

Table 3. *Spatial biodiversity between El-Hamdania, Sidi Rabeh and Zetta stations. The first two columns give the grouth form of the species and their shade-tolerant species (Sci: sciaphilous species, Hel: heliophyte species). The next two columns give the number of presence of each species in each transect. In the two columns on the right, Dprés is the spatial biodiversity of presences and Dnot is the spatial biodiversity of abundances-dominances*

Table 3a. *Spatial biodiversity between El-Hamdania and Sidi Rabeh*

GF	Shade tolerance of species	Identified species	El-Hamdania	Sidi Rabeh	Dprés	Dnot
Plant grouping of the unburned station of El-Hamdania (26 shade tolerant species)						
He	Sci	*Acanthus mollis*	2	0	-3.2	-2.3
Ge	Sci	*Arisarum vulgare*	1	0	-1.6	-1.1
Ph	Sci	*Aristolochia altissima*	1	0	-1.6	-2.3
Ge	Sci	*Asparagus acutifolius*	36	0	-52.9	-101.5
Th	Sci	*Astragalus hamosus*	4	0	-6.4	-16.4
He	Sci	*Carex flacca*	43	0	-71.1	-227.6
Th	Sci	*Chrysanthemum myconis*	3	0	-4.8	-6.9
Ph	Sci	*Clematis cirrhosa*	7	0	-11.3	-15.0
He	Hel	*Convolvulus althaeoides*	15	0	-24.3	-60.7
He	Hel	*Convolvulus sepium*	1	0	-1.6	-3.4
Ph	Sci	*Crataegus oxyacantha*	3	0	-4.8	-8.0
Ge	Sci	*Cyclamen africanum*	43	0	-71.1	-237.8
He	Sci	*Cynoglossum creticum*	11	0	-17.1	-20.8
Th	Sci	*Euphorbia phymatosperma*	2	0	-4.8	-3.4
He	Hel	*Hypericum perforatum*	3	0	-4.8	-15.0
Ch	Hel	*Lavatera arborea*	3	0	-6.4	-10.4
Th	Sci	*Mercurialis annua*	4	0	-14.5	-45.2
Ph	Hel	*Olea europea*	9	0	-49.1	-79.5
Ph	Hel	*Rosa canina*	30	0	-8.0	-25.4
Ph	Hel	*Rosa sempervirens*	5	0	-14.5	-23.3
Ch	Sci	*Ruscus hypophyllum*	10	0	-16.1	-41.7
Th	Sci	*Senecio vulgaris*	10	0	-16.1	-40.6
Ch	Sci	*Smilax aspera*	19	0	-30.9	-4.7.6
Th	Sci	*Sonchus oleraceus*	1	0	-1.6	-1.1
Ge	Sci	*Urtica dioica*	1	0	-35.8	-1.1
NanoPh	Sci	*Viburnum tinus*	1	0	-1.6	-5.7
Plant grouping of the burned station of Sidi Rabeh (47 light tolerant species)						
Ge	Hel	*Allium triquetrum*	0	21	+ 12.2	+ 19.2
Ph	Hel	*Arbutus unedo*	0	8	+ 4.6	+ 25.0
Th	Hel	*Avena alba*	0	16	+ 9.3	+ 22.1
Th	Hel	*Bellis annua*	0	12	+ 6.9	+ 8.5
Th	Hel	*Biscutella didyma*	0	9	+ 5.2	+ 6.4
Th	Hel	*Blackstonia perfoliate*	0	9	+ 5.2	+ 7.1
Th	Hel	*Brisa maxima*	0	9	+ 5.2	+ 6.4
Th	Hel	*Bromus rubens*	0	10	+ 5.8	+ 7.8

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Ph	Hel	*Calycotome spinosa*	0	28	+ 16.3	+ 72.3
He	Hel	*Carthamus multifidus*	0	7	+ 4.0	+ 9.2
Th	Hel	*Cerastium glomeratum*	0	9	+ 5.2	+ 8.5
NanoPh	Hel	*Chamaerops humilis*	0	6	+ 3.5	+ 12.1
Th	Hel	*Chrysantemum leucanthemum*	0	14	+ 8.1	+ 16.4
Th	Hel	*Crepis vesicaria*	0	10	+ 5.8	+ 18.5
Th	Hel	*Daphne gnidium*	0	10	+ 5.8	+ 17.8
Th	Hel	*Ebenus pinata*	0	22	+ 12.8	+ 28.6
He	Hel	*Echinophora spinosa*	0	6	+ 3.5	+ 7.1
He	Hel	*Echium plangatenum*	0	6	+ 3.5	+ 5.7
He	Hel	*Eryngium tricuspidatum*	0	11	+ 6.4	+ 17.1
Th	Hel	*Fedia cornucopiae*	0	12	+ 6.9	+ 9.2
He	Hel	*Festuca triflora*	0	21	+ 12.2	+ 20.7
He	Hel	*Galactites tomentosa*	0	23	+ 13.4	+ 45.2
He	Sci	*Galium tunetanum*	0	17	+ 9.9	+ 32.9
Ph	Hel	*Genista tricuspidate*	0	15	+ 8.7	+ 32.9
Th	Hel	*Geranium molle*	0	13	+ 7.5	+ 10.0
Th	Hel	*Hypochaeris laveigata*	0	9	+ 5.2	+ 9.2
He	Hel	*Inula viscosa*	0	21	+ 12.2	+ 20.7
Ch	Hel	*Lavandula stoechas*	0	8	+ 4.6	+ 7.8
Th	Hel	*Linum usitatissimum*	0	9	+ 5.2	+ 12.8
Ch	Hel	*Ononis natrix*	0	20	+ 11.6	+ 25.0
Ch	Hel	*Origanum floribundum*	0	13	+ 7.5	+ 20.7
He	Hel	*Pimpinella saxifrage*	0	6	+ 3.5	+ 10.7
He	Hel	*Plantago altissima*	0	20	+ 11.6	+ 22.1
He	Hel	*Plantago lanceolata*	0	11	+ 6.4	+ 15.0
He	Hel	*Pulicaria odora*	0	16	+ 9.3	+ 20.0
Th	Hel	*Ranunculus muricatus*	0	5	+ 2.9	+ 3.5
He	Hel	*Reseda alba*	0	16	+ 9.3	+ 16.4
He	Hel	*Salvia verbenaca*	0	8	+ 4.6	+ 8.5
He	Hel	*Scabiosa atropurpurea*	0	7	+ 4.0	+ 7.1
Th	Hel	*Sherardia arvensis*	0	6	+ 3.5	+ 5.7
Th	Hel	*Silene colorata*	0	6	+ 3.5	+ 4.3
Th	Hel	*Silene fuscuta*	0	11	+ 6.4	+ 7.8
Th	Hel	*Stachys ocymastrum*	0	5	+ 2.9	+ 3.5
Ch	Hel	*Teucrium pseudo-scordonia*	0	16	+ 9.3	+ 20.0
Th	Hel	*Trifolium anguistifolium*	0	12	+ 6.9	+ 12.8
Th	Hel	*Trifolium arvense*	0	12	+ 6.9	+ 10.0
Th	Hel	*Vicia disperma*	0	12	+ 6.9	+ 11.4
Intermediate plant grouping between El-Hamdania and Sidi Rabeh (17 species)						
He	Hel	*Ampelodesmos mauritanicum*	2	36	14.7	93.6
Th	Hel	*Anagallis arvensis*	2	18	6.0	8.0
Ch	Hel	*Cistus salviifolius*	11	43	6.0	47.1
Ch	Hel	*Cistus villosus*	33	27	-12.6	-9.4
He	Sci	*Dactylis glomerata*	2	10	2.9	-3.2
He	Hel	*Daucus carota*	8	23	3.2	5.8
Ph	Hel	*Erica arborea*	17	11	-9.4	-19.9
Th	Sci	*Fumaria capreolata*	8	18	2.6	-3.8
He	Sci	*Geranium robertianum*	9	27	3.5	-3.7
Ch	Hel	*Phagnalon saxatile*	1	13	5.3	16.9
Ph	Sci	*Phillyrea anguistifolia*	9	12	-3.2	6.7
Ph	Hel	*Pistacia lentiscus*	1	14	5.8	39.2
Ph	Hel	*Quercus ilex*	4	4	-2.6	4.2
Ph	Hel	*Quercus suber*	31	33	-8.3	22.6
Ph	Hel	*Rubia peregrina*	3	4	-2.0	-4.8
Th	Hel	*Torilis arvensis*	1	15	6.3	8.7
Th	Hel	*Vicia sativa*	1	15	6.3	8.7

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Table 3b. *Spatial biodiversity between El-Hamdania and Zetta*

GF	Shade tolerance of species	Identified species	El-Hamdania	Zetta	Dprés	Dnot
Plant grouping of the unburned station of El-Hamdania (25 shade tolerant species)						
He	Sci	*Acanthus mollis*	2	0	-2.4	-2.3
Ge	Sci	*Arisarum vulgare*	1	0	-1.2	-1.1
Ph	Sci	*Aristolochia altissima*	1	0	-1.2	-2.3
He	Sci	*Carex flacca*	43	0	-52.6	-227.6
Th	Sci	*Chrysanthemum myconis*	3	0	-3.6	-6.9
Ph	Sci	*Clematis cirrhosa*	7	0	-8.3	-15.0
He	Hel	*Convolvulus sepium*	1	0	-1.2	-3.4
Ph	Sci	*Crataegus oxyacantha*	3	0	-3.6	-8.0
Ge	Sci	*Cyclamen africanum*	43	0	-52.6	-237.8
He	Sci	*Cynoglossum creticum*	11	0	-13.1	-20.8
He	Sci	*Dactylis glomerata*	2	0	-2.4	-11.5
Th	Sci	*Euphorbia phymatosperma*	3	0	-3.6	-3.4
Th	Sci	*Fumaria capreolata*	8	0	-9.5	-23.1
He	Hel	*Hypericum perforatum*	3	0	-3.6	-15.0
Ch	Hel	*Lavatera arborea*	4	0	-4.7	-10.4
Th	Sci	*Mercurialis annua*	9	0	-10.7	-45.2
Ph	Hel	*Olea europea*	30	0	-36.3	-79.5
Ph	Sci	*Phillyrea angustifolia*	9	0	-10.7	-25.4
Ch	Sci	*Ruscus hypophyllum*	10	0	-11.9	-41.7
Th	Sci	*Senecio vulgaris*	10	0	-11.9	-40.6
Ch	Sci	*Smilax aspera*	19	0	-22.8	-4.7.6
Th	Sci	*Sonchus oleraceus*	1	0	-1.2	-1.1
Th	Sci	*Torilis arvensis*	1	0	-1.2	-1.1
Ge	Sci	*Urtica dioica*	22	0	-26.4	-86.7
NanoPh	Sci	*Viburnum tinus*	1	0	-1.2	-5.7
Plant grouping of the burned Zetta station (24 light tolerant species)						
Ph	Hel	*Arbutus unedo*	0	12	+ 10.1	+ 54.5
He	Hel	*Astragalus monspessulanus*	0	9	+ 7.6	+ 12.2
Ch	Hel	*Atractylis gummifera*	0	23	+ 19.6	+ 35.8
Th	Hel	*Blackstonia perfoliate*	0	6	+ 5.0	+ 7.8
Ph	Hel	*Calycotome spinosa*	0	40	+ 34.5	+ 152.6
He	Hel	*Centaurea aspera*	0	21	+ 17.9	+ 23.5
He	Hel	*Centaurium umbellatum*	0	25	+ 20.4	+ 35.0
NanoPh	Hel	*Chamaerops humilis*	0	6	+ 5.6	+ 6.1
Ph	Hel	*Daphne gnidium*	0	5	+ 4.2	+ 19.1
Th	Hel	*Ebenus pinata*	0	23	+ 19.6	+ 34.1
He	Hel	*Eryngium tricuspidatum*	0	9	+ 7.6	+ 13.0
He	Hel	*Ferula communis*	0	5	+ 4.2	+ 8.7
Ch	Hel	*Fumana thymifolia*	0	37	+ 31.8	+ 36.7
He	Hel	*Galactites tomentosa*	0	5	+ 4.2	+ 7.8
Ph	Hel	*Genista tricuspidate*	0	15	+ 12.7	+ 50.0
Ch	Hel	*Helichrysum stoechas*	0	9	+ 7.6	+ 11.3
Ph	Hel	*Juniperus oxycedrus*	0	24	+ 20.4	+ 95.1
Th	Hel	*Linum corymbiferum*	0	4	+ 3.4	+ 3.5
Th	Hel	*Linum usitatissimum*	0	6	+ 5.0	+ 10.4
Ph	Hel	*Lonicera implexa*	0	5	+ 4.2	+ 9.5
He	Hel	*Ononis natrix*	0	7	+ 5.9	+ 6.9
Ph	Hel	*Pinus halepensis*	0	3	+ 2.5	+ 15.6
Ch	Hel	*Plantago altissima*	0	19	+ 16.1	+ 21.8
He	Hel	*Pulicaria odora*	0	16	+ 13.6	+ 14.8
Intermediate plant grouping between El-Hamdania and Zetta station (17 species)						
He	Hel	*Ampelodesmos mauritanicum*	2	46	31.6	211.0
Th	Hel	*Anagallis arvensis*	2	12	6.0	6.8

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Ph	Sci	*Asparagus acutifolius*	36	6	-26.2	-54.9
Th	Hel	*Astragalus hamosus*	4	12	4.0	6.0
Ch	Hel	*Cistus salviifolius*	11	39	10.9	54.3
Ch	Hel	*Cistus villosus*	33	15	-12.0	-21.9
He	Hel	*Convolvulus althaeoides*	15	4	-9.3	-30.2
He	Hel	*Erica arborea*	17	7	-7.7	-26.0
He	Hel	*Daucus carota*	8	8	-2.5	-9.3
He	Sci	*Geranium robertianum*	9	8	-2.8	-12.4
Th	Hel	*Phagnalon saxatile*	1	11	6.9	10.2
Ph	Hel	*Pistacia lentiscus*	1	8	4.7	23.2
Ph	Hel	*Quercus ilex*	4	4	-1.9	6.3
Ph	Hel	*Quercus suber*	31	25	-5.4	22.1
Ph	Hel	*Rosa canina*	5	4	-2.3	-2.9
Ph	Hel	*Rosa sempervirens*	9	2	-6.6	-9.2
Th	Sci	*Rubia peregrina*	3	7	2.5	3.3

Table 3c. *Spatial biodiversity between Zetta and Sidi Rabeh*

GF	Shade tolerance of species	*Identified species*	Zetta	Sidi Rabeh	Dprés	Dnot
Plant grouping of the burned Zetta station (16 light tolerant species)						
Ph	Sci	*Asparagus acutifolius*	6	0	-8.3	-10.8
Th	Hel	*Astragalus hamosus*	12	0	-16.7	-35.0
He	He	*Astragalus monsepessulanus*	9	0	-12.5	-16.8
Ch	Hel	*Atractylis gummifera*	23	0	-32.3	-49.6
He	Hel	*Centaurea aspera*	21	0	-29.4	-32.5
He	Hel	*Centaurium umbellatum*	24	0	-33.6	-48.4
He	Hel	*Convolvulus althaeoides*	4	0	-5.5	-8.4
He	Hel	*Ferula communis*	5	0	-6.9	-12.0
Ch	Hel	*Fumana thymifolia*	37	0	-52.3	-50.8
Ch	Hel	*Helichrysum stoechas*	9	0	-12.5	-15.6
Ph	Hel	*Juniperus oxycedrus*	24	0	-33.6	-131.3
Th	Hel	*Linum corymbiferum*	4	0	-5.5	-4.8
Ph	Hel	*Lonicera implexa*	5	0	-6.9	-13.2
Ph	Hel	*Pinus halepensis*	3	0	-4.2	-21.7
Ph	Hel	*Rosa canina*	4	0	-5.5	-8.4
Ph	Hel	*Rosa sempervirens*	2	0	-2.8	-6.0
Plant grouping of the burned station of Sidi Rabeh (38 light tolerant species)						
Ge	Hel	*Allium triquetrum*	0	21	+ 14.8	+ 22.4
Th	Hel	*Avena alba*	0	16	+ 11.2	+ 25.7
Th	Hel	*Bellis annua*	0	12	+ 8.4	+ 9.9
Th	Hel	*Biscutella didyma*	0	9	+ 6.3	+ 7.4
Th	Hel	*Brisa maxima*	0	9	+ 6.3	+ 7.4
Th	Hel	*Bromus rubens*	0	10	+ 7.0	+ 9.1
He	Hel	*Carthamus multifidus*	0	7	+ 4.9	+ 10.8
Th	Hel	*Cerastium glomeratum*	0	9	+ 6.3	+ 9.9
Th	Hel	*Chrysantemum leucanthemum*	0	14	+ 9.8	+ 19.1
Th	Hel	*Crepis vesicaria*	0	10	+ 7.0	+ 21.6
He	Sci	*Dactylis glomerata*	0	10	+ 7.0	+ 8.3
He	Hel	*Echinophora spinosa*	0	6	+ 4.2	+ 8.3
He	Hel	*Echium plangatenum*	0	6	+ 4.2	+ 6.6
Th	Hel	*Fedia cornucopiae*	0	12	+ 8.4	+ 10.8
He	Hel	*Festuca triflora*	0	21	+ 14.8	+ 24.1
Th	Sci	*Fumaria capreolata*	0	18	+ 12.6	+ 19.1
He	Sci	*Galium tunetanum*	0	17	+ 11.9	+ 38.3
Th	Hel	*Geranium molle*	0	13	+ 9.1	+ 11.6
Th	Hel	*Hypochaeris laveigata*	0	9	+ 6.3	+ 10.8
He	Hel	*Inula viscosa*	0	21	+ 14.8	+ 24.1

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Ch	Hel	*Lavandula stoechas*	0	8	+ 5.2	+ 9.1
Ch	Hel	*Origanum floribundum*	0	13	+ 9.1	+ 24.1
Ph	Sci	*Phillyrea anguistifolia*	0	12	+ 8.4	+ 48.4
He	Hel	*Plantago lanceolata*	0	11	+ 7.7	+ 17.4
Th	Hel	*Ranunculus muticatus*	0	5	+ 3.5	+ 4.1
He	Hel	*Reseda alba*	0	16	+ 11.2	+ 19.1
He	Hel	*Salvia verbenaca*	0	8	+ 5.6	+ 9.9
He	Hel	*Scabiosa atropurpura*	0	7	+ 4.9	+ 8.3
Th	Hel	*Sherardia arvensis*	0	6	+ 4.2	+ 6.6
Th	Hel	*Silene colorata*	0	6	+ 4.2	+ 5.0
Th	Hel	*Silene fuscula*	0	11	+ 7.7	+ 9.1
Th	Hel	*Stachys ocymastrum*	0	5	+ 3.5	+ 4.1
Ch	Hel	*Teucrium pseudo-scordonia*	0	16	+ 11.2	+ 23.2
Th	Sci	*Torilis arvensis*	0	15	+ 10.5	+ 13.2
Th	Hel	*Trifolium anguistifolium*	0	12	+ 8.4	+ 14.4
Th	Hel	*Trifolium arvense*	0	12	+ 8.4	+ 11.6
Th	Hel	*Vicia disperma*	0	12	+ 8.4	+ 13.2
Intermediate plant grouping between Zetta and Sidi Rabeh (26 species)						
He	Hel	*Ampelodesmos mauritanicum*	**46**	36	-11.5	-51.9
Th	Hel	*Anagallis arvensis*	12	18	-2.8	2.9
Ph	Hel	*Arbutus unedo*	12	8	-5.3	-15.6
Th	Hel	*Blackestonia perfoliate*	6	9	-2.3	-2.5
Ph	Hel	*Calycotome spinosa*	**40**	28	-12.1	-35.7
Ph	Hel	*Chamaeoprs humilis*	6	6	-2.6	4.0
Ch	Hel	*Cistus salviifolius*	39	43	-5.7	-5.3
Ch	Hel	*Cistus villosus*	15	27	3.0	9.1
Ph	Hel	*Daphne gnidium*	5	10	2.3	-3.2
He	Hel	*Daucus carota*	8	23	4.2	22.1
Th	Hel	*Ebenus pinnata*	**23**	22	-5.3	-4.3
Ph	Hel	*Erica arborea*	7	11	-2.4	4.5
He	Hel	*Eryngium tricuspidatum*	9	11	-2.8	3.2
He	Hel	*Galactites tomentosa*	5	23	6.4	26.9
Ph	Hel	*Genista tricuspidata*	15	15	-4.0	-7.9
He	Sci	*Geranium robertianum*	8	27	5.5	10.4
Th	Hel	*Linum usitatissimum*	6	9	-2.3	2.9
Ch	Hel	*Ononis natrix*	7	20	3.9	11.5
Ch	Hel	*Phagnalon saxatile*	11	13	-3.0	4.0
Ph	Hel	*Pistacia lentiscus*	8	14	2.5	6.3
He	Hel	*Plantago altissima*	**19**	20	-4.2	-3.2
He	Hel	*Pulicaria odora*	**16**	16	-4.1	3.5
Ph	Hel	*Quercus ilex*	4	4	-2.0	-3.5
Ph	Hel	*Quercus suber*	25	33	-3.6	-4.4
Ph	Sci	*Rubia peregrina*	7	4	-4.1	-9.4
Th	Hel	*Vicia sativa*	6	15	3.0	4.2

On the floristic level, important floristic differences were noted, which classified them into groups of plants characterizing each study station:

(1) Between El-Hamdania and Sidi Rabeh (*Table 3a*):

The dense cork oak and holm oak forest of El-Hamdania is characterized by the presence of 26 sciaphilous dryad species assigned a (-) sign, capable of living in a closed forest on soil relatively rich in organic matter such as *Carex flacca*, *Cyclamen africanum*, *Mercurialis annua*, *Smilax aspera*, and *Urtica dioica*.

On the other hand, 47 species frequenting the transect of Sidi Rabeh recently burned were assigned a sign (+) corresponds to heliophytes that have an important needs for

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light to develop. These are *Allium triquetrum*, *Avena alba*, *Bellis annua*, *Calycotome spinosa*, *Trifolium angustifolium*, *Trifolium arvense* and *Vicia disperma*...

(2) Between El-Hamdania and Zetta (*Table 3b*):

The station of El-Hamdania still contains (25 species) sciaphilous species tolerant to shade (-).

But, the number of species present only in the burned transect of Zetta (+) is 24 light tolerant species, citing: *Atractylis gummifera*, *Calycotome spinosa*, *Centaurium umbellatum*, *Fumana thymifolia*, *Ebenus pinnata*, *Juniperus oxycedrus*, *Plantago altissima*, *Pulicaria odora*....

(3) Between Zetta and Sidi Rabeh (*Table 3c*):

The comparison of the spatial biodiversity between these two stations confirms that they are mainly made up of heliophyte species, but a greater number of the latter are observed at Sidi Rabeh (37) than at Zetta (16).

The comparison between the two burnt stations (*Table 3c*) shows that they have 16 common species with relatively different proportions: *Ampelodesmos mauritanicus*, leading the species constituting the understory of burned areas, is a heliophyte strongly present after fire (Vilà et al., 2001) and is considered as the ultimate stage of the degradation of the cork oak forest (Sauvage, 1961), followed by *Calicotome spinosa* which is released in large quantities (Trabaud, 1991), is very abundant after a fire. The abundance of *Cistus salviifolius* in burned transects, especially in Sidi Rabeh, including the presence of *Cistus villosus,* is due to their pyrophytic characteristic which allow them to colonize mainly bare areas (Trabaud, 1995) and which can dominate in the first post-fire years where their density is maximum and be eliminated in the mature stages of the succession. Thus, it is worth noting the presence of *Genista tricuspidata* and *Erica arborea*, acidiphytes that play an important role in the early stages of the dynamic evolution of the cork oak forest during post-fire succession (Ubeda et al., 2006). Its ability to produce suckers seems to be better with autumn rains (Trabaud, 1989), hence its strong presence in Sidi Rabeh, which received significant amounts of rain in autumn 2017 and spring 2018 (ONM, 2018).

Despite these similarities, an important floristic upheaval was noted during the first two years after the passage of the fire (Sidi Rabeh) due to the installation of 40 exogenous therophyte species which were more present immediately after the disturbance, constituting one of the earliest shrub stages in post-fire environments (Brakchi et al., 2015). These species which spend the dry season as seeds buried in the soil and germinate during the wet season, are also heliophytes that benefit from the arrival of light on the ground (Brakchi et al., 2015).

From a floristic point of view, the suberaie formation seems to be a community that is very well adapted to the passage of fire. In fact, it very quickly returns to its initial floristic composition due to the adaptation of the majority of its taxa to the passage of fire.

Floristic disruptions are limited to the first few years after the fire due to the installation of heliophyte herbaceous plants that are quickly eliminated after the effective recovery of endogenous sciaphilous species characteristic of the suberaie formation.

Finally, we can affirm that cork oak reacts very positively to the passage of fire. Its great resistance to fire (passive resistance pyrophyte) thanks to the protection of cork and its capacity to reject at all levels (collar, trunk, low branches, crown, roots) allows them to regenerate rapidly after a fire (Amandier, 2004) and to reconstitute quite quickly a community structurally similar to that which existed before the fire (Pery, 1986).

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Analysis of the vertical structure of the vegetation

After the fire, the vegetation grows from the lower strata towards the highest strata (until the reconstitution of the tree stratum). Immediately after the fire, stratum 1 appears which predominates during the first five years (Trabaud, 1983).

The distribution of the frequencies of the vertical strata in the three transects (*Fig. 4*) shows a strong presence of strata I and II, which correspond to the herbaceous plants in the burnt transects, thus witnessing the disturbance exerted on this plant formation. The peak of this stratum observed at Sidi Rabeh confirms that it will gain in cover just after the fire thanks to the opening in the middle and it will decrease as soon as the woody cover closes (Zetta).

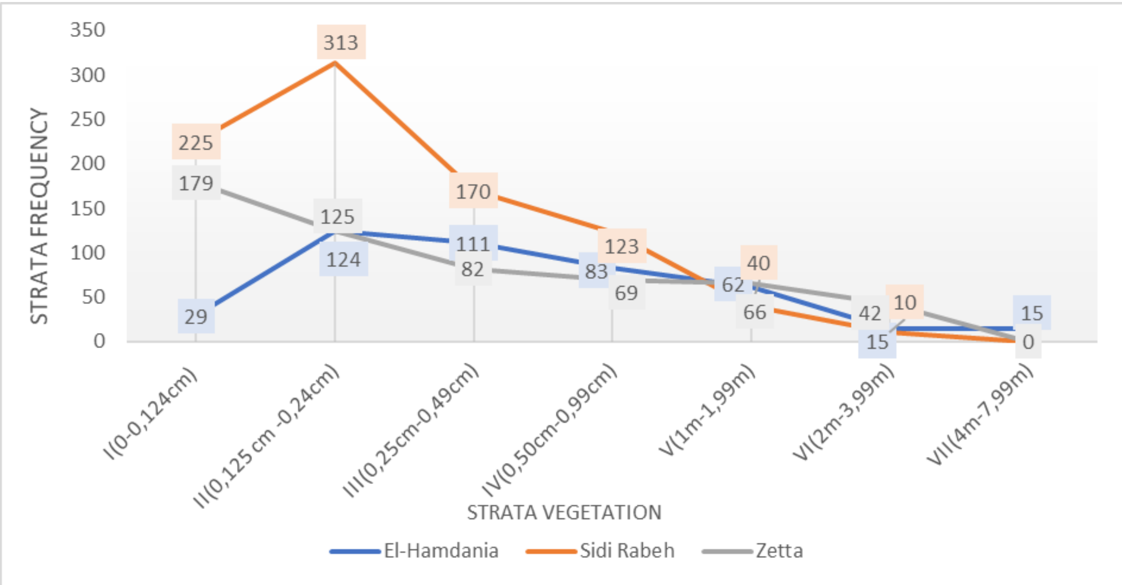

Figure 4. *The frequency distribution of the vertical strata of the three study stations (following the codification of Kadik, 2005 and Godron, 2012)*

Thus, the passage of the fire-induced the destruction and disappearance of the tree layer in the two burnt areas due to the severity and intensity of the fire. The destruction of tree subjects causes the transition from the oak forest to shrubby. The shrub stratum which occupies little space during the first two years after the fire at Sidi Rabeh, reaches its maximum in the seventh year after the fire (Zetta). This is due to the resumption of plant species such as *Arbutus unedo* (*Fig. 5*). This result is similar to that of Bekdouche (2010) in the Kabyle cork oak forest. In addition, we note the same results for the sub-shrub stratum which is mainly occupied by *Ampelodesoms mauritanicum*, the calycotome, and the cistus which are all species favored by fire.

Finally, we note then that the action of the fire led to a change of structure in the burned cork oak forest: a disappearance of the high strata (>1 m) dominated by ligneous plants to the benefit of the low strata (<1 m) denser and floristically more diversified. These results are similar to those of Trabaud (1992) in a scrubland of *Quercus coccifera* in the south of France.

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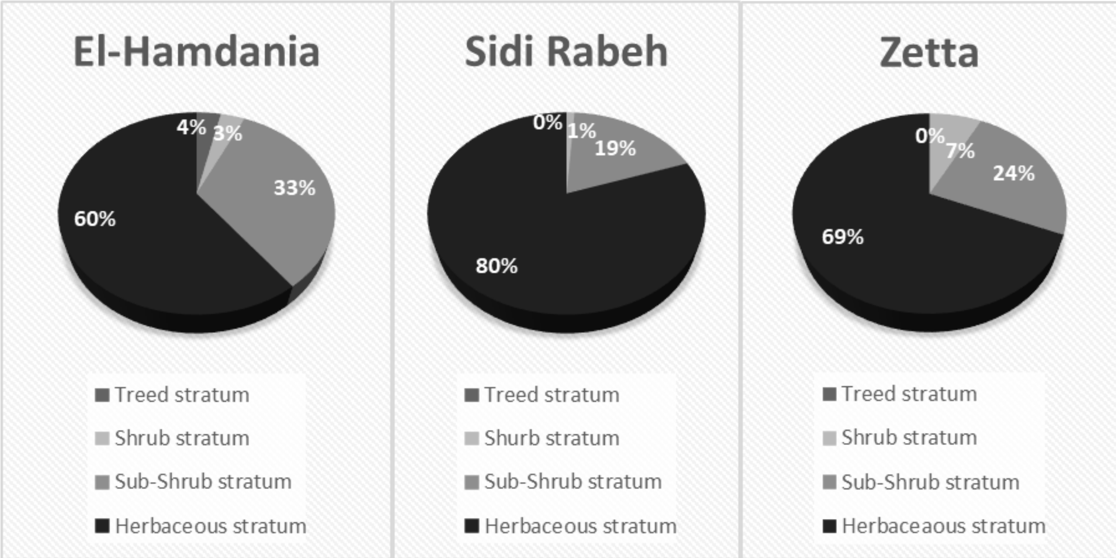

Figure 5. *Vertical structure by vegetation strata of the three study stations. (Four vegetation strata, proposed by Godron et al., 1968)*

Conclusion

In the Blidean Atlas, a detailed comparison of a transect installed in El-Hamdania in the unburned *Quercus suber* forest and two other transects installed in two stations that were burned in 2012 (Zetta) and 2017 (Sidi Rabeh) in the same plant formation shows how this suberaie has evolved following the fires.

Quite quickly after the fire, the vegetation reappears and covers the surface of the ground. The highest floristic richness was recorded two years after the fire (64 species). The indices of the area-species curve follow the same evolution, which induces a stronger heterogeneity in the burnt sites.

The purpose of our study and its particularity is to observe the evolution of biodiversity after fire by proposing 6 types of biodiversity calculated according to a frequency analysis by the application of the Brillouin formula, on the local and spatial scales.

These biodiversity indices all peak two years after the fire. To explain this result, we looked for bionomic traits of species that disappeared and those that appeared after the fire, and calculated spatio-temporal biodiversity using the Brillouin formula. The most revealing bionomic character was the heliophyte-sciaphile distinction.

It then became apparent that the increase in richness and biodiversity in the two years following the fire was caused by the arrival of several dozen heliophytes, and in particular therophyte forbs, while the number of sciaphiles that disappeared was much smaller.

During these two years, the lowest vertical stratum has developed.

The decrease in richness and biodiversity between two and seven years is caused by the removal of many of the heliophytes that were smothered by the development of the lower shrub layer. The sciaphiles that were able to begin to re-establish themselves were too few in number to compensate for these removals.

To ensure the preservation of biodiversity in this type of forest, it would be necessary to install other transects in this National Park to see, at the landscape scale, how the vegetation types can be balanced so that biodiversity does not decrease.

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