A comparative study of the saproxylic diversity of a natural and a reforested forest in Morocco: Implications for conservation and ecosystem management

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Abstract. Moroccan forest ecosystems are rich in biodiversity. However, they are threatened by deforestation. To reduce this, the country has adopted plans involving reforestation. This study compares the diversity of saproxylic litter beetles in two forests in the province of El Jadida, Morocco: the natural Haouzia matorral and the reforested Chiadma forest. The Winkler method and Tullgren funnel were used to assess saproxylic beetles, which serve as bioindicators to evaluate the effectiveness of reforestation efforts. A total of 160 specimens were sampled in the natural forest, symmetrically and concentratedly distributed, with 3% being saproxylic. In the natural bushes, anthropogenic activities have caused a low percentage of species richness. Conversely, the reforested forest has a similar abundance and richness, with 85 specimens and 7% saproxylic. However, the distribution of specimens in the reforested forest is less symmetrical and concentrated than in the natural forest. The differences in species richness are attributed to the different systems present at each site. The natural scrub has an endemism rate of 33%, which is higher than that of Chiadma (13%). These results highlight the significance of management, planning, and protection efforts to conserve these natural ecosystems, which are a national heritage. ***Keywords***: Saproxylic litter beetles, Reforestation, Biodiversity, Moroccan forest ecosystems.

1 Introduction

The geographical position makes Morocco a strategically interesting country, connecting Europe and North Africa, making it the richest in biodiversity in the Mediterranean region after Turkey, with a global endemism rate of 20% [1]. A significant portion of this biodiversity is found in forests, particularly in the litter [2]. Unfortunately, forests face significant threats from human activities such as deforestation, logging, and climate change [3,4], leading to a decrease in natural forest cover. As a response, many countries, including Morocco, have adopted management plans, focusing on reforestation primarily with fast-growing tree species, including pine (*Pinus*) and eucalyptus (*Eucalyptus*) [5]. However, fauna and flora can be used as bio-indicators, among them saproxylic beetles, which are species dependent on dead wood for part of their life cycle [6]. Using these organisms as bio-indicators allows for assessing the state of degradation of natural forests and evaluating the effectiveness of reforestation efforts by providing information on habitat and biodiversity preservation. In this perspective, our study aims to analyze taxonomic diversity in two ecosystems: a natural maquis (*Haouzia scrub*) and a reforested forest (*Chiadma forest*), and to compare the two ecosystems in terms of biodiversity to determine their conservation status. In the same context a study [7] was carried out which compared the Ants (HYMENOPTERA, FORMICIDAE) diversity in the two sites.

2 Materials and Methods

2.1 Study sites

El Jadida, at least within its 11 km of the eastern part, hosts the natural scrub of Haouzia (Figure 1), located between the latitudes N 33°18' and longitudes W 8°24'. It is situated in the Haouzia Bay, representing a site of biological and ecological interest (SIBE). Covering an area of 1073 hectares, the scrub is characterized by the presence of the Phoenician juniper (*Juniperus phoenicia*), which has adapted well to this habitat and has formed homogeneous stands characterized by a high regeneration dynamic, along with other species such as *Lycium intricatum, Pistacia lentiscus,* and *Retama monosperma* [8]. The region has a semi-arid bioclimatic environment with a mild temperate winter, marked by generally hot and dry summers, with oceanic influences along the coast. The rainy season generally runs from

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October to May, with regular fall and winter rainfall, with an annual average of about 317 mm. The oceanic influence along the coast has a significant impact on the relative humidity of the air, maintaining an average between 70 and 80%, reaching up to 90% in the morning. Winds, mainly from the northwest, are frequent and particularly strong in the coastal zone [9].

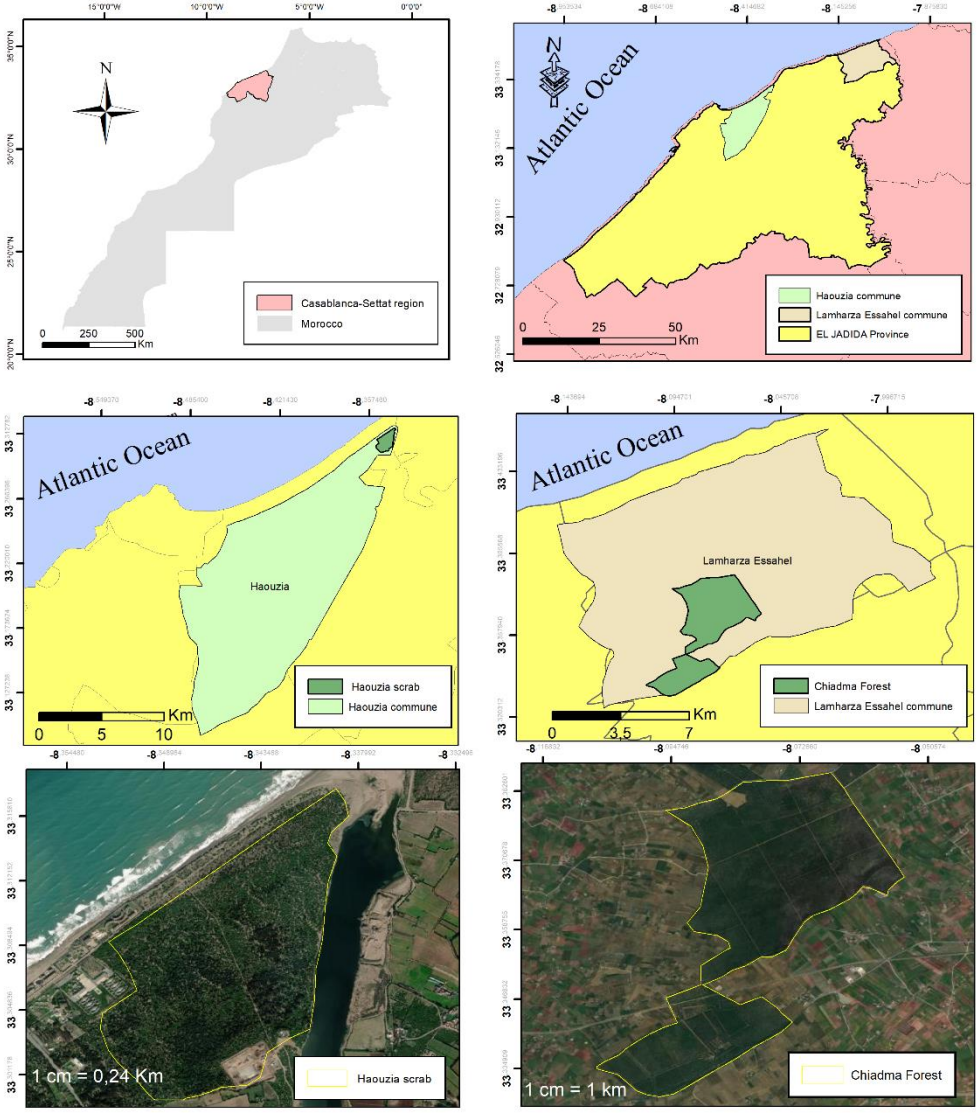

Fig. 1. Geographic location of the study sites in central Morocco (North Africa).

The 2nd site, the Chiadma forest (Figure 1), located 50 km northeast of El Jadida, covers 17% of the Lamharza Essahel municipality with an area of 2273 hectares. It is predominantly composed of Eucalyptus reforestation, located between the latitudes N 33°36' and longitudes W -8°06'. The forest is characterized by the same semi-arid climate as the Haouzia scrub. The dominant species in this environment is *Eucalyptus gomphocephala* [9].

2.2 Materials used

2.2.1. Winkler sieve

With this method, a substantial handful of litter, humus, or soil is collected and placed in a sieve. This sieve is then vigorously shaken to dislodge invertebrates into the lower part. The middle grid serves to retain large debris while allowing insects to pass through (mesh size of 8×8 mm or 12×12 mm depending on the case). The items fallen into the lower part are subsequently emptied onto a white cloth or a wide bowl, making it easier to identify individuals among the fine litter debris [10].

2.2.2. Berlese funnel

The Berlese funnel has undergone some modifications over time, but the principle remains the same. A funnel filled with soil or dead leaves is heated in some way to cause invertebrates to descend into a flask filled with alcohol placed at the base of the apparatus [11].

2.3 Sampling method

Four outings were carried out in each forest, with the collection of 10 trees per outing, spread over two

transects. At each tree, samples of leaf litter and soil (approximately 3 cm thick and weighing 2 kg) were collected, then sieved using a 12 cm mesh Winkler sieve to remove the larger elements of the litter (Figure 2).
After the samples were retrieved, they were placed in Berlese funnels containing 70% alcohol for a duration of 10 days. The specimens were sorted, counted under a stereo microscope, preserved in 96% alcohol with detailed labels, and deposited in the personal collection of Prof. Y. Benyahia at the Faculty of Sciences of El Jadida (Chouaïb Doukkali University).

Fig. 2. Figure displaying the equipment used: a) Winkler sieve, b) Berlese funnel.

2.4 Data analysis

In this study, the statistical analyses involve calculating the Shannon and Simpson indices for both the Haouzia and Chiadma ecosystems, as well as creating boxplots illustrating species abundances for each ecosystem and the Shannon Index. After verifying normality and homogeneity of variances using the Shapiro-Wilk and Levene tests, respectively, a Student's t-test was used to compare abundance means between Chiadma and Haouzia. An NMDS analysis was conducted to illustrate how samples from our two forest ecosystems compare in terms of species abundance. All the statistical analyses and plots were made with *R version 4.4.0* [12].

3 Results

During the two-month sampling period in the Haouzia scrub, a total of 160 beetles belonging to 20 different species were recorded. The most abundant family is Carabidae with 88 individuals, followed by Tenebrionidae with 38 individuals, and Staphylinidae with 31 individuals. Two families, Curculionidae and Corylophidae, are weakly represented with 2 and 1 individuals, respectively. The most represented species in the Haouzia forest include *Syntomus obscuroguttatus* (Duftschmid, 1812), followed by *Aleochara funebris* (Wollaston, 1864), *Stenosis mogadorica* (Antoine, 1936), *Crypticus paradoxus*, and *Microlestes sp*.

Data analysis of the Chiadma forest identified a total of 85 beetles belonging to 16 different species. The Carabidae family is also the most represented in this site, followed by the Staphylinidae family with 35 individuals. The Tenebrionidae family is represented by only 3 individuals, and two new families emerge in Chiadma, namely Nitidulidae and Alexiidae (Table 1). The most prevalent species in the Chiadma forest include *Syntomus obscuroguttatus* (Duftschmid, 1812), *Aleochara funebris* (Wollaston, 1864), *Heterothops dissimilis* (Gravenhorst, 1802), *Microlestes sp*, and *Syntomus fuscomaculatus* (Motschulsky, 1844).

Table 1. Comparison of families of coleopterans present in each site.

Family	Haouzia	Chiadma
Carabidae	88	44
Tenebrionidae	38	3
Staphylinidae	31	35
Curculionidae	2	0
Corylophidae	1	0
Alexidae	0	2
Nitidulidae	0	1

Both forests exhibit significant variations in the feeding habits of the recorded species. The Haouzia scrub shows a marked prevalence of predatory species, constituting 47% of the total. In contrast, the Chiadma forest displays a higher proportion, with 63% of predatory species. Predators rank second in the latter, representing 15%, while in the Haouzia scrub, Detritivores occupy this position with a percentage of 27.

Regarding the geographical distribution of the recorded species, notable differences emerge. In the Haouzia scrub, a majority of identified species have an endemic distribution, totaling 33% of the total. Europe, North Africa (Egypt, Tunisia, Morocco), and Asia follow with 28%. Conversely, the Chiadma forest reveals a more balanced distribution, with 20% of species present in Europe, North Africa, and Asia. Additionally, a distribution of 15% is observed in Europe, North Africa (Egypt, Tunisia, Morocco), and Asia, with the same percentage attributed to North Africa. Haouzia exhibits a higher species diversity with a Shannon index of 1.090 compared to Chiadma, which has a Shannon index of 0.937. However, according to the Simpson index, Chiadma displays slightly greater diversity (0.626) compared to Haouzia (0.550). These indices indicate that Haouzia possesses greater species richness and evenness, whereas Chiadma demonstrates a higher abundance of dominant species.

The box plot (Figure 3) indicates that Haouzia exhibits a broader range and a higher median in species count per sample compared to Chiadma, suggesting a more varied and abundant species presence. Chiadma's data are more clustered, reflecting less variation in species abundance. Both ecosystems display comparable extreme values in species count. The boxplot of the Shannon diversity index for Chiadma and Haouzia forests (Figure 4) shows the distribution of diversity values within each ecosystem. Chiadma has a lower median diversity index and a smaller interquartile range, which implies less variability in diversity among its samples. Haouzia, with its higher median diversity index, suggests a greater diversity of species, as well as greater variability in diversity among its samples. Haouzia appears to sustain a more diverse ecological community when compared to Chiadma.

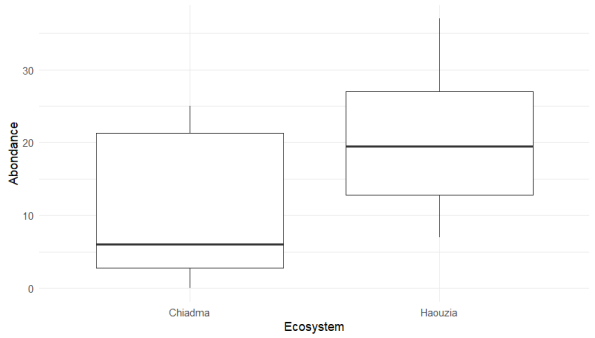

Fig. 3. Boxplot analysis of species abundance in Chiadma forest and Haouzia scrub.

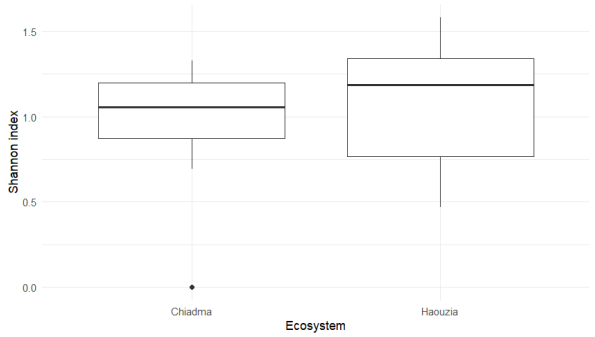

Fig. 4. Boxplot of Shannon diversity index for Chiadma forest and Haouzia scrub.

The Welch's t-test indicates that there is no significant difference in the means of abundance between the Chiadma and Haouzia ecosystems (p = 0.08669).
NMDS plot (Figure 5) illustrates how samples from our two forest ecosystems compare in terms of species abundance.

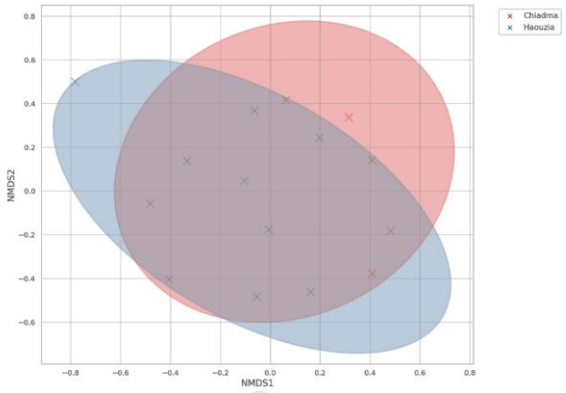

Fig. 5. Visualization of Ecological Dissimilarities via NMDS in Two Ecosystems.

Points represent samples, their position reflects similarity in species composition, while ellipsoids surround sample groups, showing variability within each ecosystem. Different colors represent the two ecosystems studied. NMDS1 and NMDS2 axes capture the main sources of variation between samples, with NMDS1 representing the primary variation and NMDS2 capturing additional variation, providing insight into the ecological distinction between our forest ecosystems in two dimensions.

4 Discussion

Of all the studies carried out on the Moroccan coast (Mediterranean or Atlantic side) [13, 14], the tendency was always to study the chosen sites to highlight their importance as sites for nature conservation, a good initiative certainly, except that the inventories carried out often concern flora, marine fauna, mammals and reptiles. Only a few very specific studies with different objectives have been interested in the study of insects, particularly beetles. This study carried out at two coastal sites, although one of them is a little further from the coast, but is sufficiently exposed to these effects, especially those of the climate. Sampling carried out on the Haouzia scrub show an important abundance of ground beetles, followed by darkling and rove beetles.
The high number of Carabidae is explained by the fact that it is one of the most abundant and diverse families of beetles with approximately 40,000 species described in the world, i.e. 15% of known beetle species. , also, they have the advantage of being numerous and occupying almost all environments. Ground beetles are also part of the epigeal macrofauna (which lives on the surface of the soil, in litter or in humus) most abundant in rural landscapes [15].
In terms of species richness, five species were identified, the most abundant being *Syntomus obscuroguttatus* (Duftschmid, 1812). This predatory species, although very widespread in the Palearctic, is found on a North African scale in Egypt, Tunisia and Morocco only. Attention should also be drawn to *Masoreus wetterhallii wetterhallii* (Gyllenhal, 1813) which is a generally rare and local species, mainly coastal, its typical habitats are among low vegetation on dry sandy or gravelly soils or at the base of plants on dunes and dune cords [16].
The Tenebrionidae form the second abundant family in the Haouzia matorral, but also the richest in endemics. Of the eight species identified, 7 are endemic and one is Moroccan endemic, typical of the Atlantic littoral or sublittoral zone: Casablanca to Mazagan (El Jadida)[17], and is fairly rare which is the *Crypticus paradoxus* Reitter 1896 . Another species described from the Atlantic coast especially from the Casablanca–axis Essaouira is *Stenosis mogadorica* Antoine, 1936, the other endemic species are still distributed throughout Morocco, in various ecosystems, some like *Blaps gigas* (Linnaeus, 1767) are synanthropes.
The abundance and richness of this family is not accidental because the latter is one of the largest families of beetles in the world, with approximately 19,000 known species with more than 2,000 genera [18]. great biodiversity is notably due to the reduction of the wings in most of their representatives [19]. Tenebrionidae are found at all latitudes, from coastal areas to above 5,000 meters (a. S. L.) in the mountains of South America, but they are especially found in all warm regions of the world, with endemism important in arid areas *ibid.*
In Morocco, one species of beetle in seven belongs to this family [20], so it has the highest rate of endemism in the country [22]. Today, nearly 700 species of Tenebrionidae are known in Morocco [17]. Thus, in relation to its surface area, Morocco is one of the most

biodiverse areas in the world for mealworms (Tenebrionidae, Coleoptera) and has the highest rate of endemism in the entire Mediterranean basin. Only Spain, in Europe, can show comparable diversity and a higher rate of endemism, reaching 60% [23]. All this explains the endemism of almost all of the species recorded in Haouzia.

Staphylinidae, the 3rd abundant family in Haouzia, is known for its wide dispersal in all types of ecosystems. Described as eurytopes, staphylinids are found everywhere and especially above ground on litter in humid environments. However, endowed with a very significant flight capacity, they are easily found in various environments, they can even allow themselves to be transported by the effect of the wind and cover long distances.

The presence of this family at the study site is not strange, especially since most staphylinids are generalist predators, their requirements in terms of habitats are not very high. The species *Aleochara funebris* (Wollaston, 1864), has a wide distribution in Europe. In Morocco, it was found in the heart of the Moroccan Rif in Talassemtane National Park [24]. Thanks to this sampling, a new species is added to the staphylinidae of Morocco, it is *Heterothops binotatus* (Gravenhorst, 1802) which has only been cited in North Africa from Algeria and Tunisia.

As for the 4th family which is that of the Curculionidae, although it is not abundant, but it shelters a species qualified as saproxylic of great importance which is *Sitona lineatus* (Linnaeus, 1758). Saproxylic beetles are defined according to [25] as being insects linked to senescent trees and dead wood – constitute good bioindicators of the biological value of forests. They make it possible to assess the state of conservation of ecosystems and to identify forests of international importance in the field of nature conservation. And because of their diversity and their ecological requirements, saproxylic beetles appear to be excellent indicators of the complexity of habitats and forest sites. The presence of such a saproxylic species can only be good for evaluating the site studied.

The new addition for the saproxylic beetles of Morocco, and that of the species *Orthoperus atomus* (Gyllenhal, 1808a) which belongs to the family Corylophidae which forms a small fungivorous family which is found at the level of the leaf litter and at the level of humus or under bark and among decaying wood. They are regularly present in appropriate extraction samples and can be found in the field during sieving. In warm weather they disperse by flying and so can be found sweeping or beating the stems and foliage of a range of plants, particularly in damp locations.

From these results, it is clear that the Haouzia scrub, although degraded, contains significant specific richness, with several endemic species, and even new ones for the Moroccan entomofauna.

As for Chiadma, the second site studied, the abundance and specific richness do not differ too much from those at Haouzia. Indeed, the species composition of the samples taken from Chiadma does not differ much from those taken at Haouzia, except for the appearance of certain species with particularities. Namely, *Calathus circumseptus* (Germar, 1824), which is a generalist predatory ground beetle and *Xantholinus linearis* (Olivier, 1795), a predator rove beetle very common in gardens and disturbed environments in general, on agricultural land where it can be an important predator of pests, meadows, wood, etc., it shows no particular preference for the type of soil. Added to these species is a scavenger, *Tachyporus nitidulus* (Fabricius, 1781), which is often found in marginal habitats or other permanently damp or wet habitats, among decaying vegetation and accumulated leaf litter, but it can also meet among rotting trunks and stumps in any situation.

Another saproxylic species is added for this sampling which is *Ischnosoma splendidum* (Gravenhorst, 1806), this staphylinidae occurs in most humid habitats, in particular open forests where it often appears under bark or logs.

Three darkling beetles are recorded, two of which are endemics, *Pimelia gibba subtriseriata* (Koch, 1941) and *Erodius granipennis granipennis* (Fairmaire, 1871), both of which have a mixed diet.

Two different families emerge at Chiadma, which are the Nitidulidae and the Alexiidae. The latter is home to a saproxylic and endemic species which is *Sphaerosoma tingitanum* (Peyerimhoff, 1917), which is often found when sifting the litter [26].

So according to this inventory, it appears that the two sites studied, although different in composition and type, one is natural which is Haouzia and the other reforested in Chiadma, are not very different either in terms of abundance or of species wealth. But it is in terms of species that Haouzia is ahead of Chiadma, by the presence of endemic species and saproxylic species. This makes the biological or heritage value of the Haouzia matorral more important than that of Chiadma, without oppressing the presence of good specific wealth at the latter.

The statistical analysis of the results has just reinforced the commentary relating to the faunal list. The species *Stenosis mogadorica* (Antoine, 1936) and *Crypticus paradoxus* (Reitter 1896), belonging to the family Tenebrionidae, are frequently abundant in dune systems with sandy soil [27, 29], which is logical to find them in the Haouzia scrub, which is characterized by the same system. On the other hand, the Chiadma forest stands out for the presence of the species *Heterothops dissimilis* (Gravenhorst, 1802) and *Syntomus fuscomaculatus* (Motschulsky, 1844), which belong to the families Staphylinidae and Carabidae respectively. These families are known for their ability to colonize a wide range of terrestrial habitats, including forest environments [30].

In addition to their difference in diversity, the two forests also support species with different diets. Saproxylophagous species are present in both sites, but with low (3 and 7% respectively) percentages. These results indicate the harmful effects of anthropogenic actions in the Haouzia scrub on these species, which play the role of environmental bioindicators [31].

Collected species from both sites shows a diverse geographical distribution. The Haouzia scrub has a

slightly higher number of distributions than that of Chiadma, and a high percentage of endemics. This indicates that the Haouzia scrub is a suitable habitat for several species with different distributions.

According to biodiversity indices, the two sites do not present a major difference in terms of biodiversity, but the Haouzia scrub shows a slight superiority in terms of number of identified species and population. This is clearly visible in the box plots analysis. These results indicate that the natural forest supports a richer diversity than the reforestation zone, particularly when the reforestation is carried out with Eucalyptus [32].
The NMDS analysis confirms two important results. First, Haouzia scrub has a symmetrical and concentrated species distribution, meaning it supports a more balanced and concentrated diversity. Secondly, it highlights the presence of species specific to the Haouzia scrub which are not present in the Chiadma forest and aims towards that. These results can be explained by the differences between the systems present in each forest, which create distinct ecological conditions favorable to certain species.
The Haouzia matorral naturally shelters species of saproxylic beetles. However, eucalyptus and pine plantations were carried out by the Department of Water and Forests with the aim of stabilizing the sand dunes. These exotic forest plantations may have a negative impact on saproxylic beetles, as clear-cutting management reduces the accumulation of dead wood and disrupts the natural decomposition cycle, leading to a decrease in food resources available for these species. This disturbance therefore constitutes a threat to the biodiversity of the natural matorral of Haouzia [32]. In fact, Haouzia matorral is home to 90 species of arthropods, mainly insects with 71 species [8]. Unfortunately, there are no catalogs listing all of these species, which limits the possibility of comparing them with the results obtained. The current results, however, make it possible to determine that 28% of these insect species are beetles. It is therefore necessary to carry out other entomological studies in order to better understand the real biological wealth present in this matorral and throughout the SIBE (Site of Biological and Ecological Importance). In addition, it is essential to put in place management, development and protection plans to preserve this natural site.

5 Conclusion

In conclusion, beetles inventory revealed a similarity in most of the identified species, with the presence of characteristic species unique to each site. However, the Haouzia scrub exhibits a higher number of species and individuals compared to Chiadma, with a better distribution and concentration of species.

This study has enriched the insect catalog of both forests, identifying 20 beetle species for Haouzia and 16 species for Chiadma, with a high rate of Moroccan endemism in the natural matorral. The presence of saproxylic beetles in the two studied sites indicates the need to readjust the monitoring and conservation strategies especially in natural forests. Anthropogenic activities such as the establishment of tourist complexes and deforestation are for a huge threat to those littoral ecosystems. Therefore, it is essential to implement a specific and urgent management program, along with conservation measures, to preserve its unique faunal richness. Looking ahead, it would be interesting to replace eucalyptus plantations with native tree species to maintain endemism rates and the country's heritage.

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