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Diversity of bark beetles (Curculionidae: Scolytinae) and their attack strategy in a natural forest of semi-arid region (Djelfa- Algeria)

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Abstract: The Aleppo pine woods in the Algerian Saharan Atlas semi-arid zone are one of the remaining woodlands and constitute the last combat desertification. The Senalba Chergui pine forests of the Djelfa region are among the last relics that fight desertification. The forests have declined recently due to climatic, anthropogenic, and biotic factors such as wood-boring insects. Their socio-economic importance necessitates reducing biotic hazards resulting from bark beetle outbreaks to reduce the vulnerability of stands exposed to these disturbances. Based on dendrometric parameters (trunk diameter, bark thickness and tree height) and variations in environmental factors (altitude and slope), six decayed trees were selected on the north and south slopes at different altitudes. Each tree was cut into 4 trunks measuring 1 meter according to the height of the tree, i.e. a total of 24 samples (trunks). The PCA analysis revealed that hillside and tree morphology are determining factors in the selection of bark beetles. In contrast, altitude did not show a significant effect on bark beetle behaviour, while tree height itself had a negative effect on attack density and vice versa.

Keywords: Decline**,** Natural forest, Senalba Chergui, Slope, Inventory**,** Curculionidae, Scolytinae

Introduction

Expansion of the human population and economy are among the main factors that enhance forest deterioration. Forest dieback, defined as the gradual deterioration of the trees'health and causes above normal mortality levels, has been documented as the main cause of global forests' deterioration. It is a very complex phenomenon affecting most of the world's forests. Tree dieback is caused by a combination of interacting and sequential factors, leading to a gradual deterioration of forests' appearance and growth and accelerating tree death (Manion 1981). Several abiotic factors and biotic agents interact to weaken and decline forest trees and determine the rate and degree of forest dieback. Such factors make forest dieback a poorly understood process that is often difficult to predict (Sala et *al.* 2010).

Natural abiotic factors, such as drought and heat-related associated with climatic changes, are among the important abiotic factors accelerating forest dieback, especially in the semi-arid zones (MacGregor & O'Connor 2002). The increase in tree mortality is associated with climate-induced physiological stress, insect outbreaks, and wildfire (Allen et *al*. 2010). Trees in the forests

in semi-arid regions are at the drier edges of their distribution range. Usually, they display a substantial decline in growth or increase in mortality in response to prolonged, repeated droughts and heatwaves (Allen 2009). Drought is the main cause associated with forest tree mortality, especially near the end of their geographic or elevational margins (Jump et *al*. 2006).

The Mediterranean basin is more vulnerable to global climate change, especially in the northern part of Africa (Giorgi & Lionello 2008). The semi-arid climate of this region, which is characterized by heat waves, summer drought episodes, and storms, enhances parasitism and the outbreak of various kinds of pests, hastening forest dieback and mortality (Gil Pelegrín et *al*. 2008, Lindner et *al*. 2010). In the semi-arid zone of the Algerian Saharan Atlas, the Aleppo pine woods are one of the main remaining natural woodlands and constitute the last natural barrier against desert advancement. Besides, the Aleppo pine is among the extremely biological and ecological diversity rich. However, the Aleppo pine forests in several sites, e.g., Senalba Chergui, Senalba Gharbi, and Sehary Guebli located respectively 4km West, 25km South West and 20 km North Est Djelfa city, are most threatened by decline and attack from various insect species (Deroueche 2015). Defining the potential pests of the sub-cortical xylophage insects that would cause damage to the Aleppo pine woods is imperative. The present study aims at assessing the impacts of tree's dendrometric parameters (i.e., trunk diameter, bark thickness, and tree height) and the environmental factors of the stands (e.g., slope aspect and elevation) on bark beetles' diversity and abundance. The study will assess attack strategies of the beetles.

Firstly, the dynamics of bark beetle establishment were studied at the host level (tree-insect relationship), by studying tree parameters as factors conditioning their distributions and abundances, in relation to stationary factors and their influences on the choice of the insect and its attack density. Secondly, a complementary climatic study was carried out over a period of three decades (from 1989 to 2019), characterising the alternation of drought periods in relation to the intensity of attacks by these pests. Temperature is a restricting factor in the activity of bark beetles, as the swarming flight that allows them to colonise new trees takes place at specific temperatures (Chararas 1962). The disturbed climatic conditions, in particular irregular precipitation with low winter quantities, and very high summer temperatures with heat waves, enlarge the surfaces actually destroyed by the phenomenon of dieback, and relatively increase the volume of wood exploited in the framework of incineration to fight the bark beetles.

Material and methods

Study area

This study was carried out in the pine forests of the massif of Senalba Chergui (Fig. 1), located about 300 km south of Algiers (between 36º36' and 36º42' N; 3º00' and 3º12' E). It is the main chain of the Saharan Atlas, lying on a hilly landscape southwest of the city of Djelfa. These natural woodlands are a protective bulwark against the desert; they cover an area of 20.000 ha spread over 12 series. The vegetation is composed of native trees dominated by the Aleppo pine (*Pinus halepensis* Mill.) associated with holm oak (*Quercus ilex* L.) and junipers (*Juniperus oxycedrus* L. and *Juniperus phoenicea* L.). The study area is physiographically and physiognomically heterogeneous. The parent rock is brown calcareous with a limestone crust (Pouget 1980).

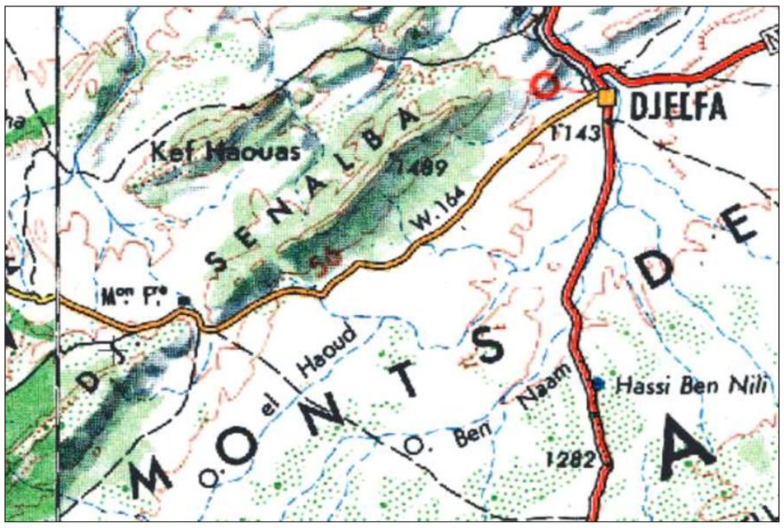

Fig. 1. Location of the Senalba Chergui range on the 1:200000 topographic map (https://www.asal.dz/files/atlas/Atlas.pdf).

Climatic synthesis

The climatic synthesis proposed for 30 years (1989 to 2019) takes into consideration the precipitation (cumulative yearly rainfall) and temperatures (maximum and minimum), with the heat waves of the summer season. A 30-year climatic data average was considered statistically (Ripert & Ladier 2005). These climatic factors trigger forest deterioration and subsequently aggravate the invasion of bark beetles. The factors are based on the National Meteorological Office (N.M.O) of the station Djelfa, located at an elevation of 1.180 m.

Sampling method

The investigation of bark beetles in semi-arid forest ecosystems is highly relevant for understanding entomological diversity, considering dendrometric and environmental factors involved in the selection of biohabitats for these pests, in order to restrict their quick spread in woodland areas. In this context, surveys were carried out during the 2018 and 2019 summer seasons in the Senalba Chergui forest, where the decline of Aleppo pine increase in several sites (Fig. 2).

Fig. 2. An outbreak of dieback in the Senalba Chergui Forests.

The selection of the studied trees was based on several environmental parameters, such as the slope aspect (north and south) and the elevation. Six sites were sampled (Fig. 3): three in the north aspect (Alt= S1=1.225 m; S2=1.216 m, S3=1.323 m), and three in the south aspect (Alt= S4=1.153 m; S5=1.339 m; S6=1.337 m). For each altitude at the different aspects, three trees were cut into four trunks of a 1-meter length according to the tree's height. The number of bark beetles colonized between the bark and the sapwood of each trunk was counted. Before debarking the trunks, preliminary trunk diameters and bark thickness measurements were performed. A species list was compiled for each trunk of trees at the different altitudes in the north and south slope aspects. The relationships between insect density, dendrometric measurements, and environmental factors were assessed.

Fig.3. A location map shows the sampled sites at different altitudes in the north and south slope aspects of Senalba Chergui massifs in the semi-arid zone of Djelfa (Algerian Saharan Atlas).

Identification of the scolytes

The bark beetle species were determined in the laboratory of the Arthropod Collection at the Museum of Natural Sciences in Barcelona (Spain) with the collaboration of A. Viñolas. Among the identification keys used Balachowski (1949), Joly (1975), Pfeffer (1995). And catalog of the Palearctic Curculionidae by Alonso-Zarazaga et *al*. (2017).

Data exploitation

The inventory made it possible to approach the diversity of bark beetles in a global way, and to relate it to the slope aspect and the altitude to highlight their possible influence on their diversity and their strategy attack.

Statistical analysis

A principal components analysis (PCA) was carried out to explain the relationships between the different environmental factors associated with the trees and insects inventoried. Such analysis can deter mine the influence of the predominant factors at the different sites on the spread of these xylophagous species on both slope aspects of the Senalba Chergui forest. The PCA enabled samples to represent considerably all the studied variables. The multi-variate analyses

are carried out with the STATISTICA software version 13.3.

Results and discussion

Climatic synthesis

The Senalba Chergui massifs belong to the semi-arid bioclimatic stage (Q_2=29.2 based on the calculation of Emberger index, Q_2=2000P/M^2-m^2. P: annual precipitation; M: maximum temperature of the warmest month in Kelvin; m: minimum value of the coldest month in Kelvin), with a cold winter and hot summer and a dry period lasting seven months (April to October).

The annual variation in rainfall and temperatures (maximum and minimum), and summer heat waves for 30 years are shown in Fig. 4. These factors affect the spread of the bark beetles that leads to forest deterioration. There was a great variation in annual rainfalls during these three decades; they ranged between 152 mm during the 1999/2000 season and 459 mm during the 2018/2019 season. The average annual rainfall was 350 mm. Therefore, there were 19 years received than the average (i.e., water deficit or dry) and 11 rainy (i.e., above the average) years. In addition, the maximum temperatures vary between 19.5 and and the averages minimum temperatures between 8 and 10.5°C (Fig. 4).

According to Bovey (1971), dry years boost the insects' spread. Insects usually lay eggs only in the bark of trees whose water metabolism is disturbed. The double effects of drought and insect invasion exaggerate tree death (Dajos 1998). Besides, temperature plays a significant role in insect spread; the higher temperatures limit the locations of bark beetles living in tree trunks. However, dry climates with alternating temperatures are particularly likely to increase the susceptibility of trees to insect attack and induce changes in tree physiology (Netherer et *al.* 2015). These disturbances impact the physiology of the plants that become vulnerable to the invasion of diverse types of bark beetles, i.e., making them ready to swarm and multiply.

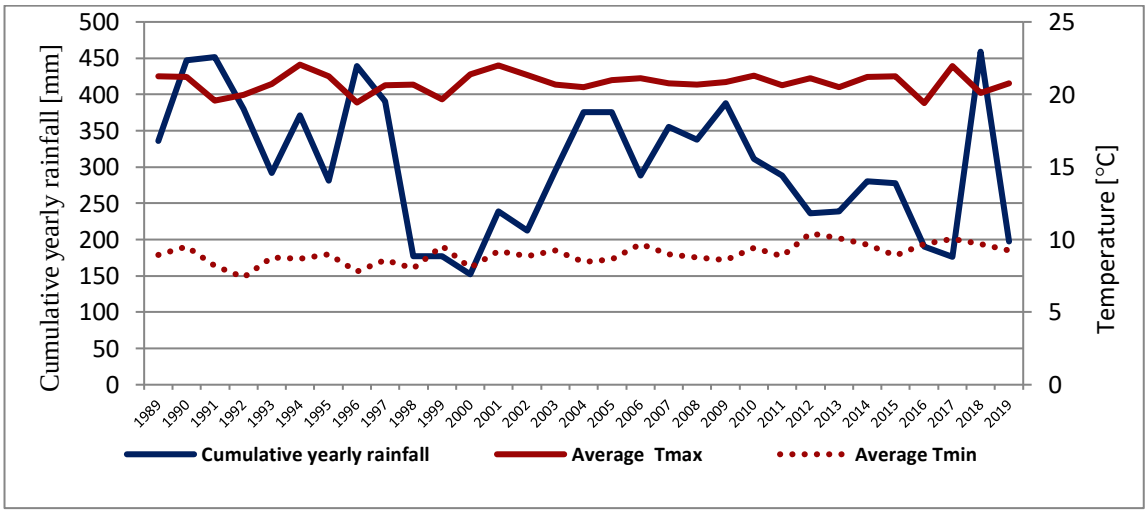

Fig. 4. Annual variations in the climatic parameters (max and min temperatures, annual precipitation) during 1989-2019.

The diversity of recorded Scolytinae species

A total of 4.089 individual beetles were collected from five species belonging to the same Subfamily Scolytinae (*Tomicus destruens* (Wollaston, 1865); *Crypturgus numidicus* (Ferrari, 1867); *Hylurgus ligniperda* (Fabricius, 1787) and *Hylastes cunicularius* (Erichson, 1836). This family of beetles is xylem feeders in coniferous

trees, boring their galleries between the bark and the sapwood. Figures 5 and 6 show the two typical and dominant species on each slope. *C. numidicus* is the most dominant species in terms of number of individuals on the North Slope, with 1.166 individuals. On the south slope, *T. destruens* is the most present with a number of 1.293.

Fig. 5. Different adults stages of *Tomicus destruens* and its imprint.

Fig. 6. *Crypturgus numidicus* and its imprint.

Diversity according to slope aspect

The slope aspect had an important role in the spatial distribution of different species of the bark beetles in the Senalba Chergui woodland. Five and four species were recorded in the south- and north-facing directions, respectively. Besides, the total number of insects was much higher in the south -(individuals)- than in the north-facing direction. The most abundant species in the two aspects were *T. destruens* and *C. numidicus.* The first was significantly more abundant on the south than the north-facing slope, but the opposite was true for the latter species. The numbers of *Tomicus destruens* and *C. numidicus* were 1.293, and 539 in the south and north-facing slope, respectively, but the numbers of *C. numidicus* were 848, and 1.166 in the south and north-facing slope, respectively (Fig. 7). *H. ligniperda* and *Orthotomicus erosus* occurred on both aspects with low numbers (93 and 60 and the south and north-facing aspects, respectively, for the first and 67 and 21 individuals for the latter. *H. cunicularius* were present only with low abundance (2 individuals) on the south-facing aspect but not occur on the north-facing aspects.

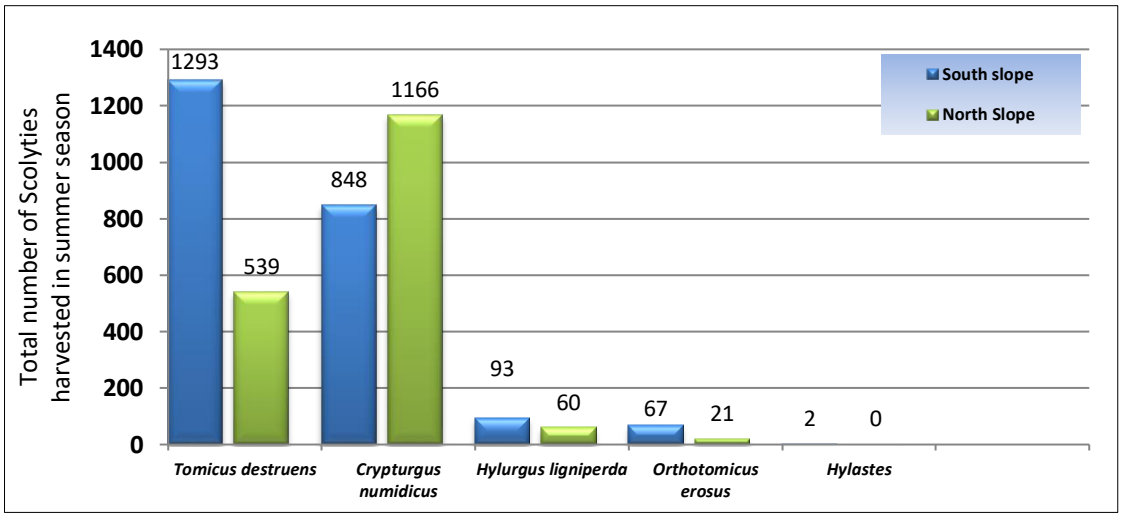

Fig. 7. Scolytinae species inventoried in both the North and South slopes.

The southern slope marked intense aggression by the destructive *T. destruens*, while the northern one is more uneven and degraded, justifying other anthropic or climatic factors that speed up and makes the southern exposure the most vulnerable environment.

Diversity according to elevation

The abundance of the sampling species fluctuates according to altitude; the highest values are recorded on the southern slope at an elevation of 1.337 meters (Table 1). At the same altitude the number is lower.

On the North Slope side, as the elevation increases, the abundance of some species becomes greater. On this same slope, both *C. numidicus* and *T. destruens* show reversed abundances. At the same elevation, when one is abundant the other is very low.

In the South Slope side, high elevations generate two species belonging to *Hylastes* genera, which only appears at an elevation above 1.339 m. At the same altitude, *T. destruens* occurs in four fold increase in comparison to a low altitude (1.153 m), whereas *C. numidicus* is present in very abundant at low altitudes, and may disappear at high altitudes above 1.340 m. The rest of the species such as *O. erosus* and *H. ligniperda* attack pine trees at any height and on any side slope, thus the number of species is closely related to the elevation; as elevation increases, the abundance is greater.

Table 1. Scolytes number according to elevation.

Sampling sites	North slope			South slope		
	A1	A2	A3	A'1	A'2	A'3
Elevation [m]	1.225	1.216	1.323	1.153	1.339	1.337
Total number of individuals	1.069	1.149	1.276	729	1.789	2.112

Strategy and behavior of bark beetles on infested trees

According to site parameters

The abundance of the different bark beetles differed according to stationary parameters (Elevation, slope aspect). The results show that the southern slope is attacked more by five species of bark beetles. The total number of Scolytes inventoried is equal to 2.303 specimens, among them the most threatening one is the destructive *T. destruens,* while in the northern slope there is a total of 1.786 beetles, with *C. numidicus* as the most important one.

T. destruens species acts in high density on pine trees with large diameter and thick bark, the highest density is recorded at a height of 3 meters on the southern exposure, it fluctuates between 36 and 567 galleries /m^2 with a total of 356 specimens. On the other hand, the number of the most important specimens is 749 specimens recorded at a height of 1 meter (Ep = 34.4 cm and Ø = 22 mm). Subjects presenting an important density of attack do not have necessarily a significant number of individuals. On the north side, the attack densities recorded vary between 21 and 326 galleries/m^2 , however the most consistent number of individuals is 634 linked to the most consistent attack density at 4 m height (Ep=17.2 cm and Ø= 3 mm).

The intensity of *Scolytinae* attack can be affected by the morphological characteristics of the tree. Their development is faster in trees with thick phloem (Haack 1985).

Both *T. destruens* and *C. numidicus* are two species that have an inverse distribution of occurrence, when one is present in large number the other is quite low profile. The hillside seems to have an impact on the behaviour of these two species.

Since the southern slope of the Senalba forest is more exposed to climatic warming than the northern slope, which is classified as more humid, and since the sampling period coincides with the summer season (June, July, August) when the average seasonal temperature reaches 35°C, this stimulates the migration of *T. destruens* towards the southern slope where the rise in temperature presents the most favorable conditions for its installation and subsequent proliferation. This species has a very high population density on this slope. Hylastes is very low compared to the other species. On contrary, *H. ligniperda* acts separately, its number is closely linked to the trunk diameter, this species causes substantial damage when its number is high. *C. numidicus* is widespread on the northern slopes. On both exposures, *O. erosus* and *H. ligniperda* are less frequent. Hylastes occurs particularly on the southern hillside.

According to climatic parameters

The directed distribution of all inventoried species reveals a particular attack pattern for each species, influenced by several factors classified according to the choice of the species, of which environmental factors are the most significant. Furthermore, global warming is among the causal factors of this degradation, and its role is primordial in the selective choice of subjects and their outbreaks. However, the alternation of dry periods combined with periods of heat waves recorded during the summer season of 2019, with a summer average temperature close to 35°C, the monthly average temperatures in July and August exceed 34.93°C. This period is marked by the lack of rainfall, particularly in June (P=0 mm), and an elevation in temperature which has an impact on the multiplication of the Scolytes (duplication of the number of generation) which increase the envading of the area forest. Also, it increases bark beetle attacks on healthy or already weakened trees, increasing the extent of damage, *T. destruens* is associated with high temperatures (Horn et *al.* 2012). The

reddening of the pine needles of Senalba Chergui, often pronounced at the top, testifies the destruction of the green tissues after extensive attack which, in most cases, leads to the death of the trees.

Climatic changes resulting in repeated droughts have strongly affected the health status of forest stands (Sarris et *al.* 2011, Girard et *al*. 2012, Sanchez-Salguero et *al*. 2012). Drought is particularly susceptible to increase the vulnerability of trees to insect attacks and to induce changes in tree physiology (Netherer et *al*. 2015). The climatic changes that have taken hold in recent decades have resulted in an increase in the frequency of droughts, the combination of high temperatures and the reduced resistance of trees triggers outbreaks of insect populations (Netherer & Schopf 2010, Durand-Gillmann et *al.* 2012). This cycle could be repeated once or several times a year (Lieutier 2004). Furthermore, stressed plants may be more attractive or more accepted by insects. Repeated episodes of drought can directly affect tree mortality (Allen et *al.* 2010) and abundance of insects (Wood 1982, Tanner et *al.* 2018).

The results obtained in this study demonstrate the combined effect of the lack of rain and temperature increases on the extension of bark beetle attacks, which has been increasing since 2001 at high levels across the Pine populations of “Aleppo, which in agreement with the results of Deroueche (2006, 2015) obtained in the same forest ecosystem.

Martinez Chevez (2019), has shown that bark beetle diversity, in natural forests, has a strong relationship with seasonal climatic variations that significantly influence the damage caused by bark beetle. In this context, Durand-Guillmann (2014) has demonstrated that climate has an effect on the (host - bark beetle) interaction.

The colonization of trees by bark beetle species takes place preferably on those that lose their defense abilities and the death process occurs more or less quickly depending on the intensity of the attacks, which increases throughout the entire tree (Stilwell et *al*. 2014).

In this climate change context, Horn et *al.* (2012) show that *T. destruens* is a species that can be driven to migrate northwards. Vasconcelos et *al*. (2003) suggest that it could attack non-Mediterranean pine species.

The survival probability of trees following attacks is related to the interaction between the ability of trees to mobilize defense mechanisms and the abundance of attacks (Paine et *al*. 1997). Therefore, stressors that weaken tree defense mobilisation have generally been associated with the onset of bark beetle outbreaks (Marini et *al.* 2012).

In the case of trees infestation by Scolytinae, leaf yellowing appear one to two months after the attack (Lieutier et *al*. 1992). *T. destruens* act as a primary pest and attack trees in full vitality, but the rest of the pine bark beetle species can only act in groups and in a secondary order.

Analysis of the relationships between the predictor variables

The PCA allowed a distribution of the studied variables (parameters relating to both trees and species inventoried) on the two axes of the factorial plan ½ explained by 53.78% of the values. This analysis facilitate to distinguish group of variables that are closely related to the F1 axis, explained by 30.39% of the values. This group contain *H. ligniperda* on the negative side of the axis, and *T. destruens* on the opposite side.

Analysis of the correlations between the variables on the PCA mapping shows a relationship between the species harvested and the tree parameters, the site parameters and even between the species themselves. *T. destruens* and *C. numidicus* are correlated negatively, whileone is present in large numbers, the other one is being found in small numbers. The first colonizes the southern slope of the Senalba chergui while

the other one is quite widespread on the south side. It is known that the southern slope of the Senalba forest is more humid than the northern slope. However, due to the increased temperatures during the summer sampling (June, July, August), Cryptugus has migrated to the southern slope where the highest number of this species is recorded. Populations of *T. destruens* are actively multiplying on the north slope to reach the south side (Chakali 2007). Otherwise, there are variables that are closely related to the F2 axis, explained by 23.39% of the values. These are Hylastes and Crypturgus, however *O. erosus* is weakly represented by Axis 2.

Trunk Bark thikness and the attack density are well represented in the factorial plan 1/2, they are closed to the axis 2, and are highly correlated negatively to each other, showing the high scolytes attack when bark thikness is small.

Inaccordance with the ecological requirements of each species and in terms of bark thickness, some species are located in the branches and others in the trunks (Amezaga & Rodriguez 1998), which reflects a spatial segregation that is generally linked to niche sharing.

Durand-Guillmann (2014), show that bark beetles attack trees already weakened by repeated droughts and with a poor health status. *T. destruens* preferentially chooses vigorous trees, higher girth and bark thickness, which agrees with our results.

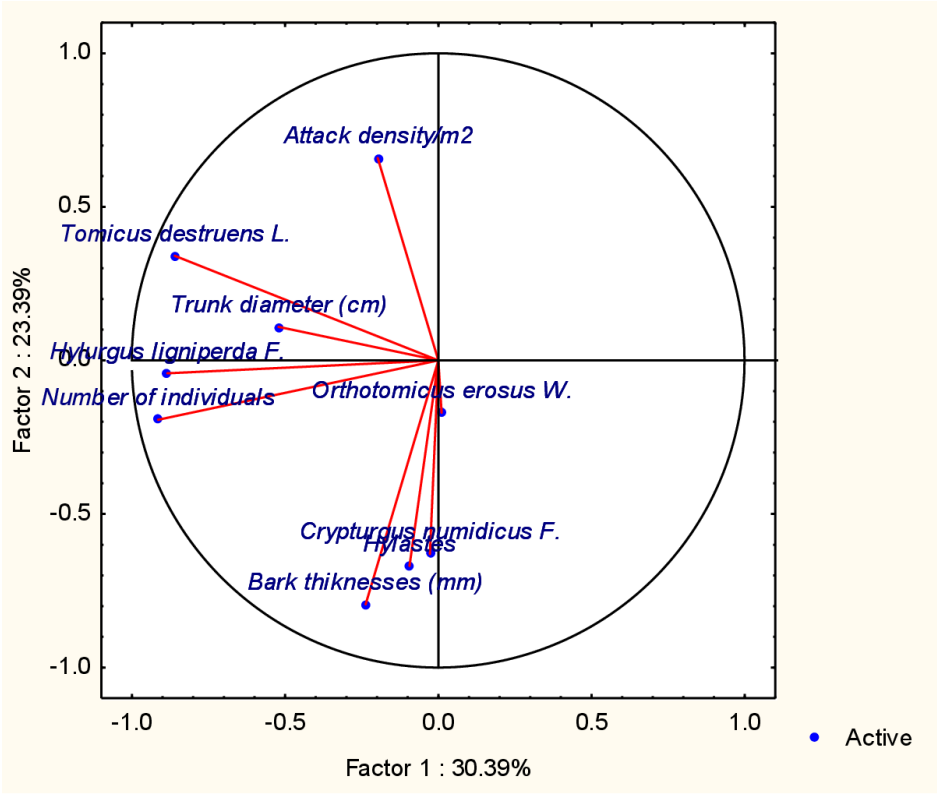

Fig. 8. Projection of the variables on the factor-plane ½.

The PCA enable the projection of the tree logs sampled in both slopes. Two groups are highlighted in the factorial plan ½, the first one includes, in majority, samples of the south slope, the second those of the north side. The side factor (hillside) is an important parameters that influenced the distribution of the scolytes and their attack.

However, once a bark beetle outbreak has been initiated, the classic recommendation to

limit its progression is to cut down trees (Leverkus et *al*. 2018). In this context and in order to reduce the epidemic's spread, the Senalba Chergui pine forests have undergone a removal, within the framework of sanitation, the volume of wood removed in order to restore all the forests in the region of Djelfa during the period (1988 to 2000) rises up to 40.000 m^3 (Chakali 2007), and for the period from 1999 to 2010 only for the Senalba Chergui pines the volume was estimated at 12.086 m^3 (Deroueche 2015).

In recent years, from 2018 to 2022, the exploited volume has been 34.927 m^3, an alarming decrease for these extremely fragile ecosystems.

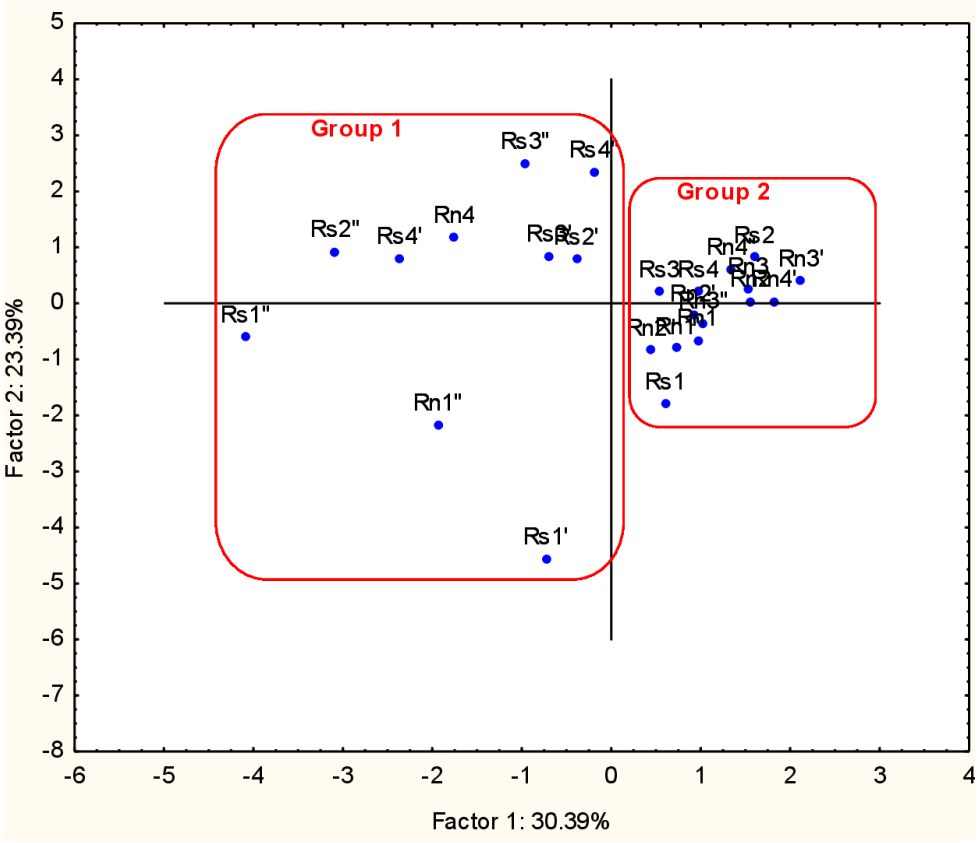

Fig. 9. Projection of the tree logs on the factor-plane ½.

Conclusion

The inventory of bark beetle species associated to the pine forests of Senalba Chergui, considering the impact of stationary parameters by their components; altitude, slope and dendrometric parameters (diameter of the trunk and thickness of the bark) shows an irregular variability in the rate of the infestation of host by these species reflecting the selective choice of the insect

The destructive *T. destruens* acts as a primary pest attacking the subjects in full vitality particularly the South slope. Other species as *C. numidicus* and *O. destruens* are of secondary order provoke damages under the effect of group and settle on pine in deficiency, they are consequent in North slope. These species of bark beetles are the most formidable, they are selective in their choices, preferring and looking for subjects with a large diameter and thickness, whose altitude parameter is insignificant in its outbreak.

Consequently, the southern slope is the most threatened by the degradation due to the important number of bark beetles, and its importance in the degradation of this heritage

which are in decline. The density of attack is substantial in the high altitudes with a rather remarkable number of individuals in the base of the subjects and decreases progressively according to the height of the host. The bark beetle species presents a selective capacity according to several parameters of the host and the accumulation of the environmental conditions privileges and accelerates their pullulation and multiplication.

To reduce the extent of losses caused by these forest bark beetles, the most important action to be taken is incineration, as well as the avoidance of monospecificity in reforestation in artificial forest ecosystems (often monospecific), which are usually quite fragile.

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