INVASION OF CORK OAK (*QUERCUS SUBER* L.) BY MARITIME PINE (*PINUS PINASTER* AIT.) IN NORTHEASTERN ALGERIA: PRELIMINARY RESULTS OF A FIRST APPROACH IN EXPLORATION OF INVOLVED FACTORS

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Abstract. Algerian cork oak forests undergo a continuous decline both in surface and in cork quantity and quality. Invasion by woody species constitutes one of the aspects of cork oak decline. Mainly Maritime pine is cited as invader species across cork oak northeastern area. In this study, an approach based on exploration of field factors including soil and vegetation through 9 phyto-ecological surveys followed by a laboratory assay on the allelopathic potential of Maritime pine using fresh needles, senescent needles and litter leachate were carried out in search of factors of the invasion. The soil sample analysis did not reveal any difference within the measured parameters except for organic matter which varied to some extent. The vegetation survey revealed the presence of 24 plant species belonging to 19 botanical families. Macerates of fresh needle and senescent needle and litter leachate of maritime pine had no significant effect on the germination of cork oak. Invasion by Maritime pine in the studied site was evidenced. The Correspondence factor analysis combined with ascending hierarchical classification and field observation highlight two gradients of cork oak forest evolution: gradual evolution and degradation evolution marked by a strong invasion by Maritime pine. Sustainable management practices in favor of cork oak are needed to restore this degraded site.
Keywords: *floristic surveys, allelopathy, germination, evolution gradient, degradation gradient*

Introduction

The flora and vegetation of any area are influenced by natural factors related to its geographic location (Geology, topography, soils, water conditions and fauna) as well as current and historical anthropogenic factors (Jackowiak, 2023). In the southern Mediterranean region, particularly in North Africa, the combination of these factors along with climate change has largely disturbed the main forest ecosystems, which are experiencing a continuous decline in their areas, biodiversity and productivity (M'Hirit, 1999; FAO, 2018). The forest understory structures have witnessed a decrease in their characteristic sylvatic species and the matorralization of most of the forests can be observed by the replacement of typical forest groups by preforest groups, such as *Tetraclinis* forests and Aleppo pine forests (Barbero et al., 1990). According to the same authors, the extension of coniferous forests (expansion model) is favored by their spatial, biological and ecological selection abilities and at the same time, the under-utilization of sclerophyllous oak coppice (resistance model) and hardwood coppice (stabilization model) has led to new forest structures and architectures that differ significantly from the main climatic groups defined to date through phytosociological and synchronic approaches.

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Tree invasions have escalated in importance in the last few decades (more species, greater area invaded, more types of impacts, increasing complexity of management challenges), and are increasingly studied from many perspectives (Richardson et al., 2014). Many woody plants have been recently recognized as major invasive species with serious impacts on species diversity and functioning of invaded ecosystems (Pyšek et al., 2014). In this context, Bourmérias (2015) reported that the invasive potential of conifers, especially pines, is particularly pronounced in temperate zones where vast areas of hardwood species have been conquered by coniferous species after the destruction of the primitive forest by man. According to the same author, in a large part of Mediterranean France, on the "ruins" of the oak grove, a *cistus* garrigue has taken place, followed by the paraclimatic Aleppo pine forest. In the Gascony moors, the western cork oak has been replaced by maritime pine, while the luxurious Chinese Virginia forest has been replaced by monotonous *Pinus taeda* pinewood. Oak-pine forest mixtures are often considered as transient stages in ecological succession, assuming that pines may facilitate the establishment of late-successional species like oaks (Pausas et al., 2004). Accordingly, combined pine and oak plantations are proposed for degraded land restoration on the basis of the complementary features of both groups of species (e.g. *Pinus halepensi*s - *Quercus ilex* and *Pinus pinea* - *Quercus suber*).

Research on invasive species has recently increased considerably, enabling the assessment of general trends in tree invasion and the formulation of several hypotheses on determinants of invasion success (Higgins and Richardson, 1998) and on means and mechanisms facilitating and accompanying the invasion phenomenon (Lamarque et al., 2011). Despite the complexity of invasions, there has been substantial progress in understanding patterns and processes, but the mechanism of invasion and of ecosystem disruption remains unclear (Richardson et al.2014; Wainright et al., 2021). Natural invasions by gymnospermous species are rarely assessed correctly, regardless of the triggering factor (Quézel, 1990). Only a few invasive trees have been well studied, many of them in only a small part of their invasive range (Richardson et al., 2014). In general, environmental factors that prevent or facilitate invasion are predictable, but other factors may be present that ultimately determine the success or failure of Pinaceae invasion, such as biotic interactions (Nunez et al., 2017). Among the biotic process involved in plant-plant interactions controlling plant community organization and dynamic (Callaway and Walker, 1997) and local distributions of plant species around the world (Hierro and Callaway, 2021), a strong attention has been paid during the last decades to allelopathy (Santonja et al., 2019) as a key phytochemical process in plant diversity and dynamic particularly in Mediterranean ecosystem (Inderjit et al., 2011; Fernandez et al., 2013; Hashoum et al., 2017). Allelopathy is one of the mechanisms that help to explain the invasion success of some plant species (Nazum Uddin et al., 2017). Allelopathy plays an important role in many aspects of plant invasions including plant invasiveness, resistance to invasive plant of native community and control of invasive plants (Chen et al., 2017).

Several genera of gymnospermous trees have shown proven allelopathic effects on other plants, either though *in vitro* assays, or *in situ* community studies (Teixeira Da Silva et al., 2015). The Allelopathic effects of gymnosperms have been mostly attributed to the leachable extracts of needles, bark and litter that have fallen to the ground (Cimmino et al., 2014). In most of the case studies, the leaching of phenolics from the litter predominantly of tree needles, which remain on the ground for a longer time due to slow decomposition rate, are held responsible for the allelopathic effect exerted by gymnosperms species (Singh et al., 1999). Among Mediterranean gymnosperous trees,

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the phytotoxic and allelopathic effects of Aleppo pine (*Pinus halepensis* Miller) were the most widely studied from diverse plant organs including fresh, senesced, and decaying needles and roots that produce a wide range of secondary metabolites (Fernandez et al., 2013), which have been reported to exert potent negative allelopathic effects on seed germination and growth of several herbaceous target species including *Festuca arundinacea* Schreb, *Cynodon dactylon* (L.) Pers, *Avena sativa* L. and *Lemna minor* (Nektarios et al., 2005), *Stipa tenacissima* (Navarro-Cano et al., 2010), *Lactuca sativa* and *Linum strictum* (Santonja et al., 2019) and even on plants species of the forest canopy layer (Fernandez et al., 2013).

Maritime pine (*Pinus pinaster* Ait.) is an evergreen gymnospermous tree species belonging to *Pinaceae*. It is a plastic species characterized by its fast growth, calcifuge, shade intolerance and being rustic (Rameau et al., 1989; Guingnabert, 2018) and well resistance to disturbances (Tassin et al., 2007). This species possesses characteristics that ensure to its organs a good resistance against fire (Rigolot and Fernandez, 2005). Moreover, the specie's prolific seed production, wind-dispersed seed, and rapid growth rate, support the qualification of the species as an aggressive colonizer in some of the countries where it was introduced (CABI, 2021), thereby it has been listed among the 5 most invasive pines in the world (Rejmánek and Randall, 1994). Though, invasion of cork oak by maritime pine is one of the most easily observed invasions in Northeastern Algeria, it remains not sufficiently documented. A part of the cartographic work of Meliani et al. (2020), there are no other studies on the real causes of this phenomenon that illustrate one aspect of the degradation of cork oak forest. In this study, allelopathic laboratory experiment and field survey were carried out to explore the potential causes of invasion of cork oak area by maritime pine across a site where the phenomenon is clearly represented. We believe that this first approach will help us to enhance our knowledge on the phenomenon and to suggest appropriate management measures to restore invaded sites and to conserve cork oak habitat.

Materials and methods

The methodology includes ex-situ and in-situ studies. The ex-situ study consists on a laboratory bioassay to assess the Allelopathic potential of maritime pine on the germination of cork oak. The in-situ study consists on the prospection of field's factors including soil and vegetation that could help to explain the invasion of cork oak by maritime pine.

Study site description

The study was carried out in a site located 14 km west of Jijel in Northeastern Algeria (*Fig. 1*). The site belongs to the Kissir forest. It is bordered on the south by the Guerrouch forest, on the north by the Mediterranean Sea, on the west by the municipality of El-Aouana and on the east by the municipality of Jijel. The site was chosen for the high landscape attraction of the invasion of cork oak by maritime pine and the presence of different degrees of invasion (*Fig. 2*).

The analyze of the climatic data of the period 1994-2014 (ONM, 2015), shows that the study site climate is Mediterranean with an average annual rainfall of 934.41 mm and an average annual temperature of 17.83°C recorded for the period 1994-2014 (ONM, 2015). Dominant winds occur every month of the year, with varying frequency and speed, and

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are generally northwesterly, especially during winter. However, there are a few Sirocco days, which occur irregularly on average 11 days a year during the summer (ONM, 2015).

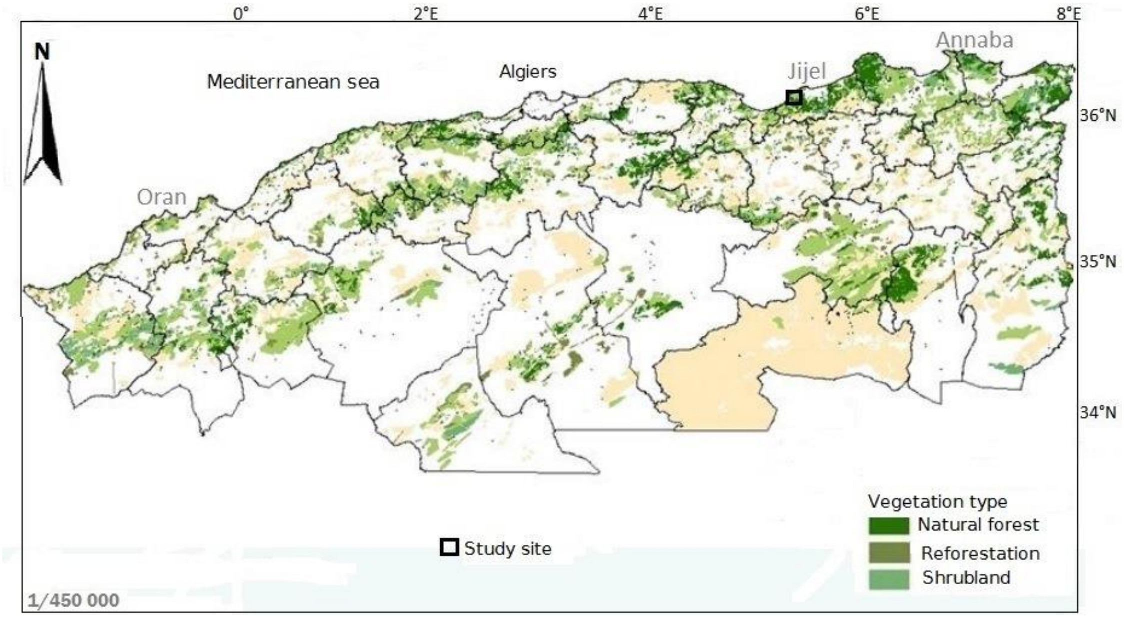

Figure 1. *Location of the studied site. (Map generated from the forest distribution map in Algeria (DGF, 2018))*

Figure 2. *The invasion of Cork oak by Maritime pine in the studied site*

In terms of geology, the lithostratigraphic units forming the Wadi de Kissir site are represented by Numidian flysch substratum, Oligo-Miocene-Kabyle and Quaternary sediments (Andrieux and Djellit, 1989).

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Field study

Floristic surveys

The method used in this study is the phyto-ecological survey, based on an inventory of floristic and ecological data. After a field prospection, we identified 3 transects in the three directions North (N), East (E) and West (W); the South slope being inaccessible. In each transect, 3 phyto-ecological surveys (*Table 1*) combining topographic, pedologic, floristic and historic data (e.g. fires, clearings) were carried out at subjectively selected points (Gillet, 2000; Bouxin, 2008) representing different degree of invasion: areas dominated exclusively by cork oak (uninvaded), areas partially invaded by maritime pine and areas where maritime pine dominates cork oak. At each survey point, vegetation and field data were collected in a circular plot of 10 m diameter corresponding to an area of 78.50 m^2 matching with the suitable area recommended for the study of the Mediterranean matorral vegetation type (Benabid, 1984). For each survey, the general characteristics of the site, including slope, exposure, morphology, soil and vegetation cover (in %) were noted. Species encountered in each survey were identified using the flora of Quézel and Santa (1963) and assigned with an abundance-dominance coefficient of the Braun-Blanquet ordinal scale of 1 to 5. To characterize the regeneration of cork oak, the number of seedlings present in each plot was also recorded. The field surveys were carried out during the period of April-May 2016.

Table 1. *Geographic location of the surveys (coordinate system UTM-WGS 84)*

Survey	Geographical coordinates			Exposure
	Longitude (decimal)	Latitude (decimal)	Altitude (m)	
S1	5.6705°	36.7929°	62	East
S2	5.6711°	36.7929°	33	East
S3	5.6715°	36.7930°	24	East
S4	5.6734°	36.7900°	86	North
S5	5.6730°	36.7902°	56	North
S6	5.6727°	36.7911°	33	North
S7	5.6739°	36.7918°	42	West
S8	5.6737°	36.7918°	57	West
S9	5.6735°	36.7918°	33	West

UTM: Universal Transverse Mercator; WGS: World Geodetic System; S: survey; m: meter

Floristic data analysis

Among the ordination techniques used for the analogical comparison of floristic surveys, we have chosen the factorial correspondence analysis (FCA). The results of the FCA analysis were then confirmed by an ascending hierarchical classification (AHC). In fact, according to Kent and Ballard (1988), the simultaneous use of ordination (FCA) and classification (AHC) methods could enhance the assessment of environmental factors associated with vegetation type observed. The analyses were made using “PC

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ORD version 4" software, which is specially designed to perform multivariate analyses of ecological data (Mc Cune and Mefford, 1999).

Study of soil characteristics

To investigate edaphic parameters that could help to explain the phenomenon of invasion, the 09 floristic surveys were accompanied by soil sampling at the center of each circular sample plot. Soil samples were taken at 20 cm depth using a soil auger. After sampling, soil samples were placed in sealed plastic bags and transported to the laboratory, where they were sieved at 2 mm to remove undesirable matter (debris, roots, earthworms, etc.). Standard soil analyses (texture, pH, electrical conductivity and organic matter) were carried out at the INRF's central laboratory of Bainem according to the analytical protocols described by Aubert (1978).

Laboratory experiment: allelopathic potential of maritime pine

Allelopathic substances are released to the environment through four ecological processes: volatilization, leaching, root exudate and decomposition of plant material (Rice, 1984; Thompson, 1985). Coniferous show an allelopathic potential that is mainly due to phenolic compounds in needle litter on the soil (Maimoona et al., 2011) and as most compounds involved in allelopathic interactions are water-soluble (Rice, 1984), we investigated the allelopathic effect of maritime pine needles on cork oak acorns through litter leachate and needle macerate. Two solutions were thus prepared: leachate from the holorganic soil layer and macerate from fresh and senescent maritime pine needles.

Preparation of the solutions

Litter leachate

To prepare litter leachates, a sampling layer of litter was gently removed by hand shovel at 20 cm depth. The litter layer was then placed in a perforated tray and watered with 1 L of rainwater collected on rainy days of the year. The water precipitated after 24 h of leaching through the soil layer was filtered and stored in a closed bottle then kept in refrigerator for the germination test.

Needle macerate

Maceration involves placing a plant or part of a plant in cold water (aqueous maceration) or vegetable oil (oily maceration) for several hours, or even days, to allow the active constituents to diffuse properly (Kraft and Hobbs, 2004). Needles are always extracted in non-calcareous, non-chlorinated rainwater (Bernard et al., 2012). For this experiment, two different types of macerates were prepared:

1. Fresh needle macerate (FM) cut immediately after harvest and soaked in rainwater for 5 days.
2. Senescent needle macerate (SM) obtained by oven-drying fresh needles at 45°C for 72 h then soaking them in rainwater for 24 h as described by Bulut and Demir (2007).

Macerates were prepared at ambient laboratory temperature (20-24°C) with increasing concentrations of 10, 20, 30, 40 and 50%. The extracts obtained were filtered and then placed in the refrigerator for the germination test.

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Germination test

The germination test was conducted in the laboratory of the Jijel regional forestry research station using cork oak acorns harvested from trees growing wild in the study site. To assess the effect of leaching and maritime pine needle macerates on the germination of cork oak acorns, 10 apparently undamaged acorns were sown horizontally in glass boxes half-filled with wadi sand previously sterilized at 200°C for 2 h to avoid any sort of contamination (Merouani et al., 2005). The boxes were then generously moistened with one of four solutions: litter leachate, fresh needle macerate, senescent needle macerate and rainwater as a control. The experiment was laid out in completely randomized design with three replications and thus consisted on a total of 360 acorns. Treatments were then incubated at 20°C (Merouani et al., 2001) for 30 days during which the boxes were regularly moistened with an equal volume of the corresponding solutions (Fernandez et al., 2006).

Sampling and measurement

To evaluate the Allelopathic potential of maritime pine on the germination of cork oak, germination percentage and percentage inhibition of germination were calculated at the end of the experiment. Germination percentages were calculated on the 30th day as the ratio between the number of acorn germinated and the total of acorns used in each treatment (moistening solution), whereas percentage inhibition of germination was calculated at the end of the germination period using *Equation 1*:

$$I.G\ (\%) = ((G-g)/G) \times 100 \qquad \text{(Eq.1)}$$

where G represents the percentage of germination in distilled water and g represents the percentage of germination in the moistening solution.

Analysis of germination data

Germination data from allelopathic bioassay were subjected to a one-way ANOVA. To ensure normality and homogeneity, percentages values were arcsine-transformed prior analysis. Post-hoc Newman-Keuls test was used to explore differences between means at 95% significant level. Analyses were performed with XLSTAT software package.

Results

Soil characteristics

The results of the physical and chemical characterization of soil samples representing the 9 floristic surveys are summarized in *Table 2*.

Table 2. *Results of the physical and chemical characterization of the soil samples*

Parameter	Soil sample								
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**
Texture	LS	LS	LS	LS	LS	LS	LS	LS	LS
pH	6.30	6.20	6.20	6.50	6.30	6.00	6.50	6.50	6.50
Conductivity (mS/cm)	0.80	0.80	0.70	0.70	0.70	0.80	0.80	0.70	0.70
Organic matter (%)	12.63	8.42	9.05	2.73	4.31	4.42	4.21	4.73	3.47

L: Loam; S: Sand; S1 to S9: soil samples representing the nine field surveys respectively

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pH values ranged from 6 to 6.5, indicating a slight acidity according to the scale of Baize (2000), whereas the electrical conductivity values ranged from 0.7 for the surveys S3, S4, S5, S8 and S9 to 0.8 for the surveys S1, S2, S6 and S7, reflecting a slight salinity according to Aubert (1978). The Schaffer's (1975) scale for interpreting organic matter content assigns soil samples from surveys S1, S2 and S3 to the class of very rich soils in organic matter, whereas soil samples from surveys S4, S5, S6, S7, S8, and S9 belong to the class of rich soils in organic matter.

Floristic surveys

The 9 surveys carried out at the study site revealed the presence of 24 plant species, representing 18 belonging to 19 botanical families (*Table 3*).

Table 3. *Results of the floristic surveys. Plant taxa were listed according to their presence in each floristic survey without any order. All plant taxa encountered are shown here*

Surveys		S1	S2	S3	S4	S5	S6	S7	S8	S9
Exposure		E	E	E	N	N	N	W	W	W
Altitude (m)		86	33	24	86	56	80	24	45	22
Elements of the ground surface, other observations		Rocky outcrops	-	-	Traces of fire	Traces of fire	-	Rocky outcrops, traces of fire	Rocky outcrops	Rocky outcrops
Species	Code	Abundance-dominance coefficient								
Quercus suber	Q. su	5	3	2	5	4	5	5	2	1
Pinus pinaster	P. pi	5	3	2	2	5	5	1	5	5
Erica arborea	E. ar	3	2	3	2	3	3	2	1	+
Phillyrea angustifolia	P. an	+	+	+	2	.	1	1	+	.
Arbutus unedo	A. un	1	1	.	.	+	+	+	.	.
Ampelodesmos mauritanicus	A. ma	1	1	+	+	+	+	+	+	+
Smilax aspera	S. as	+	+	+	+	+	.	+	+	+
Calycotome spinosa	C. sp	+	.	.	.	.	.	.	.	+
Pistacia lentiscus	P. le	+	.	+	+	.	.	.	.	+
Viburnum tinus	V. ti	.	+	+	+	1	.	+	+	+
Cytisus triflorus	C. tr	.	+	+	.	.	.	+	.	.
Daphne gnidium	D. gn	.	+	.	+	.	.	.	.	.
Cistus salviifolius	C. sa	.	+	+	.	.	.	.	.	.
Genista numidica	G. nu	.	+	.	2	.	.	.	.	+
Genista tricuspidata	G. tr	.	.	+	.	.	.	.	.	.
Lonicera implexa	L. im	.	.	+	.	.	.	+	.	.
Asparagus acutifolious	A. ac	.	.	.	+	.	.	.	.	+
Chamaerops humilis	C. hu	.	.	.	+	.	.	+	.	.
Myrtus communis	M. co	.	.	.	+	.	.	+	1	+
Prunus avium	P. av	.	.	.	.	+	.	+	.	.
Laurus nobilis	L. no	.	.	.	.	.	.	+	+	.
Salix pedicellata	S. pe	.	.	.	.	.	.	.	.	.
Rubus ulmifolius	R. ul	.	.	.	.	.	.	.	.	+
Inula viscosa	I. vi	.	.	.	.	.	.	.	.	+

Among the quoted families, the Fabaceae family was the most represented with 4 species (*Calycotome spinosa*, *Cytisus triflorus*, *Genista tricuspidata* and *Genista numidica*) followed by the Rosaceae and Ericaceae families with 2 species (*Prunus avium* and *Rubus ulmifolius*) and (*Erica arborea* and *Arbutus unedo*), respectively. The other families were represented by only 1 species.

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The eigenvalues of the first three axes (*Table 4*) indicate that the CFA representation is sufficient to analyze the relationships between surveys, species and ecological variables of the studied site.

Table 4. *Eigenvalues of the first three factorial axes*

Axes	Eigenvalues
1	0.18
2	0.14
3	0.12

The examination of the graphical representation of the first factorial plan of species (*Fig. 3*), plan of surveys (*Fig. 4*) and the CAH (*Fig. 5*) have allowed extracting two survey groups.

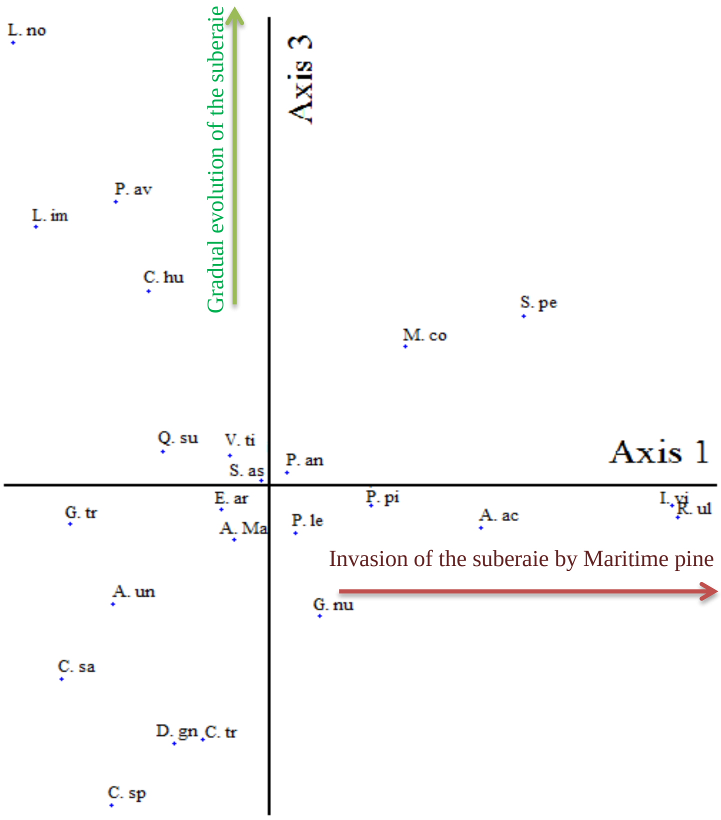

Figure 3. *Factorial plan of the species (Axis 1-3). The full names of the species shown here by codes are given in Table 2*

Group 1: Consisting of 3 surveys (S6, S8 and S9), grouped in the positive quadrant of axis 1 and all showing more or less degraded structures. This group is dominated by maritime pine, which is well adapted to poor and acid soil. It is mainly composed of *Pinus pinaster*, *Rubus ulmifolius*, *Inula viscosa*, *Asparagus acutifolius*, *Salix pedicellata*, *Myrtus communis*, *Genista numidica*, *Pistacia lentiscus* and *Phillyrea angustifolia.*

Group 2: Consisting of 6 surveys (S1, S2, S3, S4, S5 and S7) forming a spread-out cloud stretching in a parallel direction to axis 3. This group is dominated by species

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characteristic of relatively developed areas including *Quercus suber*, *Erica arborea*, *Viburnum tinus*, *Ampelodesmos mauritanicus*, *Calycotome spinosa*, *Chamaerops humilis*, *Daphne gnidium*, *Smilax aspera*, *Cytisus triflorus*, *Prunus avium*, *Arbutus unedo*, *Cistus salviifolius*, *Genista tricuspidata*, *Lonecera implexa* and *Laurus nobilis*.

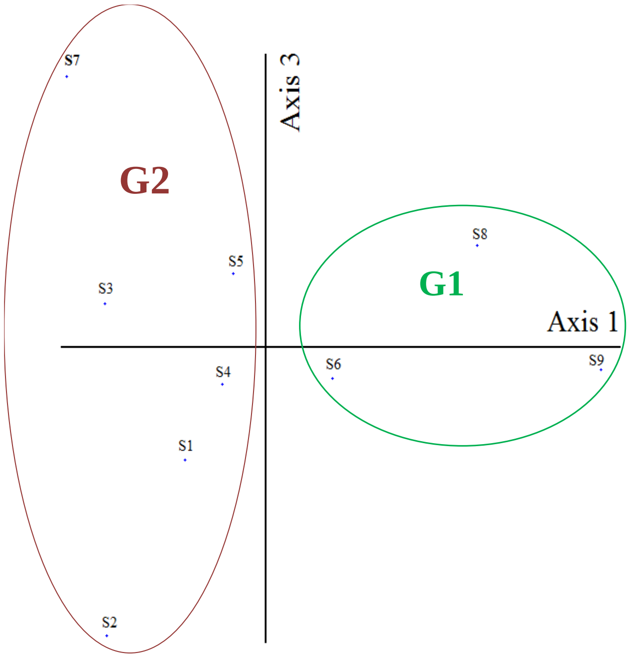

Figure 4. *Factorial plan of the surveys (Axis 1-3). S: survey; G1: group 1; G2: group 2*

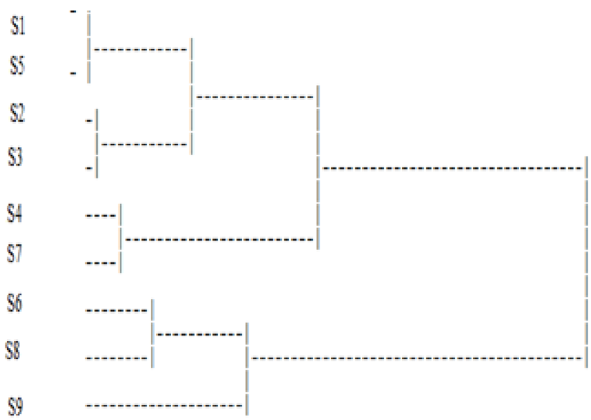

Figure 5. *Dendrogram of the global analysis. S: surveys*

Allelopathic potential of maritime pine

The results of the ANOVA applied on data related to germination percentage showed that the effect of moistening solutions on final germination percentage was non-significant at the probability level of 5% (P = 0.283). Our results confirm the absence of an inhibitory effect of maritime pine on the germination of cork oak acorns. In fact, as shown in *Figures 6*, *7* and *8*, the curves representing the different macerate have approximately the same shape. Although acorns irrigated with fresh needle macerate prepared at 10% concentration showed faster germination during the first week of sowing, germination of acorns irrigated with fresh and senescent needle macerate followed the same kinetics regardless of solution concentration. The majority of acorns have germinated after 21 with rates exceeding 90%. In contrast, acorns moistened with distilled water (control) and leachate showed less germination than acorns moistened with the other solutions. The germination curves for both the control and the leachate take a straight line from day 21 and stabilize until the end of the test at an average of 86.6%.

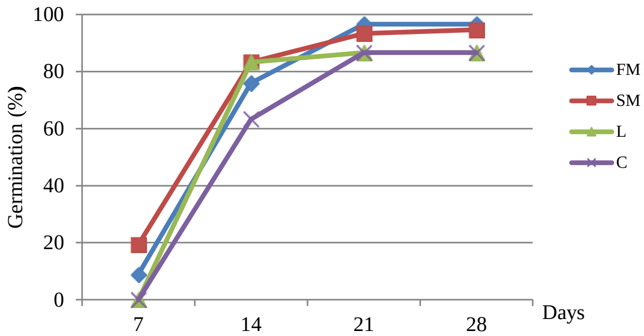

Figure 6. *Effect of needle macerate and litter leachate on the germination of cork oak acorns. FM: Fresh needle macerate; SM: Senescent needle macerate; L: Litter leachate; C: Control*

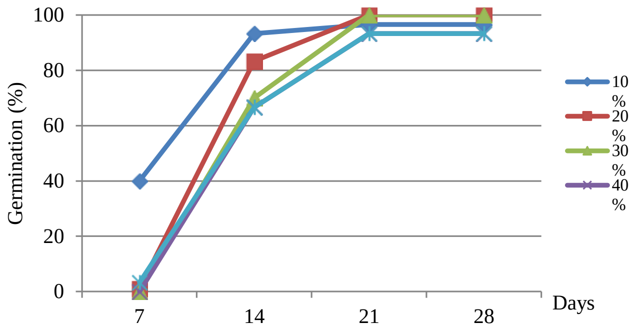

Figure 7. *Effect of fresh needle macerate of different concentrations on the germination of cork oak acorns. Percentage values from 10% to 50% represents graded concentrations of macerates prepared by diluting mother macerate*

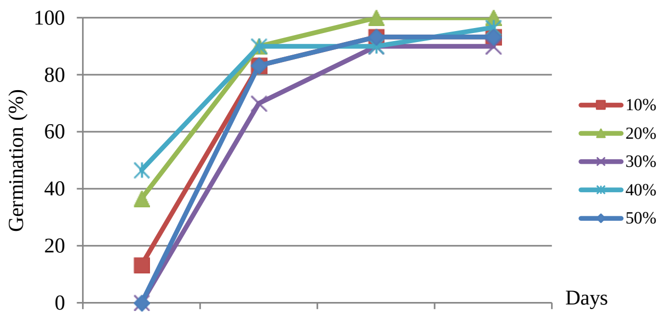

Figure 8. *Effect of senescent needle macerate of different concentrations on germination of cork oak acorns. Percentage values from 10% to 50% represents graded concentrations of macerates prepared by diluting mother macerate*

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Discussion

The present work was carried out in search of factors that may help to understand the phenomenon of the invasion of cork oak by maritime pine, which has been observed across the Algerian cork oak area. The approach adopted in this study was based on the in-situ study of some ecological factors at a site where the three different stages of invasion are represented (land dominated exclusively by cork oak (not invaded), land partially invaded by maritime pine and land where maritime pine dominates cork oak), followed by ex-situ experiment to study the allopathic potential of fresh, senescent and decaying needles (litter) on the germination of cork oak acorns.

Allelopathic potential of maritime pine

Overall, the results obtained from the allelopathic experiment showed that the three prepared solutions (fresh needle macerate, senescent needle macerate and litter leachate) had no significant effect on the germination of cork oak acorns. With a germination percentage of 86.6%, the leachate from litter extracted under maritime pine seems to have a slight inhibition on the germination of cork oak acorns compared to fresh needle macerate (96.6%) and senescent needle macerate (94.6%), but the difference was not significant in all. Litter contains considerable quantities of water-soluble substances, which are more or less easily leached out, depending on the type of litter (Navarro-Cano et al., 2010). Moreover, since allelochemicals must accumulate in sufficient quantities to have any effect (Gama et al., 2006), it is interesting to note here that a portion of the substances released on and by the litter is subject to erosion and leaching, due to the slope of the study site. In contrast, at the intra macerate level, the statistical results revealed that acorn germination was concentration dependent for fresh needles extract. The germination percentages of the acorns threated by fresh needle macerate of the concentrations 10, 20 and 30% were higher than that of the acorns threated by macerates of concentrations of 40 and 50%. These findings corroborate those of Batish et al. (2002), Turk and Tawaha (2003), Arslan et al. (2005), Nandal and Dhillon (2005), Uremis et al. (2005), who reported that the inhibitory effect increases with increasing extract concentration. The inconsistency of our findings with those obtained with other species of the same genus seems to be due to differences in the chemical composition of the prepared extracts and the degree of sensitivity of the target species, besides the method of preparation of the extracts that could significantly affected the concentration of allelochemicals (Nektarios et al., 2005).

Field factors and vegetation

The physico-chemical analyses carried out on the soil samples representing the 9 vegetation surveys showed no overall variability in texture, pH and salinity parameters among the three studied sites, organic matter reflects, however, certain variability. The soil where cork oak dominates maritime pine was more rich in organic matter (OM = 12.63%) than the soil where cork oak was replaced by maritime pine (OM = 4.21 to 4.73%). Soil organic matter depletion under *Pinus pinaster* canopies results from the slow decomposition of the needles compared with the faster decomposition of cork oak leaves. Moreover, our result agrees with Izhaki et al. (2000) who stated that Mediterranean pine forests tend to accumulate thick layers of needles under their canopy. Coniferous trees often produce moder and mor type humus, the development of which then leads to the evolution of the acid brown soils of the initial

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deciduous forest to soils that are more or less podzolic (Bonneau, 1985). On the other hand, although it allows the subjacent soil to maintain a moisture level suitable for seed germination, the thick litter under the maritime pine, constitutes, on the other hand, a physical barrier preventing acorns to reach the soil more favorable to germination and eventual seedling survival.

Vegetation description through analysis of the raw matrix consisting of 9 surveys and 24 species, using factorial correspondence analysis (FCA) followed by hierarchical ascending classification (HAC), revealed two distinct groups: one dominated by *Pinus pinaster* and the other by *Quercus suber*. The projection of surveys and species along axes 1 and 3 correspondingly revealed two ecological gradients; a gradient of gradual evolution of the cork oak forest and a gradient of degradation of the cork oak forest. The positive part of factorial axis 1 groups the data from cluster I from the study site's western exposure, and the negative part of axis 1 groups the data from the study site's eastern and northern exposures. Species with a high relative contribution on the positive side of axis 1 are the main species of the classic floristic procession of cork oak. This axis clearly showed a significant decline in the density of cork oak trees and by the total absence of cork oak seedlings, the presence of phanerophytes such *Myrtus communis*, *Pistacia lentiscus* and *Phillyrea angustifolia*, indicating fresh and pre-forest ambiance and characterizing the *Pinus pinaste*r forest vegetation. In fact, the clear foliage of the maritime pine allows the development of understory layer. An abundance of maritime pine in the western part of the site is clearly discernible from other exposures. The presence of maritime pine may be due to an old plantation in the east of the study site, which, due to a lack of appropriate silvicultural management, has contributed to the colonization of this slope by this species considered as invasive (Lowe et al., 2000) and recognized as one of the taxa characteristic of the expansionist model of the Mediterranean forest (Barbero and Quézel, 1989; Barbero et al., 1990).

The middle part of the axis 1 is occupied mainly by Ericaceae reacting vigorously by developing a dense and impenetrable shrub stratum resulting in an unbalanced cork oak ecosystem, which limits the regeneration of this heliophilous species. In fact, high scrubland of *Arbutus unedo* and *Erica arobrea* constitutes the first stage of degradation of the acidophilous oak-dominated woodland (Zanndouche, 2011).

As regards species with a high relative contribution on the negative side of axis1, these are species characteristic of the cork oak forest vegetation. Field observation of the vegetation shows that the existing cork oak trees are well established, with no signs of dieback and with the presence of some cork oak seedlings. *Pinus pinaster* appears rarely in this side of the axis 1. Thus, the axis 1 represents a gradient of degradation of the cork oak forest increasing in the direction of the axis, favoring invasion by maritime pine.

Axis 3 reveals two groups of species. The first group, on the positive side of axis 3, corresponds to surveys where the vegetation is more developed and physiognomically denser, with little appearance of maritime pine. The surveys show species typical of dense, less sunny forests, little disturbed by fire and colonizing soils of varying richness. In the shrub stratum cohabits ombrophilous species that colonize more advanced soils such as: *Prunus avium, Laurus nobilis, Viburnum tinus, Lonecera implexa* and *Myrtus communis*. The second group, on the negative side of axis 3, includes heliophilous species indicators of open habitats, such as *Erica arborea, Genista tricuspidata, Ampelodesmos mauritanicus, Calycotome spinosa, Genista numidica* and *Cistus salviaefolius,* characteristic of pre-forest environments, exposed to

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strong sunlight, frequently exposed to fire and adapted to poor soils. Thus, the axis 3 reveals a gradient of gradual evolution of the suberaie, increasing in the direction of the axis.

The study area shows an average decline of the suberaie, which is in line with Axis 1. For instance, the grass *Ampelodesmos mauritanicus* which was present in all the floristic surveys of the two groups, clearly indicate the disturbance of the suberaie by fire (Ouelmouhoub and Benhouhou, 2007). Other species, even if they are of little appearance in the surveys, show some degree of disturbance, such as *Cistus salviifolius* Belonging to *Cistaceae* recognized as pioneer species of degraded areas (Robles, 1998).

Conclusion

Overall, our results revealed the state of degradation of cork oak in the studied site that require an urgent restoration program in favor of this important species of the Mediterranean forest. The measures that to be integrated within a sustainable management plan should include, among others, removal of maritime pine before trees reached reproduction stage and silvicultural operations in order to favor the natural regeneration of the species. More in deep research including dendroecological, mapping and climatic studies is needed to a better understanding of the cover change and dynamic replacement between cork oak and maritime pine across invaded sites.

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