EARLY POST-FIRE VEGETATION DYNAMICS: A PRELIMINARY STUDY OF A FOREST IN NORTHWEST TUNISIA

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Abstract. Wildfires are a complex phenomenon regarding their propagation, mode of action, their effects on the environment, and can be catalysts for ecosystem change. In this context, we studied the current state of the burnt vegetation of Mekna II, Tabarka forest, Tunisia. The Braun-Blanquet method was adopted by fixing phytosociological readings in the strata studied in the chosen area (400 m²). Ecological parameters were determined in order to estimate the state of the vegetation. The results obtained showed that the dynamics of regeneration after a fire were modified, in particular, the rejection rate of the burnt subjects is clearly higher than the rate of the non-burnt subjects. On the other hand, the dynamics of post-fire vegetation have shown that species that multiply by seed (*Cistus salviifolius*, *Cistus monspeliensis*, and *Inula viscosa*) are the first to settle and gradually give way to species that sprout stumps. In addition, soil analysis at the level of the vegetative strata in question (subjects of fires) has shown that the pH and electrical conductivity vary slightly.
Keywords: *regeneration, forest, fire, vegetation frequency, biological spectrum*

Introduction

Forests are one of the primary contributors to biodiversity in Tunisia. They cover about 1.3 million hectares which is about 8% of the country's area. The Tunisian forest domain includes a wide variety of natural and artificial formations (DGF, 2010). Forest ecosystems and other Mediterranean wooded species are an important component of the territories. They contribute significantly to the development of rural areas, poverty reduction, and food security for populations in Mediterranean territories. Historically, forest fires are major natural disturbances to the composition and structure of forests (FAO, 2013) in the Mediterranean mountainous regions. Due to fragmentation of forest areas and the loss of natural habitats and biodiversity they represent a primary threat (Jaziri and Baccouche, 2020). Among all the factors contributing to forest degardation in the Mediterranean and more particularly in Tunisia, forest fires are the most devastating. Due to their intensity losses of large forest areas and pre-forests occur in short time (Chriha and Sghari, 2013). Despite the state's efforts to halt the degradation of the forest heritage, its decline continues from one year to the next due to many factors, particularly fires (Tebani and Aoufi, 2024).

Cork groves dominated by cork oak are an emblematic ecosystem of Mediterranean regions. Although cork oak is adapted to Mediterranean fire regimes, due to its thick and insulating bark, repeated and intense fires can disturb the natural regeneration of these ecosystems (Diaz-Delgado et al., 2002). They can also encourage the spread of invasive plant species and alter the floristic composition of oak stands, thus compromising biodiversity and ecological balance.

The Mekna forest is among the forests affected by local fires in the region of Jendouba, Tunisia. The latter is the most privileged region of the country (Emberger, 1955), it belongs to Kroumirie with a humid bioclimatic floor. The forest of Mekna, like that of the majority of the forests of Kroumirie, the main production was cork. In addition to some ancillary revenue from game felling rights, the exploitation of stones. There is no recorded exploitation of wood, cork oak, or artificial species (development report of Mekna II (1984-2007)).

Due to the importance of this forest, we are interested in the study of burnt strata, substitutions, and degraded cork oak and pine pinea to know the effect of fire on the regeneration of vegetation in this zone.

Materials and methods

Study site description

This study was carried out in the forest of Mekna (Tabarka), in Northwest Tunisia, (*Fig. 1; Table 1*).

Before the fire, the forest of Mekna seems dense with intense vegetation (1375 trees/ha) with a pinion pine volume around 367.5 m^3/ha and oak cork of the order of 360.3 m^3/ha (IFN, 2010).

The forest was burned in July 2020 and the field observations were made in April 2022.

The fire area is around 53 ha. This involves the partial or total destruction of vegetation. All the trees affected in the forest of Mekna are not dead because some species affected regenerated, the case of *Lavandula stoechas*, *Pistacia lentiscus, Erica arborea, Myrtus communis, Calicotome villosa.*

Figure 1. *Location of studied sites after fire (Mekna II forest)*

Table 1. *Annual average precipitation and temperature in Tabarka (2021)*

Months	J	F	Mr	Ap	M	J	Jl	Au	S	O	N	D
P (mm)	171	151	101	82	49	15	03	13	61	98	173	182
T (°c)	10	9.8	11.9	14.3	17.6	21.7	24.8	25.2	22.3	19.3	14.5	11.3

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Methodology

The study area is divided into 3 strata of vegetation based on the state of each part (*Fig. 2*):

- Stratum 1: burned (cork oak and pinion pine) *(Fig. 2a)*
- Stratum 2: degraded (pure cork oak) (*Fig. 2b*)
- Stratum 3: substitution (cork oak and pinion pine) (*Fig. 2c*)

The forest fire burned all three types of stands at the same time. the characteristics of the different sites studied are illustrated in *Table 2*.

Figure 2. *Illustration of the three vegetative strata studied: (a) burned stratum 1 (cork oak and pinion pine); (b) degraded stratum 2 (pure cork oak) and (c) substitution stratum 3 (cork oak and pinion pine)*

To study the dynamics of vegetation after the fire, the Braun-Blanquet method was adopted (Braun-Blanquet, 1932; Guinochet, 1973) by setting phytosociological records of 400 m², including 8 records for the burned stratum and 4 records for each of degraded stratum (pure cork oak) and substitution (cork oak and pinion pine). The (16) plots were distributed over all of the sites studied. The location of the surveys is based on fundamental criteria which is the ecological homogeneity.

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In order to study the floristic of the station, we used the minimum area of the environment which corresponds to the smallest surface necessary for most species to be represented (Dajoz, 1978).

The degraded site has a low-density cork oak forest due to tree mortality caused by several decline factors (Hasnaoui, 2008).

The soil sampling in the three stratum was carried out in April 2022. Five superficial soil samples were taken from the upper 20 cm of each stratum after removing litter and debris from the surface and then were mixed, homogenized and considered as a composite and representative samples of each site. These composite samples were oven dried at 70°C and sieved through a 2 mm mesh sieve.

Organic Carbon and total Phosphorus content of soil was determined by the colorimetric method and organic nitrogen content (%) was determined by Kjeldahl method.

The characteristics of the study sites are shown in *Table 2*.

Table 2. *Characteristics of the study sites*

Sites	Burned stratum	Degraded stratum	Substitution stratum
Coordinates	36°94’39.62”N 8°85’17.97”E	36°93’75.65”N 8°85’31.06”E	36°93’96.4”N 8°85’47.16”E
Altitude (m)	110–150	110	150
Soil type	Luvisols	Luvisols	Sandy soil
Vegetation	*Quercus suber + Pinion pine*	*Quercus suber*	*Quercus suber + Pinion pine*

Parameters studied

Frequency: It corresponds to the number of individuals per unit area (m² or ha) or volume.

Biological type: The biological types or biological forms that designate the adaptive behavior of the species. They provide information on the type of plant formation, its origin, and its transformations. It is based on the position occupied by the meristems in dormancy concerning the level of the ground during the difficult season and is thus subdivided into Phaneropytes; Chamephyte; Cryptophytes and Therophytes. The classification to which we have referred is that of Raunkier (1934).

Biological spectrum: The number of species belonging to each biological type is counted. Subsequently, the percentage of each biological type is calculated.

Disturbance Index: To be able to assess the state of degradation of the individualized groups, a disturbance index (IP) was calculated for each group. This index defined by Hebrard et al. (1995) is given by the following ratio:

$$IP = \text{Chamephytes} + \text{Therophytes} / \text{Total number of species} \times 100 \qquad \text{(Eq.1)}$$

The different variables observed in the field were processed by Excel software.

Detection of burnt and post-fire areas: Large forest areas are often inaccessible by road and/or located on steep mountain slopes. The contours of the burnt and post-fire areas of the Mekna forest are established from satellite observation after the fire (Google Earth 2020 satellite images) (*Fig. 1*). This method allows the spatial location of the disaster area (damaged).

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Results

Vegetation study

Vegetation frequency

The burnt Cork oak and Pinion pine stratum are characterized by the presence of different species with varying frequencies. *Cistus salviifolius*, *Cistus monspeliensis*, and *Inula viscosa* are the most dominant species with frequencies of around 33.76%; 23.51%, and 22.16% respectively. On the other hand, *Pistacia lentiscus*, *Erica arborea*, *Phillyrea latifolia* and *Myrtus communis* are less frequent. We should also point out fairly low frequencies of the order of 1.56% and 0.04% respectively for *Calicotome villosa* and *Quercus suber* (*Fig. 3*).

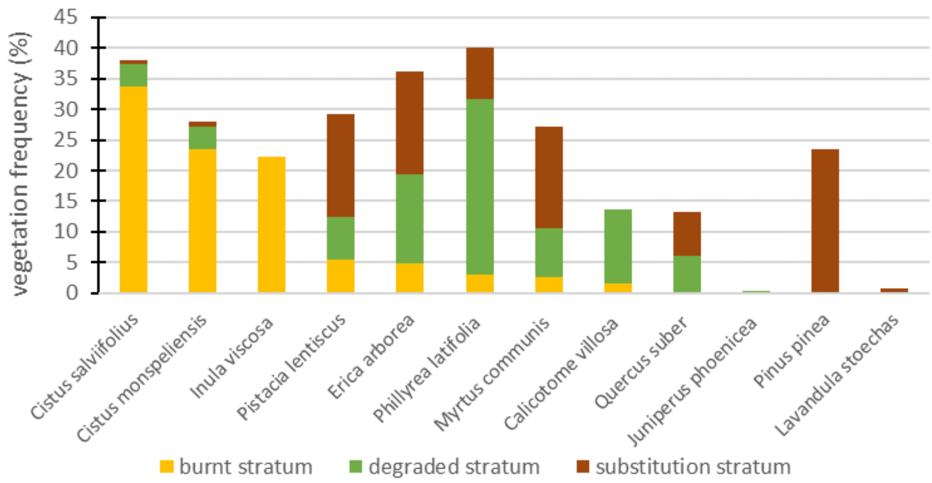

Figure 3. *Vegetation frequency of the vegetative strata studied: burnt, degraded and substitution stratum*

In the degraded stratum, *Phillyrea latifolia* species has the highest rate with a percentage of around 28.68%. Whereas for the species: *Calicotome villosa*, *Erica arborea*, *Erica multiflora*, *Cistus monspeliensis*, *Cistus salviifolius*, *Myrtus communis*, *Pistacia lentiscus*, and *Quercus suber* their frequencies vary between 3.68% and 14.44%. While *Juniperus phoenicea* exists with low frequency (0.40%) (*Fig. 3*).

In the Substitution stratum, a significant presence was reported for *Pinus pinea* (23.46%), and the species: *Myrtus communis*, *Pistacia lentiscus*, and *Erica arborea* (16.75%). On the other hand, *Erica multiflora*, *Phillyrea latifolia* (8.37%), and *Quercus suber* (7.26%) exist with medium frequencies. Low frequencies are recorded in: *Lavandula stoechas*, *Cistus salviifolius* and *Cistus monspeliensis* with percentages of the order of 0.83%, 0.55%, and 0.83% respectively (*Fig. 3*).

The common species are presented in the three strata studied: burnt, degraded, and substitution. We encountered: *Quercus suber*, *Myrtus communis*, *Erica arborea*, *Pistacia lentiscus*, *Cistus monspeliensis*, *Phillyrea latifolia*, and *Cistus salviifolius* with variable presence frequencies.

At the level of the burnt stratum, *Quercus suber* showed a very low frequency. While there is a strong regeneration of *Cistus salvifolius* (33.76%) and *Cistus monspeliensis* (23.51%). On the other hand, the species *Phillyrea latifolia*, *Erica arborea*, *Myrtus communis*, and *Pistacia lentiscus* record an average regeneration.

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Within the degraded stratum, the common species with strong regeneration is *Phillyrea latifolia* with a frequency of around 28.88% followed by *Erica arborea* (14.34%), while *Pistacia lentiscus* and *Quercus suber* showed average regeneration.

While the substitution stratum is dominated by three common species which are *Pistacia lentiscus*, *Myrtus communis*, and *Erica arborea* (16.75%), followed by *Phillyrea latifolia* and *Quercus suber* marked average frequencies. The species *Cistus salviifolius* and *Cistus monspeliensis* recorded low frequencies at this stratum (*Fig. 3*).

Biological spectrum

The vegetation at the level of the burnt stratum represents different biological types. It is richly dominated by nanophanerophytes (*Calicotome villosa*, *Erica arborea*, and *Pistacia lentiscus*) represented by 34%. In addition, this stratum has a high percentage of chamaephytes (33%) represented by *Cistus monspeliensis*, *Cistus salviifolius* and *Inula viscosa*. On the other hand, there is the appearance of vegetation based on macrophanerophytes (22%) represented by *Myrtus communis* and *Phillyrea latifolia*. However, there is a less strong presence of Mesophanerophytes (11%) presented by *Quercus suber* (*Fig. 4a*).

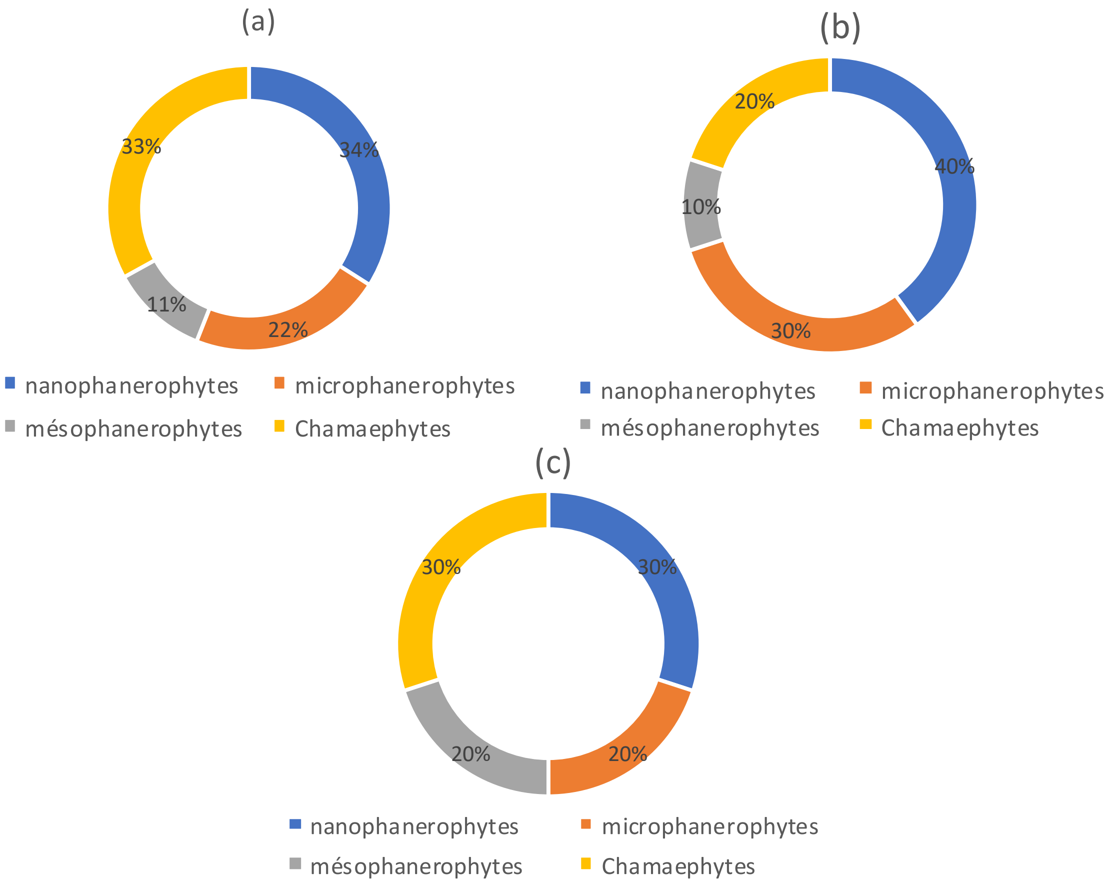

Figure 4. *Biological spectrum of the vegetative strata studied: burnt stratum (a), degraded stratum (b) and substitution stratum (c)*

The phytosociological surveys carried out at the level of the degraded stratum showed a biological type variability that is dominated by the presence of

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nanophanerophytes (*Calicotome villosa*, *Erica arborea*, *Erica multiflora,* and *Pistacia lentiscus*) with a percentage of around (40%). We also encountered microphanerophytes (30%) represented by *Phillyrea latifolia, Myrtus communis,* and *Juniperus phoenicea*. On the other hand, we notice the appearance of vegetation based on chamaephytes (20%) represented by *Cistus monspeliensis* and *Cistus salviifolius*. In addition, mesophanerophytes were present but with low percentages (10%) in the case of *Quercus suber* (*Fig. 4b*).

The substitution stratum is characterized by a variable floristic composition dominated by two biological types, chamaephytes, and nanophanerophytes (30%). The first is represented by *Lavandula stoechas*, *Cistus salvifolius,* and *Cistus monspeliensis*, while the second is represented by *Pistacia lentiscus*, *Erica arborea,* and *Erica multiflora*. On the other hand, the two biological types are microphanerophytes and mesophanerophytes (20%). The microphanerophytes are represented by *Myrtus communis* and *Phillyrea latifolia*, while the mesophanerophytes are represented by *Quercus suber* and *Pinus pinea* (*Fig. 4c*).

Disturbance index

The highest disturbance index (33.33%) is recorded in the burned stratum, followed by the substitution stratum (30%). This indicates that the fire is causing intense disturbances at the level of the cork oak and pinion floristic procession. On the other hand, the degraded stratum is the least affected (20%) because it still retains its natural vegetation and its floral procession and has never been damaged by fire.

Soil study

The pH measured varies between 6.4 and 6.7 for the burned soil and the unburned soil respectively (*Table 3*) which indicates a weak acid environment for the three types of soils. In particular, sandy soil has a higher pH (6.7) compared to burned (6.6) and degraded soil (6.4).

Table 3. *Main physical and chemical properties of the soils sampled from the three sites studied*

Sites	Burned stratum	Degraded stratum	Substitution stratum
pH	6.6	6.2	6.5
P (ppm)	76	98	110
C (%)	9.27	7.7	1.66
N (%)	1.1	1.5	0.5

The sandy soil is richer in total phosphorus (110 ppm), followed by the unburned soil (degraded) while this content is less expressed at the level of the burned soil (76 ppm).

There is a high production of organic carbon, which is more pronounced in burnt soil than in degraded soil. This rate is very low in sandy soil.

Regarding Nitrogen, it is an important element that plays a crucial role in the growth of plants. we can see that the degraded and burnt soil have the high total nitrogen levels. whereas this rate is very low in sandy soil (*Table 3*).

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Discussion

The burned stratum is characterized by the dominance of pyrophyte species (*Cistus salviifolius*, *Cistus monspeliensis* and *Inula viscosa*) which are indicators of degradation of the cork oak floral procession. On the other hand, a low presence of *Calicotome villosa* species, *Phillyrea latifolia* and *Erica arborea* (floristic procession of cork oak). This is confirmed by the work of Zammit (2008), where he reported that wildfire (under moderate conditions) is a natural way to sterilize the soil, free up space for the growth of new seedlings, and stimulate the growth of herbaceous plants.

Indeed, Saidi et al. (2006) suggest that the fire, having destroyed the vegetation, leaves a lot of free space for seed species to settle (*Cistus salvifolius* and *Cistus monspeliensis*).

However, the substitution stratum is marked by a dominance of *Pinus pinea* with a floristic procession of the very dense cork oak. While the frequency of pyrophyte species is low. The reforestation of degraded strata of cork oak by pinion pine causes a reduction in the cover of the shrub.

After the fire, not all the plant cover vegetates, there is another dynamic process of flora. Our results obtained agree with the work of Debierre (1927) and Abdessemed (1984) who showed that the dynamics of the vegetation from the spring following the fire show an exuberant development of some species of the herbaceous carpet and a good resumption of undergrowth regeneration. Fires lead to profound changes in the distribution of plant species and species.

Duarte et al. (2018) report that after 6 months, and in all types of undergrowth affected by fire, there is a prevalence of germination, mainly in mesophanerophytic communities. However, in microphanerophytic communities, there is a clear predominance of regeneration by rejection from stumps by Mediterranean shrubs. It is also verified that the germination of the dominant tree (*Pinus pinaster*) shows low values, indicating a low capacity to recover the previous forest structure without intervention.

For pH variation, Gomendy (1992) agree that, following a fire, the pH rises in the organic horizon and at the surface of the organo-mineral horizon. This may be due to the massive addition of ashes left after the fire, which slightly increased the pH.

The fire changed the availability of soil phosphorus by mineralizing it. Our results are in agreement with the work of Cade-Menun et al. (2000) who showed that soil phosphorus is not completely altered by fire since it is not very volatile and difficult to leach. However, the burning of vegetation and litter strongly modifies its availability, in particular by mineralizing organic phosphorus into orthophosphate PO_4^{3-} which is the only form of phosphorus that can be used in the living world.

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According to Gonzàlez-Pérez et al. (2004), the first visible effect of fire on soils is the loss of organic matter ranging from the low volatilization of certain compounds, to the carbonization of this matter, and up to its complete oxidation.

Regarding Nitrogen, the differences observed between the stations seem to be linked to the level of organic matter present (Selmi, 1985).

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Generally, fire leads to the volatilization of organic nitrogen (Fisher and Binkley, 2000) and therefore it is less abundant at the soil surface. However, a large number of studies show a net increase in mineral nitrogen in the soil after the passage of fires, mainly in ammoniacal form. Thus, Stock and Lewis (1986) recently measured, a few hours after a controlled burn under Aleppo pine, a quantity of mineral nitrogen in ammoniacal form four times greater than before the fire in the first two centimeters of the soil, whereas that mineral nitrogen in nitric form had decreased. Total nitrogen levels are higher in February and April but decrease in March and May.

Conclusion

According to this study, the dynamics of the vegetation after a fire in the forest of Mekna II, Tabarka, mentioned a variability and change in the floristic composition at the level of the three strata studied. In particular, the structure of the vegetation, the biological spectrum as well as the abundance of some species are generally pyrophytes.

Indeed, we have noticed that the reforestation of degraded cork oak strata by pinion pine has a remarkable effect on the floristic procession. It causes a reduction in the cover of the shrub as well as biodiversity.

In addition, the results of field investigations revealed that the pinion pine does not vegetate after the fire, the severely burned cork oak does not vegetate, and the eucalyptus is the unique species which resisted after the fire.

Following these results, reforestation operations can be envisaged to reconstitute the burnt forest. The species recommended by this type of operation are cork oak in the first place and Eucalyptus in second place; the gable pine is to avoid the ground does not allow it. Since fires have an impact on the flora and fauna biodiversity of forest ecosystems, it is necessary to plan strict programs for monitoring and fighting forest fires.

REFERENCES

[1] Abdessemed, K. (1984): Les problèmes de la dégradation des formations végétales dans l'Aures (Algérie) Première partie: la dégradation, ses origines et ses conséquences. – Forêt méditerranéenne, VI(1): 19-26.
[2] Braun-Blanquet, J. (1932): Plant Sociology. The Study of Plant Communities. – McGraw-Hill, New York.
[3] Cade-Menun, B. J., Berch, S. M., Preston, C. M. and Lavkulich, L. M. (2000): Phosphorus forms and related soil chemistry of podzolic soils on Northern Vancouver Island II. The effects of clear-cutting and burning. – Canadian Journal of Forest Research 30: 1726-1741.
[4] Chriha, S., Sghari, A. (2013): Les incendies de forêt en Tunisie. Séquelles irréversibles de la révolution de 2011. – Méditerranée 121: 87-93.
[5] Dajoz, R. (1978): Précis d'écologie. – Dunod, Paris.
[6] Debierre, F. (1927): Le chêne-liège en Tunisie. – Imprimerie Centrale,Tunis.
[7] Diaz-Delgado, R., Lloret, F., Pons, X., Terradas, J. (2002): Satellite evidence of decreasing resilience in Mediterranean plant communities after recurrent wildfires. – Ecology 83(8): 2293-2303.
[8] Direction Générale des Forêts. (2010): Inventaire des forêts par télédétection. Résultats, du deuxième inventaire forestier et pastoral national. – Ministère de la Défense Nationale

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DOI: http://dx.doi.org/10.15666/aeer/2303_51235132

Ministère de l'Agriculture, des Ressources Hydrauliques et de la Pêche et Ministère de l'Enseignement Supérieur et de la Recherche Scientifique.
[9] Duarte, P., Herménégildo, H., Figueiredo, A., Lourenço, L. (2018): Régénération de la vegetation post-incendie dans les forêts cotières de pins. L'exemple de « Mata Nacional De Leiria ». – Conférence, V[ème] Colloque de l'AFGP.
[10] Emberger, L. (1955): Une classification biogéographique des climats. Recherches et Travaux du Laboratoire de Botanique, de Géologie et de Zoologie de la Faculté des Sciences de Montpellier. – Série Botanique, 7: 3-43.
[11] FAO (2013): Etat des forêts méditerranéennes. – FAO, Rome.
[12] Fisher, R. F., Binkley, D. (2000): Ecology and Management of Forest Soils. 3rd Ed. – John Wiley & Sons, New York.
[13] Gomendy, V. (1992): Transferts thermiques et modifications physico-chimiques dans les horizons supérieurs du sol lors du passage du feu. – Mémoire de DEA, INRA Avignon, CNRS Montpellier, Université Nancy.
[14] González-Pérez, J. A., González-Vila, F. J., Almendros, G., Knicker, H. (2004): The effect of fire on soil organic matter, a review. – Environment International 30: 855-870.
[15] Guinochet, M. (1973): Phytosociologie. – Masson, Paris.
[16] Hasnaoui, F. (2008): Diagnostic, causes et conséquences du dépérissement de la chênaies du Nord Ouest de la Tunisie. – Thèse de doctorat, INAT Tunisie, Université de carthage.
[17] IFN (2010): Inventaire Forestier National de la Tunisie. – Ministère de l'Agriculture. Direction Générale des Forêts, Tunis.
[18] Jaziri, B., Baccouche, N. (2020): Suivi par télédétection de la dynamique de la végétation de Jbel Bil Lahrish un an après l'incendie de 2017 (Bizerte-Beja, Tunisie septentrionale). – Geo. Eco. Trop. 44(1): 65-82.
[19] Raunkier, C. (1934): The Life forms of Plants and Statistical Plant Geography; Being the Collected Papers of C. Raunkiaer. – Oxford Clarendon Press, Oxford.
[20] Saidi, Y., Aloui, A., Hasnaoui, F., Chaabane, A. (2006): Dynamique de la végétation après incendies dans la Forêt de Melloula. – Gestion Intégrée des Forêts de Chêne-Liège et de Pin d'Alep T 2 9(2): 69-89.
[21] Selmi, M. (1985): Différenciation des sols et fonctionnement des écosystèmes forestiers sur grés numidien de Kroumirie (Tunisie). Ecologie de la Subéraie - Zeenaie. – Doctorat d'état es - Sciences Naturelles, Univ de Nancy.
[22] Stock, W. D., Lewis, O. A. M. (1986): Soil nitrogen and the role of fire as a mineralizing agent in a South African Coastal Fynbos ecosystem. – Journal of Ecology 74: 317-328.
[23] Tebani, M., Aoufi, F. (2024): Les incendies comme un principal facteur de dégradation de l'écosystème forestier en Algérie (cas de la forêt de l'Ouarsenis). – Conference paper.
[24] Zammit, O. (2008): Détection de zones brûlées après un feu de forêt à partir d'une seule image satellitaire SPOT 5 par techniques SVM. – Thèse de doctorat, Université de Nice-Sophia Antipolis.

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