



Original article

Post-fire dynamics of recolonization by *Cistus* plants in the Aleppo pine and Cork oak forests in Bejaia region, central north Algeria

Imene Benzina*, Farid Bekdouche, Abdelkrim Si Bachir

Laboratory "Biodiversity, Biotechnology and Sustainable Development", Faculty of Nature and Life Sciences, University Mostefa Benboulaïd Batna 2, 05078 - Algeria

E-mail address (*corresponding author): i.benzina@univ-batna2.dz

ORCID iD: Imene Benzina: <https://orcid.org/0000-0003-1649-9232>; Farid Bekdouche: <https://orcid.org/0000-0001-5148-930X>; Abdelkrim Si Bachir: <https://orcid.org/0000-0001-8501-1830>

ABSTRACT

In August 2021, very intense fires swept through various forested areas in northern Algeria, particularly in Kabylia. The population dynamics of *Cistus salviifolius* and *Cistus monspeliensis* were studied along a post-fire successional gradient during the first nine months (September 2021 – May 2022), in two forest communities: the Cork oak (*Quercus suber*) and the Aleppo pine (*Pinus halepensis*) forests in the coastal zone of Bejaia province. The *Cistus* spp. germinations were counted monthly in each forest on 10 plots of 1 m², evenly distributed along 2 transects of 45 m each. The results showed that the majority of germinations occur in December with 207.5 ± 24.2 seedlings in the Cork oak forest and 171.3 ± 18.0 seedlings in the Aleppo pine forest. Student's t-test does not reveal significant differences for December between the two communities. During the first months following the fire (September and October 2021), germinations were almost absent. The monthly rainfall in September 2021 was estimated at 16.25 mm, an insufficient amount for effective germination. Late germination results in an extension of its period, showed a high rate in January 2022 with 42.2 ± 2.1 and 11.5 ± 0.8 seedlings, respectively, in the Cork oak forest and the pine forest. Beyond January, germination was practically nonexistent in both communities. Therefore, the majority of the seed germination was concentrated in November, December, and January with a unimodal germination pattern.

KEY WORDS: *Cistus* species germination, fire, *Pinus halepensis*, *Quercus suber*, Bejaia

ARTICLE HISTORY: received 2 January 2024; received in revised form 23 April 2024; accepted 29 April 2024

1. Introduction

One of the major disturbances that affects vegetation communities across the world is wildfires (SIMLER-WILLIAMSON ET AL., 2021). In Mediterranean ecosystems, fires are recurrent, and the plants in place have adapted to this disturbance, which they have been enduring for many years (ARIANOUTSOU, 1998; PAUSAS ET AL., 2008; PAUSAS & KEELEY, 2014). To regenerate, perennial plants use two strategies: vegetative regeneration by producing offshoots, and sexual

regeneration from seeds carried by the mother plant or buried in the soil (KEELEY ET AL., 2005; RAMIADANTSOA ET AL., 2023). Nevertheless, with the current frequency of fires, pest attacks, climate change and other disturbances across various regions of the globe, species adapted to the historical disturbance regime are becoming increasingly vulnerable (SEIDL ET AL., 2017; MC DOWELL ET AL., 2020; HIGUERA & ABATZOGLOU, 2021).

The majority of the perennial species in Mediterranean plant communities recover from fire

by vegetative means, while very few species recover exclusively by seeds. Among these obligatory seeders, we find *Cistus* spp. that sometimes form pure stands due to their demographic strategy (THANOS & GEORGHIOU, 1988) and inhibition of other species by allelopathic phenomena producing toxic substances (phenols, terpenes, flavonoids, polyacetylenes, steroids, etc.) (HERRANZ ET AL., 2006). *Cistus* spp. are widely recognized as the most frequently found colonizers in regions of the Mediterranean basin that are susceptible to fires (THANOS, 1999; AGUAYO-VILLALBA ET AL., 2021). Although, they are rarely found in the later phases of forest succession, they usually remain in the soil seed bank and swiftly re-emerge following a fire (TAVŞANOĞLU & GÜRKAN, 2005). KEELEY ET AL. (2005) noted that several species that take advantage of the conditions created by fire are limited to the very early years and only reappear with the occurrence of a subsequent fire. In this context, *Cistus* spp. seeds have a hard tegument, which inhibits water absorption from the environment and allows the seeds to remain dormant for a long time (CORRAL ET AL., 1990; TRABAUD ET AL., 1997; ARIANOUTSOU, 1998). Dormancy is lifted either by heat shock (SILVA DIAS ET AL., 2019; PAUSAS & LAMONT, 2022), by strong sunlight in bare areas or by smoke produced by burning vegetation (DAYAMBA ET AL., 2008; PAUSAS & LAMONT, 2022). The additive effect of the heat shock and smoke released during vegetation combustion on the germination of the soil seed bank of some species in fire-prone sites has been demonstrated (ROY & SONIE, 1992; THANOS ET AL., 1992; THOMAS ET AL., 2003; CROSTI ET AL., 2006).

During the very early years of forest succession following fire, *Cistus* plants establish themselves on a massive scale, with high rates of germination from the soil seed bank (ESHEL ET AL., 2000). Because of this rapid and massive recovery, *Cistus* plants play a major role in protecting soils against water erosion in the first few months after the fire (TRABAUD & OUSTRIC, 1989; BUHK ET AL., 2007). Indeed, the first autumn rains are accompanied by a significant loss of mineral elements from the soil, as woody plants are slow to regrow. *Cistus* plants and herbaceous species with massive germination and rapid vegetative recovery can mask this slowness. Therefore, because of their importance during the first stages of plant succession after fire, *Cistus* plants are widely studied in various ecosystems of the Mediterranean region (THANOS & GEORGHIOU, 1988; FERRANDIS ET AL., 1999; HERRANZ ET AL., 1999; TAVŞANOĞLU & GÜRKAN, 2005; FRAZÃO ET AL., 2018; LUNA & CHAMORRO, 2016; LUNA

ET AL., 2023). Research on this topic in the south side of the Mediterranean is unfortunately less important (BEKDOUCHE, 2010; BEKDOUCHE ET AL., 2016).

The aim of this study was to analyse the germination dynamics of *Cistus* spp. seedlings during the first months following a fire in the two most common forests in Algeria: the Cork oak forest (*Quercus suber* L.) and the Aleppo pine forest (*Pinus halepensis* Mill.).

2. Materials and methods

2.1. Study area

During August 2021, extremely severe and fatal wildfires occurred, leaving a lasting mark in the history of several forested regions in northern Algeria, particularly in the Kabylia region. To monitor the re-establishment dynamics of *Cistus* species in these burned forests, we selected two sites along the coastal zone of Bejaia city, located between 100 and 300 m a.s.l. The first one is represented by the Aleppo pine (*Pinus halipensis*) forest of Adrar Oufarnou, located within the territory of Gouraya National Park (a biosphere reserve) (36°46'46" N ; 5°01'42" E), about 5 kilometers to the northwest of Bejaia city. The second one is the Cork oak (*Quercus suber*) forest located in the Bouhatem forest massif (36°50'20" N; 4°55'40" E), at approximately 2 kilometers from the village of Saket on National Road N 24, which leads from Bejaia to Azeffoun city (Tizi Ouzou) (Fig. 1).

The most recent fires on the two sites date back to the summer of 2017, so the vegetation in place at the time of our study in 2021 was five years old. The standing charred trunks and the surrounding unburned remnants provided information about the vegetation structure and the dominant species prior to the fire. While *Quercus coccifera*, *Phillyrea latifolia*, *Erica multiflora* and *Cistus monspeliensis* dominate the pine forest, the Cork oak forest is dominated by *Phillyrea latifolia*, *Erica arborea* and *Arbutus unedo*. Both communities covered 70 to 80% of the soil surface, reaching its maximum between 1 to 2 meters in height.

According to data collected from the nearest meteorological station (Bejaia Airport) for the period 1970–2022, the average maximum temperatures for the hottest month (August) and the coldest month (January) are 29.9 °C and 7.52 °C respectively. The average annual rainfall was 743 mm. The two sampling sites are characterized by a Mediterranean sub-humid bioclimate with a warm variant.

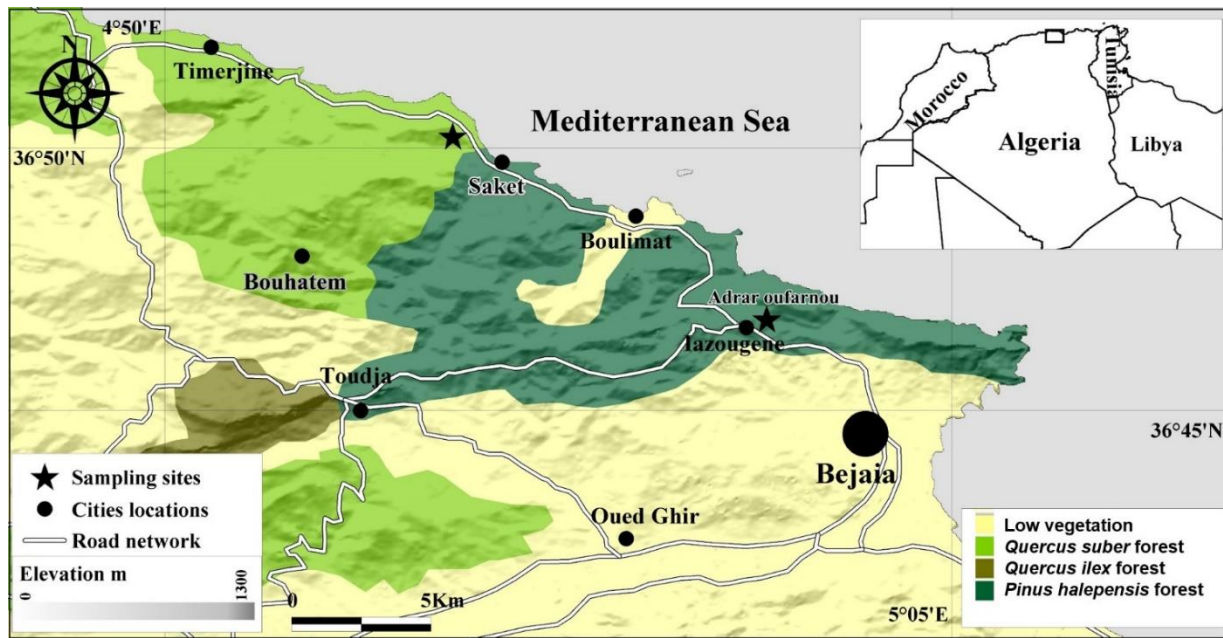


Fig. 1. Location of sampling stations in the Bejaia region (central north Algeria)

2.2. Sampling sites and germination monitoring

The sampling sites exhibit similar climatic and environmental conditions. They were all affected by the fire on the same date and were chosen to minimize the relief effect (located on flat terrain) and to ensure uniformity regarding the pre-fire vegetation state. To monitor the demography of the two most common *Cistus* species (*Cistus salviifolius* and *C. monspeliensis*), regular observations were conducted during the first nine months following the wildfire (from September 2021 to May 2022) in the studied forests (Aleppo pine and Cork oak). For each of the two communities, *Cistus* spp. germinations were counted monthly on ten plots of 1 m² (P1 to P10), evenly distributed along two transects, each 45 m long and 25 m apart from each other (Fig. 2). Each month, the seedlings were carefully uprooted to avoid disturbing the plots (a destructive method) and then counted.

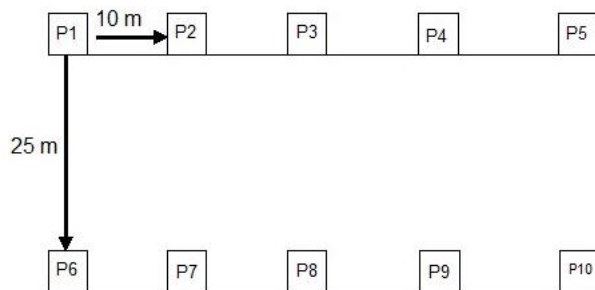


Fig. 2. The experimental setup for counting seeds of *Cistus* spp.

2.3. Statistical analysis

Prior to statistical analysis, data were tested for parametric assumptions with the Kolmogorov-Smirnov test of normality and Levene's test of variance homogeneity. Outputs showed that the tested data respect parametric test conditions. For each site, the monthly monitoring data on the number of germinated seeds were processed through repeated measures analysis of variance (ANOVA). Post hoc comparison of means was made using the Tukey HSD test. Comparison of the seedling number between the pine and the Cork oak forests was conducted using the Student's t-test for each date. The statistical analysis was performed using XLSTAT (2014.5.03), and the presented results are means $\pm$ 2 SE (standard error).

3. Results

Our results concern the recolonization of surfaces burned by *Cistus* spp. during the first nine months after fire. The results obtained indicate that the majority of germinations occur in December, with an average of 207.5 ± 24.2 seedlings for the Cork oak forest and 171.3 ± 18.0 seedlings for the Aleppo pine forest. The lowest values were recorded in September in both communities with the same value of 1.0 ± 0.1 (Table 1).

Table 1. Comparison of the mean seedling number of *Cistus* plants recorded during the first nine months after fire in the Cork oak forest and the Aleppo pine forest in the Bejaia region

Months	Cork oak forest mean (± 2 SE)	Aleppo pine forest mean (± 2 SE)	t-test between the two communities	Precipitation (mm)
September 2021	1.0 $\pm$ 0.1 h	1.0 $\pm$ 0.1 g	0.38 (ns)	16.25
October 2021	2.3 $\pm$ 0.1 g	2.0 $\pm$ 0.3 e	0.56 (ns)	56.14
November 2021	34.0 $\pm$ 2.3 c	12.1 $\pm$ 2.1 b	14.25 (*)	188.22
December 2021	207.5 $\pm$ 24.2 a	171.3 $\pm$ 18.0 a	1.98 (ns)	52.32
January 2022	42.2 $\pm$ 2.1 b	11.5 $\pm$ 0.8 b	27.53 (*)	48.78
February 2022	9.2 $\pm$ 0.7 d	4.5 $\pm$ 0.4 c	11.23 (*)	26.16
March 2022	6.6 $\pm$ 0.5 e	1.2 $\pm$ 0.1 f	20.50 (*)	50.30
April 2022	4.1 $\pm$ 0.4 f	2.5 $\pm$ 0.1 d	8.79 (*)	64.52
May 2022	2.4 $\pm$ 0.2 g	1.0 $\pm$ 0.1 g	16.86 (*)	34.03

Note: For each community, months sharing the same letter do not show a significant difference between them (Tukey's test, $P < 0.05$). Between the two communities, the significantly different months are noted with an asterisk (*) and those without differences with ns (t-test, $P < 0.05$)

During the initial two months after the fire, specifically in September and October 2021, the germination process was notably limited, with a maximum of only 2.3 ± 0.1 seedlings recorded. This lack of germination activity can likely be attributed to the prevailing weather conditions during August and September 2021. It's noteworthy that the first significant rainfall conducive to germination is only observed in October. September 2021 saw a monthly rainfall estimate of 16.25 mm, which is deemed insufficient to trigger effective germination processes. Consequently, the late germination extends over time, leading to relatively higher germination rates observed in January 2022, with 42.2 ± 2.1 seedlings in the Cork oak forest and 11.5 ± 0.8 seedlings in the Aleppo pine forest. Post-January, germination activity diminishes significantly in both forest communities. Therefore, the primary phase of seed germination appears to be concentrated during the months of November, December, and January, exhibiting a distinct unimodal germination pattern (Table 1).

Tukey's test showed that there was a significant difference in germination between the majority of the studied months in the Cork oak *Cistus* spp. community (groups: a, b, c, d, e, f and h), whereas germination in October 2021 and May 2022, showed no significant difference (group: g). Statistical analysis conducted in Aleppo pine forests revealed significant variations in germination rates of *Cistus* spp. among most of the studied months (groups: a, b, c, d, e, f, and h). However, no significant difference in germination

was observed between September 2021 and May 2022 (group: g) (Table 1).

The variation in germination is statistically significant between the Cork oak forest and the Aleppo pine for six months (November, January, February, March, April and May). No significant difference was revealed for the other three months (September, October and December) (t-test, $P < 0.05$) (Table 1).

4. Discussion

For the third month (November) following the fire disturbance, the recolonization of the studied area becomes increasingly effective. Various indigenous species from the burned communities start to recover, primarily through vegetative reproduction, likely due to the improved meteorological conditions at the beginning of winter. Others, which lack this ability, regenerate through sexual reproduction, either from seeds produced by the parent plant or from the seed bank buried in the soil. Indeed, many dominant species in Mediterranean ecosystems following fire regenerate through vegetative means (LLORET, 1998). Other species lack the capacity to withstand the trauma caused by the passage of the fire, and their regeneration relies solely on seed germination (FERRANDIS ET AL., 1999).

The extensive germination of *Cistus* spp. seeds at studied sites corroborates the findings reported by various authors (FERRANDIS ET AL., 1999; HERRANZ ET AL., 1999; TAVŞANOĞLU & GÜRKAN, 2005; DE LUIS ET AL.,

2008 a, b; [GHEBREHIWOT ET AL., 2012](#)). Germination is stimulated by the heat emitted by the fire, which breaks the dormant state of the seed by cracking its hard seed coat, allowing the embryo to absorb water, and removing mechanical restrictions on radical expansion ([PAPAVASSILIOU ET AL., 1994](#); [KEELEY & BOND, 1997](#); [HERRANZ ET AL., 1998](#)). In the region of Sydney (Australia), [AULD & DENHAM \(2006\)](#) have estimated that approximately 15% of fire-prone flora have their seed dormancy broken by the heat shock. Typically, temperatures ranging between 60 and 150°C positively stimulate germination ([DE LUIS ET AL., 2005](#)). For some species, this germination is stimulated by the smoke produced by vegetation combustion ([DAYAMBA ET AL., 2008](#)). [AULD & DENHAM \(2006\)](#) noted that the embryo dormancy of nearly half of the flora in the Sydney region was broken by the combined effect of heat and smoke. The smoke generated by the burning fuel promotes seed germination to a peak, which then declines due to either high concentrations or prolonged exposure, inhibiting germination ([LIGHT ET AL., 2002](#)) or outright killing the seeds ([KEELEY & FOTHERINGHAM, 1998](#)).

The initial observation we can draw from our results is the importance of site variability. This is particularly evident in the germination numbers for December, as reflected in the high standard errors calculated. This can be explained by the interaction of multiple factors, mainly topography, predation, differential ash accumulation, the state of pre-existing vegetation, and contributions through seed dispersal. In general, to accurately assess the effect of any factor on vegetation after a disturbance, it is essential to consider all interacting factors, including the pre-disturbance vegetation (determined by past disturbance regimes), disturbance characteristics, spatial factors, and post-disturbance abiotic conditions ([DUGUY & VALLEJO, 2008](#)).

Topography can play a significant role in seed movement, due to slopes; seeds can be carried by rainwater to depressions (hydrochory). The distance travelled depends on the intensity of runoff and the weight of the transported seeds. Predation mainly affects other plant families such as legumes ([PAPAVASSILIOU ET AL., 1994](#)), and it is primarily instigated by ants. According to [FERRANDIS ET AL. \(1999\)](#), predation of *Cistus* spp. seeds by ants appears to be negligible. Ant-mediated seed dispersal (myrmecochory) is the most significant form of zoochory, leading to the accumulation of diaspores in caches. This results in a heterogeneous distribution, which can partly explain the pronounced variability in seedling distribution.

The distribution of seedlings is also influenced by the location of *Cistus* spp. individuals in the pre-fire vegetation (mother plants). The seed density dispersed is high near the source population. The density of seeds concerning the distance from the mother plant conforms to a negative exponential distribution, meaning that the number of seedlings decreases rapidly as the distance from the mother plant increases ([THANOS, 1999](#)). This can explain the abundance of seedling recruitment in some areas compared to others. Several studies conducted in this regard have observed a high seed density under the mother plants and a prevalence of barochory compared to other modes of seed dispersal ([IZHAKI ET AL., 2000](#)). [TRABAUD & OUSTRIC \(1989\)](#), estimated that the distance of seedlings from the burned mother plant is 55.8 ± 3 cm for *Cistus monspeliensis* and 62.4 ± 7 cm for *Cistus salvifolius*. These relatively short distances explain the high site variability observed in studied sites. Therefore, the pre-fire vegetation state plays a significant role in the dynamics of seedlings during the recolonization of the environment. The temporal distribution of germination in the two studied communities exhibits a three-phase pattern. The first phase is characterized by a late germination of approximately two months, during the second phase there is a substantial increase in germination, followed by a decline and stabilization in the final stage. For the first phase, the late germination in September and October could be attributed to the severe drought conditions that characterized this period. It might also be a consequence of seed dormancy, as even some light rainfall in October (56.14 mm of monthly rainfall) did not result in the germination of the soil seed bank.

According to the results of [RIVAS ET AL. \(2006\)](#) in the case of germination for six legume species, this latency phase varies from 15 to 30 days. This was deduced by [HERRANZ ET AL. \(1998\)](#) as a form of seed adaptation, through a mechanism that prevents germination during occasional rains and delays until the period of abundant rainfall, which is conducive to the establishment and survival of young seedlings. Otherwise, a significant gap between rain events would undoubtedly lead to the death of the seedlings in studied sites. This analysis could explain why there is massive germination from November to January. [PAPAVASSILIOU & ARIANOUTSOU \(1993\)](#) and [ARIANOUTSOU & NE'EMAN \(2000\)](#) observed that the emergence of legumes and *Cistus* spp. seedlings after summer fires concurs with the first autumn rains. Most seedlings appear from November to December when the

favourable conditions for germination are met, namely, precipitation and mild temperatures. In this regard, TANGNEY ET AL. (2022) highlighted that post-fire vegetation recovery depends on temperature and humidity. The final phase observed in our case, corresponding to a decline and cessation of germination, may be due to rising temperatures, low and irregular precipitation, and a dramatic reduction in the stock of seeds capable of germination. Unlike the observations made by TRABAUD & OUSTRIC (1989), which reported a bimodal distribution of germination in *C. salvifolius* and *C. monspeliensis* (autumn and spring), while our observations show a unimodal germination pattern. This could be explained by the extension of the favourable germination period in the northern Mediterranean region. The studies conducted by DE LUIS ET AL. (2008b) confirm our interpretation. In fact, for each year of observation after a controlled fire in southern Spain, these authors report a unimodal germination pattern for Cistaceae in a low woodland formation dominated by *Ulex parviflorus*. They detected a significant initial peak in the autumn of the first year, followed by a smaller peak in the autumn of the second year.

The wildfires in the summer of 2021 appear to have been intense and severe due to the substantial accumulation of fuel since the last fires in 2017 and favourable meteorological conditions. The high intensity of the fire leads to significant mortality of seeds distributed at the surface level (DE LUIS ET AL., 2008b). The majority of germination comes from the seed bank located in the deeper layers of the soil, which probably explains the relatively long germination time of around 2 months, from mid-August to early November. The sharp decline in germination rates after January is probably due to the depletion of the stock of seeds capable of germination, stored in the lower layers of the soil during the period between the last two successive fires. Indeed, *Cistus* plants reach maturity after 2 to 3 years (DUGUY & VALLEJO, 2008; SILVA DIAS ET AL., 2019), which allows them to rebuild their seed bank.

The difference in substrate between the Cork oak forest and Pine forest communities could also have an effect on the germination rate. However, due to the *Cistus* plant's adaptability to various soil types, it is challenging to determine the extent to which this factor plays a role and influences germination in both communities. What is certain is that vegetation dynamics are more pronounced on siliceous soil than on limestone (QUEZEL & MEDAIL, 2003).

Another hypothesis regarding the substantial

germination and dominance of *Cistus* species in fire-prone environments could be the inhibition of germination of other species due to the toxic substances secreted by *Cistus* plants. This phenomenon of allelopathy has been particularly studied in various species of the *Cistus* genus by CHAVES & ESCUDERO (1997); LOBON ET AL. (2002) and HERRANZ ET AL. (2006).

Our results have been deduced and compared with existing research on the subject, attempting to highlight some factors that may have a direct or indirect influence on the germination of *Cistus* spp. seeds encountered during the study (habitat openness, pre-fire vegetation cover, predation, seed dispersal, climatic and edaphic conditions). We believe that, for a better understanding of the germination question after the fire, experimentation under controlled conditions appears to be the only approach that allows for maximum control over sources of variability and provides precise answers.

It is important to emphasize the crucial role played by *Cistus* species in the evolution of fire-affected communities. They protect the soil against water erosion during the initial months after the fire, as woody species in the communities gradually regenerate through vegetative means. The early months are when the risk of erosion is most significant due to the bare landscape. The occurrence of fire, combined with heavy rainfall, leading to changes in soil properties, is one of the primary reasons for accelerated erosion (PARDINI ET AL., 2004; STAVI, 2019; NELSON ET AL., 2022). The loss of the topsoil and, consequently, the slow regeneration of vegetation can inhibit the formation of soil organic matter and the establishment of species, thereby intensifying erosion processes (STINCA ET AL., 2020).

5. Conclusion

Our research presents findings on the contribution of *Cistus* species to the regeneration of plant communities after forest fires in the southern part of the Mediterranean region. No major difference was observed between the two communities, with peak germination in December. During the first two months following the fire, germination is notably scarce, a phenomenon ascribed to both the severity of the fire and the prevailing weather conditions in September 2021. The prolonged delay in germination led to comparatively elevated values in January 2022, both in the Cork oak and the Aleppo pine forests. Beyond January, germination sharply declines, likely due to the depletion of the seed stock capable of

germination. Therefore, the majority of germination is concentrated in November, December, and January. We observe a unimodal germination pattern. Germination is statistically higher in the Cork oak community for all months, except for December, which shows no significant difference due to significant spatial variability and for the two first months after the fire due to lack of germination. Several discussed factors influence the recolonization of fire-affected communities by *Cistus* species. To understand the impact of each of these factors, it appears essential to undertake experimental studies by monitoring germination on permanent plots subjected to controlled fires.

Acknowledgments

The authors would like to thank the Algerian Ministry of Higher Education and Scientific Research (MESRS) and the Directorate-General for Scientific Research and Technological Development (DGRSDT). The authors are also grateful to Dr. Arar Abdelkrim for his invaluable help.

References

- Aguayo-Villalba A.Á., Álvarez-Gómez C.M., Aisa-Ahmed M., Barrosa-Rodríguez L. M., Camacho-Lopez S., Cocero-Ramirez A., Sanchez-Romero C. 2021. Effect of fire on viability and germination behaviour of *Cistus ladanifer* and *Cistus salvifolius* seeds. *Folia Geobotanica*, 56: 215–225.
- Arianoutsou M. 1998. Aspects of demography in post-fire mediterranean plant communities of Greece. in: Rundel P.W., Montenegro G. & Jaksic (Eds). *Landscape degradation in mediterranean-type ecosystems, Ecological studies* 136. Springer-Verlag, Berlin/Heidelberg: 273–295.
- Arianoutsou M., Ne'eman G. 2000. Post-fire regeneration of natural *Pinus halepensis* forest in the east Mediterranean basin. in: Ne'eman, G. & Trabaud, L. (eds.). *Ecology, biogeography and management of Pinus halepensis and P. brutia forest ecosystems in the Mediterranean basin*. Backhuys Publishers, Leiden: 269–289.
- Auld T.D., Denham A.J. 2006. How much seed remains in the soil after a fire? *Plant Ecology*, 187: 15–24.
- Bekdouche F. 2010. Evolution après feu de l'écosystème subéraie de Kabylie (nord algérien). PhD Thesis. University of M. Mammeri Tizi-Ouzou, Algeria.
- Bekdouche F., Sidi H., Tassadit A. 2016. Analyse de la recolonisation après incendie par les cistes et les légumineuses dans des pinèdes à *Pinus halepensis*: Le cas d'Ain Skhoun (Bejaia). *Revue Ecologie et Environnement*, 12: 25–33.
- Buhk C., Meyn A., Jentsch A. 2007. The challenge of plant regeneration after fire in the Mediterranean Basin: scientific gaps in our knowledge on plant strategies and evolution of traits. *Plant Ecology*, 192: 1–19.
- Chaves N., Escudero J.C. 1997. Allelopathic effect of *Cistus ladanifer* on seed germination. *Functional Ecology*, 11: 432–440.
- Corral R., Pita J.M., Pérez-García F. 1990. Some aspects of seed germination in four species of *Cistus* L. *Seed Science and Technology*, 18: 321–325.
- Crosti R., Ladd P.G., Dixon K.W., Piotta B. 2006. Post-fire germination: The effect of smoke on seeds of selected species from the central Mediterranean basin. *Forest Ecology and Management*, 221: 306–312.
- Dayamba S.D., Tigabu M., Sawadogo L., Oden P. 2008. Seed germination of herbaceous and woody species of the Sudanian savanna-woodland in response to heat shock and smoke. *Forest Ecology and Management*, 256: 462–470.
- De Luis M., Raventos J., Gonzales-Hidalgo J.C. 2005. Factors controlling seedling germination after fire in Mediterranean gorse shrublands. Implications for fire prescription. *Journal of Environmental Management*, 76: 159–166.
- De Luis M., Raventos J., Wiegand T., González-Hidalgo J.C. 2008b. Temporal and spatial differentiation in seedling emergence may promote species coexistence in Mediterranean fire-prone ecosystems. *Ecography*, 31: 620–629.
- De Luis M., Verdu M., Raventos J. 2008a. Early to rise makes a plant healthy, wealthy, and wise. *Ecology*, 89, 11: 3061– 3071.
- Duguy B., Vallejo V.R. 2008. Land-use and fire history effects on post-fire vegetation dynamics in eastern Spain. *Journal of Vegetation Science*, 19: 97–108.
- Eshel A., Henig-Sever N., Ne'eman G. 2000. Spatial variation of seedling distribution in an east Mediterranean pine woodland at the beginning of post-fire succession. *Plant Ecology*, 148: 175–182.
- Ferrandis P., Herranz J.M., Martinez-Sanchez J.J. 1999. Effect of fire on hard-coated Cistaceae seed banks and its influence on techniques for quantifying seed banks. *Plant Ecology*, 144: 103–114.
- Frazão D.F., Raimundo J.R., Domingues J.L., Quintela-Sabaris C., José C., Gonçalves J.C., Delgado F. 2018. *Cistus ladanifer* (Cistaceae): a natural resource in Mediterranean-type ecosystems. *Planta*, 247, 2: 289–300.
- Ghebrehiwot H.M., Kulkarni M.G., Kirkman K.P., Van-Staden J. 2012. Smoke and heat: influence on seedling emergence from the germinable soil seed bank of mesic grassland in South Africa. *Plant Growth Regulation*, 66: 119–127.
- Herranz J.M., Ferrandis P., Copete M.A., Duro E.M., Zalacain A. 2006. Effect of allelopathic compounds produced by *Cistus ladanifer* on germination of 20 Mediterranean taxa. *Plant Ecology*, 184: 259–272.
- Herranz J.M., Ferrandis P., Martinez-Sanchez J.J. 1998. Influence of heat on seed germination of seven Mediterranean Leguminosae species. *Plant Ecology*, 136: 95–103.
- Herranz J.M., Ferrandis P., Martinez-Sánchez J.J. 1999. Influence of heat on seed germination of nine woody Cistaceae species. *International Journal of Wildland Fire*, 9: 173–182.
- Higuera P.E., Abatzoglou J.T. 2021. Record-Setting Climate Enabled the Extraordinary 2020 Fire Season in the Western United States. *Global Change Biology*, 27: 1–2.
- Izhaki I., Henig-Sever N., Ne'eman G. 2000. Soil seed banks in Mediterranean Aleppo pine forest: the effect of heat, cover and ash on seedling emergence. *Journal of Ecology*, 88: 667–975.
- Keeley J.E., Bond W.J. 1997. Convergent seed germination in South African fynbos and California chaparral. *Plant Ecology*, 133: 153–167.
- Keeley J.E., Fotheringham C.J. 1998. Smoke-induced seed germination in California chaparral. *Ecology*, 79: 2320–2336.
- Keeley J.E., Pfaff A.H., Safford H.D. 2005. Fire suppression impacts on postfire recovery of Sierra Nevada chaparral shrublands. *International Journal of Wildland Fire*, 14: 255–265.
- Light M.E., Gardner M.J., Jager A.K., Van Staden J. 2002. Dual regulation of seed germination by smoke solutions. *Plant*

- Growth Regulation*, 37: 135–141.
- Lloret F. 1998. Fire, canopy cover and seedling dynamics in Mediterranean shrubland of northeastern Spain. *Journal of Vegetation Science*, 9: 417–430.
- Lobon N.C., Gallego J.C.A., Diaz T.S., Garcia J.C.E. 2002. Allelopathic potential of *Cistus ladanifer* chemicals in response to variations of light and temperature. *Chemoecology*, 12: 139–145.
- Luna B., Chamorro D. 2016. Germination sensitivity to water stress of eight Cistaceae species from the Western Mediterranean. *Seed Science Research*, 26, 2: 101–110.
- Luna B., Piñas-Bonilla P., Zavala G., Pérez B. 2023. Timing of fire during summer determines seed germination in Mediterranean Cistaceae. *Fire Ecology*, 19: 52.
- Mc Dowell N.G., Allen C.D., Anderson-Teixeira K., Aukema B.H., Bond-Lamberty B., Chini L., Clark J.S., Dietze M., Grossiord C., Hanbury-Brown A. 2020. Pervasive Shifts in Forest Dynamics in a Changing World. *Science*, 368: eaaz9463.
- Nelson A.R., Narrowe A.B., Rhoades C.C., Fegel T.S., Daly R.A., Roth H.K., Chu R.K., Amundson K.K., Young R.B., Steindorff A.S., Mondo S.J., Grigoriev I.V., Salamov A., Borch T., Wilkins M.J. 2022. Wildfire-dependent changes in soil microbiome diversity and function. *Nature Microbiology*, 7: 1419–1430.
- Papavassiliou S., Arianoutsou M. 1993. Regeneration of the leguminous herbaceous vegetation following fire in a *Pinus halepensis* forest of Attica, Greece. [in:] L. Trabaud, R. Prodon (eds). *Fire in Mediterranean Ecosystems. Ecosystems Research Report n°5*, Commission of the European Communities: 19–125.
- Papavassiliou S., Arianoutsou M., Thanos C.A. 1994. Aspects of the reproductive biology of fire following species of leguminosae in a *Pinus Mepemis* Mill. Forest. [in:] D.X. Viegas (ed.) *Proc. 2nd International Conference of Forest Fire Research*. Portugal, Suppl. 24: 1–12.
- Pardini G., Gispert M., Dunjo G. 2004. Relative influence of wildfire on soil properties and erosion processes in different Mediterranean environments in NE Spain. *Science of the Total Environment*, 328: 237–246.
- Pausas J.G., Keeley J.E. 2014. Evolutionary ecology of resprouting and seeding in fire-prone ecosystems. *New Phytologist*, 204, 1: 55–65.
- Pausas J.G., Lamont B.B. 2022. Fire-released seed dormancy – A global synthesis. *Biological Reviews*, 97: 1612–1639.
- Pausas J.G., Llovet J., Rodrigo A., Vallejo V.R. 2008. Are wildfires a disaster in the Mediterranean basin? A review. *International Journal of Wildland Fire*, 17: 713–723.
- Quezel P., Medail F. 2003. *Ecologie et biogéographie des forêts du bassin méditerranéen*. Editions Elsevier, Paris.
- Ramiadantsoa T., Ratajczak Z., Turner M.G. 2023. Regeneration strategies and forest resilience to changing fire regimes: Insights from a Goldilocks model. *Ecology*, 104, 6: e4041.
- Rivas M., Reyes O., Casal M. 2006. Influence of heat and smoke treatments on the germination of six leguminous shrubby species. *International Journal of Wildland Fire*, 15: 73–80.
- Roy J., Sonié L. 1992. Germination and population dynamics of *Cistus* species in relation to fire. *Journal of Applied Ecology*, 29: 647–655.
- Seidl R., Thom D., Kautz M., Martin-Benito D., Peltoniemi M., Vacchiano G., Wild J., Ascoli D., Petr M., Honkaniemi J. 2017. Forest Disturbances under Climate Change. *Nature Climate Change*, 7: 395–402.
- Silva Dias L., Pires Pereira I., Soveral Dias A. 2019. Seed Germination in *Cistus ladanifer*: Heat Shock, Physical Dormancy, Soil Temperatures and Significance to Natural Regeneration. *Plants*, 8: 63.
- Simler-Williamson A.B., Metz M.R., Frangioso K.M., Rizzo D.M. 2021. Wildfire alters the disturbance impacts of an emerging forest disease via changes to host occurrence and demographic structure. *Journal of Ecology*, 109: 676–691.
- Stavi I. 2019. Wildfires in grasslands and shrublands: a review of impacts on vegetation, soil, hydrology and geomorphology. *Water*, 11: 1042.
- Stinca A., Ravo M., Marzaioli R., Marchese G., Cordella F.A., Rutigliano F.A., Esposito A. 2020. Changes in multi-level biodiversity and soil features in a burned beech forest in the southern Italian coastal mountain. *Forests*, 11: 983.
- Tangney R., Paroissien R., Le Breton T.D., Thomsen A., Doyle C.A.T., Ondik M., Miller R.G., Miller B.P., Ooi, M.K.J. 2022. Success of post-fire plant recovery strategies varies with shifting fire seasonality. *Communications Earth & Environment*, 3: 126.
- Tavşanoğlu Ç., Gürkan B., 2005. Post-fire dynamics of *Cistus* spp. in a *Pinus brutia* forest. *Turkish Journal of Botany*, 29: 337–343.
- Thanos C.A. 1999. Fire effects on forest vegetation, the case of Mediterranean pine forests in Greece. [in:] G. Eftichidis, P. Balabanis, A. Ghazi (Eds), *Wildfire Management*. Proceedings of the Advanced Study Course held in Marathon, Greece: 323–334.
- Thanos C.A., Georgiou K. 1988. Ecophysiology of fire-stimulated seed germination in *Cistus incanus* ssp. *creticus* (L.) Heywood and *C. salvifolius* L. *Plant Cell & Environment*, 11: 841–849.
- Thanos C.A., Georgiou K., Kadis C., Pantazi C. 1992. Cistaceae: a plant family with hard seeds. *Israel Journal of Botany*, 4: 251–263.
- Thomas P.B., Morris E.C., Auld T.D. 2003. Interactive effects of heat shock and smoke on germination of nine species forming soil seed banks within the Sydney region. *Austral Ecology*, 28: 674–683.
- Trabaud L., Martínez-Sánchez J.J., Ferrandis P., González-Ochoa A.I., Herranz J.M. 1997. Végétation épigée et banque de semences du sol: leur contribution à la stabilité cyclique des pinèdes mixtes de *Pinus halepensis* et *P. pinaster*. *Canadian Journal of Botany*, 75: 1012–1021.
- Trabaud L., Oustric J. 1989. Comparaison des stratégies de régénération après incendie chez deux espèces de ciste. *Revue d'Ecologie (Terre & Vie)*, 44: 3–13.
- XLSTAT. 2014. Copyright Addinsoft (XLSTAT Version 2014.5.03) and Addinsoft Registered Trademarks of Addinsoft. www.xlstat.com.