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ANT (HYMENOPTERA, FORMICIDAE) DIVERSITY IN A NATURAL VS REFORESTED AREA ALONG THE MOROCCAN ATLANTIC COAST

Asmaa Fernane [1], Ahmed Taheri [2,*], Aya Najjari [3] & Joaquín-Luis Reyes-López [4]

[1,2,3] Laboratory of Plant Biotechnology, Ecology and Ecosystem Valorization. Faculty of Sciences of El Jadida, Chouaïb Doukkali University, P.O. Box 20, El Jadida 24000, Morocco.
[4] Area of Ecology, University of Cordoba, Building C-4 "Celestino Mutis," Rabanales Campus, 14071-Córdoba, Spain.

[1] Email: fernane.asmaa@ucd.ac.ma – ORCID iD: https://orcid.org/0009-0007-9445-639X
[2] Email: taheri.ahmed@ucd.ac.ma – ORCID iD: https://orcid.org/0000-0001-7402-525X
[3] Email: najjari.a@ucd.ac.ma – ORCID iD: https://orcid.org/0000-0002-5336-4364
[4] Email: joaquin@uco.es – ORCID iD: https://orcid.org/0000-0002-0702-4588

[*] Corresponding author: taheri.ahmed@ucd.ac.ma

ABSTRACT

The coastline of El Jadida province is one of Morocco's Atlantic coastal areas with exceptional biological, ecological, and landscape interest, ranging from the mouth of the Oum Er Rabia river to the dunes and coastal forests. However, this protected area remains little known in terms of its entomological component and has not yet benefited from any conservation measures. To address this lack of entomological data, we conducted field surveys in four ant sampling campaigns between April and May 2022 using the pitfall trap method in two different sites: the "Biological and Ecological Interest Site" of Haouzia and the exploited forest of Chiadma. We recorded a total of 19 ant species, belonging to 11 genera and three subfamilies: Myrmicinae (70.39%), Dolichoderinae (17.66%), and Formicinae (11.96%). The most abundant species were *Aphaenogaster senilis* and *Tapinoma simrothi*, accounting for 49.36% and 17.66% of the specimens, respectively. The highest diversity of ants was found in the natural scrub of Haouzia, with 13 species and a Shannon index of 5.9, compared to 11 species and a Shannon index of 3.5 in the reforested forest of Chiadma. Moreover, with the exception of *Aphaenogaster theryi* and *Cataglyphis vaucheri*, all the captured ant species are new records for the coastline of El Jadida Province, and both sites together showed a very high rate of Moroccan endemism of ants (31.57%). Non-metric multidimensional scaling analysis showed a clear separation between the two surveyed ecosystems. Our results suggest a potential negative effect of *Eucalyptus* reforestation on local biodiversity, and highlight the urgent need for conservation measures to protect the remarkable biodiversity hosted by the "Biological and Ecological Interest Site" of Haouzia and its surroundings.

Keywords. Biodiversity, Formicidae, reforested forest, Atlantic coast, Biological and Ecological Interest Site, Morocco.

RESUMEN

Diversidad de hormigas (Hymenoptera, Formicidae) en un área natural vs otra reforestada a lo largo de la costa atlántica marroquí

La costa de la provincia de El Jadida es una de las zonas costeras atlánticas marroquíes con destacado interés biológico, ecológico y paisajístico, que se extiende desde la desembocadura del río Oum Er Rabia hasta las dunas y bosques costeros. Sin embargo, esta área protegida sigue siendo poco conocida en términos de su componente entomológico y aún no ha sido objeto de medidas de conservación. Para abordar esta falta de datos entomológicos, realizamos cuatro campañas de muestreo de hormigas entre abril y mayo de 2022, utilizando el método de trampa de caída en dos sitios diferentes: el "Sitio de Interés Biológico y Ecológico" de Haouzia y el bosque explotado de Chiadma. Registramos un total de 19 especies de hormigas, pertenecientes a 11 géneros y tres subfamilias: Myrmicinae (70,39%), Dolichoderinae (17,66%) y Formicinae (11,96%). Las especies más abundantes fueron *Aphaenogaster senilis* y *Tapinoma simrothi*, que representaron el 49,36% y el 17,66% de los especímenes, respectivamente. La mayor diversidad de hormigas se encontró en el matorral natural de Haouzia, con 13 especies y un índice de Shannon de 5,9, en comparación con 11 especies y un índice de Shannon de 3,5 en el bosque reforestado de Chiadma. Además, a excepción de *Aphaenogaster theryi* y *Cataglyphis vaucheri*, todas las especies de hormigas capturadas son nuevos registros para la costa de la provincia de El Jadida, y ambos sitios mostraron conjuntamente una tasa muy alta de endemismo de hormigas marroquíes (31,57%). El análisis de escalamiento multidimensional no métrico mostró una clara separación entre los dos ecosistemas muestreados. Nuestros resultados sugieren un potencial efecto negativo de la reforestación de eucaliptos en la biodiversidad local, y destacan la urgente necesidad de medidas de conservación para proteger la notable biodiversidad albergada por el “Sitio de Interés Biológico y Ecológico” de Haouzia y sus alrededores.

Palabras clave. Biodiversidad, Formicidae, bosque reforestado, costa atlántica, Sitio de Interés Biológico y Ecológico, Marruecos.

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Introduction

Morocco is one of the most ecologically diverse countries in the Mediterranean region, characterized by its extreme diversity in terms of bio-climate, geomorphology, vegetation, and fauna. This diversity underlies the richness of landscapes and high-quality natural habitats in the country. Morocco encompasses a wide range of ecosystems, including forests, pre-forests, pre-steppes, steppes, Saharan regions, and aquatic ecosystems (marine, coastal, and continental), which cover various bioclimatic stages, ranging from dry and semi-arid to sub-humid and humid (Benabid, 2000).

The coastline of Morocco is characterized by various types of habitats, including coastal perimeters, lagoons, estuaries, islands, beaches, and cliffs (Franchimont & Saadaoui, 1998). Coastal ecosystems, in general, play a significant ecological role, providing 43% of the services offered by the Biosphere despite covering only 6.3% of the Earth’s surface (Levrel *et al*., 2012). In the case of Morocco, the coastal zone extends for 3500 km, along the Mediterranean Sea and Atlantic Ocean, and holds strategic importance in terms of tourism and economic development, as it has the highest population density and concentration of infrastructure (Morocco’s environmental state report, 2020). Consequently, the Moroccan coast boasts the highest number of humid zones in North Africa, such as lagoons, estuaries, and river mouths, including the Moulouya, Tahadart, and Oum-Er-Rabia. Thirty-eight of these humid zones are designated as Ramsar sites (RSIS, 2023), such as the Sidi Boughaba reserve, or as Biological and Ecological Interest Sites (BEIS), like the Bay of Haouzia.

The Bay of Haouzia, located on the Atlantic coast of Morocco, has been classified as a littoral Biological and Ecological Interest Site (BEIS) in the 1996 Master Plan for Protected Areas (MPPA, 1996). It is comprised of a complex sandy system, including beaches, dunes, estuary, forest, etc., and is of significant faunal, ecological, ecosystemic, and landscape value. The biodiversity of Haouzia Bay is characterized by the presence of a diverse flora (DREFLCD-C, 2019), including 8 species (19% of the species inventoried within the BEIS of Haouzia) of heritage interest, such as endemics, rare, or threatened species in Morocco. This protected coastal area is also home to 104 species of terrestrial invertebrates, with arthropods comprising the majority at 90 species, of which almost 79% are insects (SEAFBV-DREF/HA, 2007). In terms of reptiles and amphibians, the DREFLCD-C report (2019) lists the presence of 8 reptile species and 4 amphibian species, while the Haouzia Bay Technical Data Sheet L22 (MPPA, 1996) mentions the presence of *Pelobates varaldii* Pasteur & Bons, 1959, observed only 20 km east of the site. The area is also rich in nesting and migratory birds. As for mammals, the recent DRELCD-C report (2019) indicates the presence of three species in the Bay of Haouzia.

The SEAFBV-DREF/HA (2007) report indicates that the list of arthropod species in Haouzia Bay is not included in the technical sheet of the protected site, indicating that the natural biological richness of the area, particularly with regard to insects, remains largely unknown. In order to contribute to the knowledge and characterization of the fauna of the BEIS of Haouzia, a study was undertaken to develop a catalog of ant species richness. This study aimed to highlight the importance of preserving the natural state of this unique ecosystem in the region. As part of the study, surveys were extended to a few kilometers beyond the BEIS, in the exploited forest named Chiadma, and a comparison was made between the two habitats in terms of ant taxonomic biodiversity.

Material and methods

Study sites

This research was conducted in two sites located near the city of Azemmour in the northern part of the Province of El Jadida, Western Morocco (Fig. 1). The first site is part of the Haouzia Bay ecosystem, which is classified as a “Biological and Ecological Interest Site” priority 2 (L22) by the Master Plan for Protect-

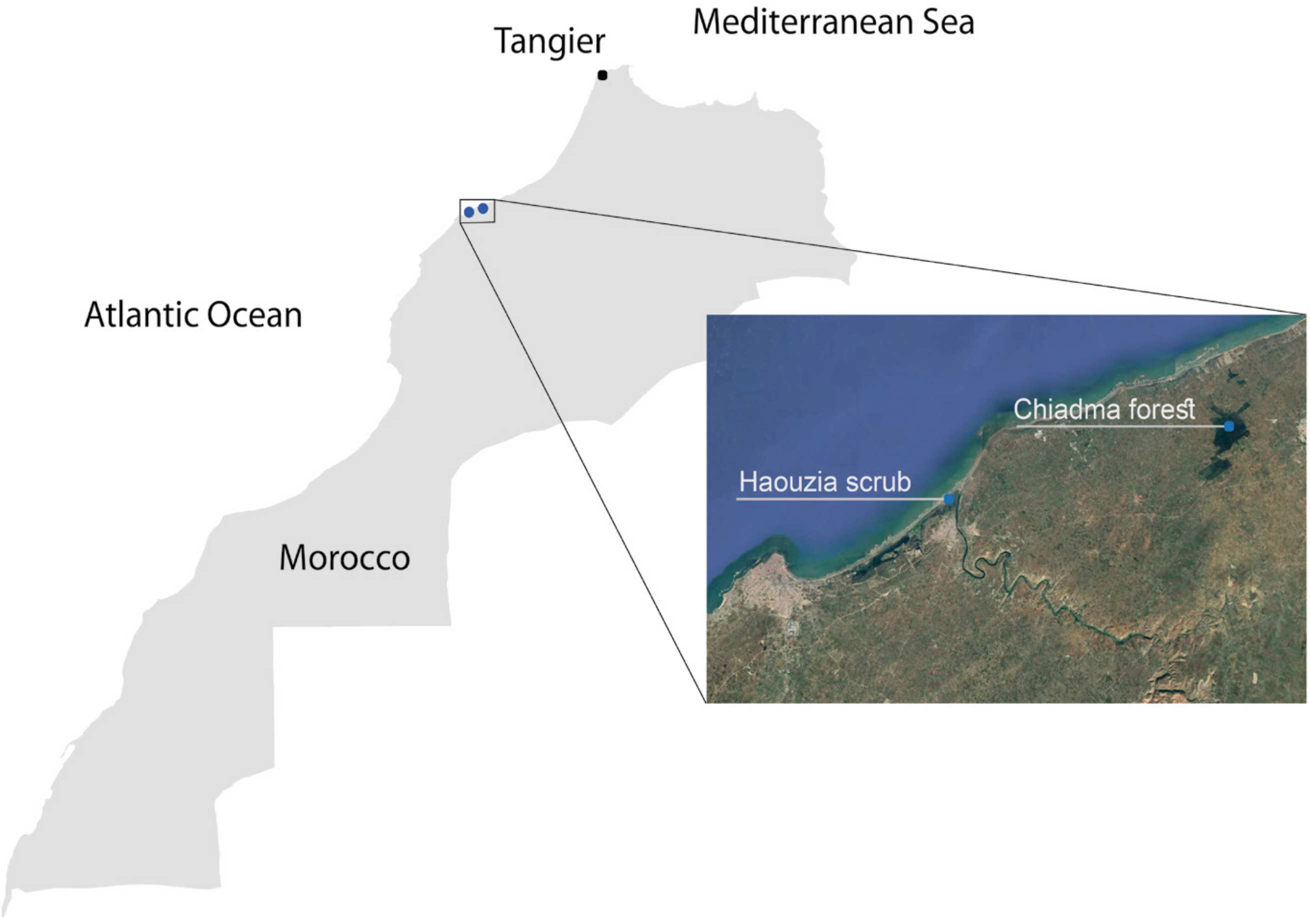

Fig. 1.– Geographic location of the study sites in central Morocco (North Africa).

Fig. 1.– Ubicación geográfica de los sitios de estudio en el centro de Marruecos (norte de África).

ed Areas, as established in 1996 by the Department of Water and Forests. This BEIS includes the most downstream part of the Oum-Er-Rabia wadi up to the estuary, as well as the immediate slopes and stretches of the beaches of El Houzia (south) and a small portion of the Lalla Aicha beach (north). The approximate area of Haouzia Bay is 1,495 ha (DREFLCD-C, 2019). The Haouzia forest and scrub vegetation, which covers an area of 1073 ha, is divided into two parts: the El Jadida forest with an area of 268 ha, and the dune of Azemmour, where our sampling was conducted, covering an area of 805 ha of wooded coastal dunes with sandy and sandy loam soil (Hammada, 2007). From a typological perspective, our study area has been classified as "coastal dunes, old juniper plantation, and reforested dunes" by the DREFLCD-C (2019). The second site, Chiadma forest, is a managed forest of *Eucalyptus gomphocephala* DC., 1928, and *Acacia* Mill., 1754, covering a total area of 941 ha within the municipality of Mharza Sahel (north of Azemmour). Both sites have a thermo-Mediterranean climate (warm and temperate) with significant oceanic influences (DREFLCD-C, 2019). According to the Koppen-Geiger climate map (Kottek *et al.*, 2006), the climate at the study site is classified as type Csa, with an average annual temperature of 18.5 °C and average annual precipitation of 371 mm.

Sampling method

We used ground pitfall traps (Agosti *et al.*, 2000; González *et al.*, 2021) for our sampling. These traps are easy to use and capture a wide range of myrmecofauna, making them suitable for comparing different environments. Similar techniques have been utilized in various myrmecological studies in North Africa, such as the Talassemtane National Park in northern Morocco and the Yakouren forest in Algeria (Taheri *et al.*, 2014; Abdi-Hamecha *et al.*, 2021).

We used interception traps made of 150 cc plastic pots (ref 409702, DELTALAB SL) for our study. These traps have a diameter of 5.5 cm and a depth of 7 cm. To set up the traps, we filled them to 3/4 of their capacity with a mixture of detergent. The traps were then planted in the ground, without leaving a cavity around the pot to avoid the loss of insects. The protocol was to place the traps for 4 days, following the method described by Agosti *et al.* (2000).

In each of the two ecosystems, a total of 60 traps were placed at two sampling points and along three transects each. Each transect was 20 m long, and the traps were spaced 2 m apart. The distance between the two transects was 10 m, while the distance between the two sampling points was 100 m. Overall, a total of 120 traps were deployed in the study areas.

The collection was conducted during four prospecting campaigns between April and May 2022, and the collected specimens are preserved in the personal collection of Ahmed Taheri at the Faculty of Sciences of El Jadida (Chouaïb Doukkali University).

Data analysis

The data from the pitfall traps were analyzed using R software, version 4.1.1 (R Core Team, 2022). This software was used to generate rarefaction curves and calculate diversity indices. Non-metric multidimensional scaling (NMDS) techniques were used to assess visual differences between ant communities in the two areas, using Bray-Curtis distance (or Sorensen distance) as a normalization method commonly used in ecology and environmental science. Permutational Multivariate Analysis of Variance Using Distance Matrices (adonis2 function in R) was used for statistical comparisons between the zones, also with Bray-Curtis distance.

The method of Dufrêne & Legendre (1997) was used to search for indicator species, based on their degree of specificity to a particular habitat and their fidelity, which is the frequency of occurrence within the same habitat, both measured independently for each species and expressed as a percentage. This analysis produces values (IndVal) ranging from 0 (no indicator) to 1 (perfect indicator). Species with high values are considered better indicators as they are more likely to be detected in contrast to rare species (Dufrêne & Legendre, 1997). The "indicspecies" library in R was used for this analysis (De Cáceres & Legendre, 2009).

Results

During the collections carried out in the two sites (Chiadma and Haouzia), a total of 1246 workers belonging to three subfamilies (Dolichoderinae, Formicinae, and Myrmicinae), 11 genera, and 19 species were recorded. Myrmicinae was the most abundant subfamily, accounting for 70.38% of the total individuals, with 6 genera and 11 species. Dolichoderinae accounted for 17.66% of the individuals, represented by a single genus and a single species, while Formicinae accounted for 11.96% of the individuals, represented by 4 genera and 7 species (Table 1). Among the recorded species, 31.57% were endemic to Morocco, including *Aphaenogaster theryi*, *Cataglyphis vaucheri*, *Camponotus serotinus*, *Messor vaucheri*, and *Temnothorax productus*.

The analysis of the rarefaction curve indicated that the sampling effort was adequate (Fig. 2) and revealed clear differences in species richness between the two

Table 1.– Species captured in the prospected sites: abbreviated names (ab), total number of individuals (n), relative abundances (Ar), and endemic status (Moroccan endemic species)*.

Tabla 1.– Especies capturadas en los sitios prospectados: nombres abreviados (ab), número total de individuos (n), abundancias relativas (Ar) y endemicidad (especies endémicas marroquíes)*.

Subfamily	Species	ab	Haouzia		Chiadma	
			n	Ar %	n	Ar %
Dolichoderinae (17,66%)	*Tapinoma simrothi* Krausse, 1911	TAPSIM	217	34,94	3	0,48
Formicinae (11,96%)	**Cataglyphis vaucheri* (Emery,1906)	CATVAU	16	2,58	2	0,32
	Cataglyphis viatica (Fabricius,1787)	CATVIA	0	0	63	10,08
	Camponotus lateralis (Olivier, 1792)	CAMLAT	3	0,48	0	0
	Camponotus ruber Emery, 1925	CAMRUB	0	0	44	7,04
	**Camponotus serotinus* Cagniant, 1996	CAMSER	0	0	2	0,32
	Lasius grandis Forel, 1909	LASGRA	7	1,13	0	0
	Plagiolepis schmitzii Forel,1895	PLASCH	5	0,8	7	1,12
Myrmicinae (70,39%)	*Aphaenogaster senilis* Mayr, 1853	APHSEN	208	33,5	407	65,12
	**Aphaenogaster theryi* Santschi, 1923	APHTHE	0	0	57	9,12
	Crematogaster auberti Emery, 1869	CREAUB	39	6,28	0	0
	Crematogaster laestrygon Emery, 1869	CRELAE	8	1,28	0	0
	Messor barbarus (Linnaeus, 1767)	MESBAR	10	1,61	0	0
	Messor minor (André, 1883)	MESMIN	0	0	3	0,48
	**Messor vaucheri* Emery, 1908	MESVAU	23	3,7	0	0
	Monomorium subopacum (Smith, 1858)	MONSUB	31	5	0	0
	**Temnothorax productus* (Santschi, 1918)	TEMPRO	38	6,12	0	0
	Temnothorax sp.	TEMSP	0	0	8	1,28
	Tetramorium semilaeve André, 1883	TETSEM	16	2,58	29	4,64

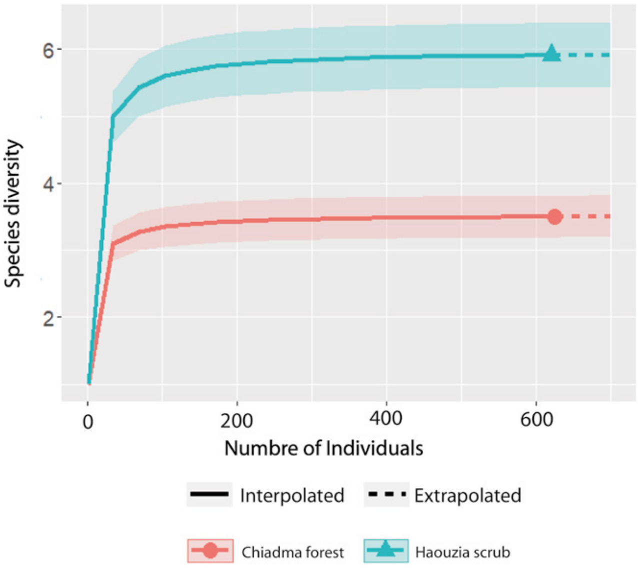

Fig. 2.– Rarefaction curve. The Y axis represents the Shannon index for each zone.

Fig. 2.– Curva de rarefacción. El eje Y representa el índice de Shannon para cada zona.

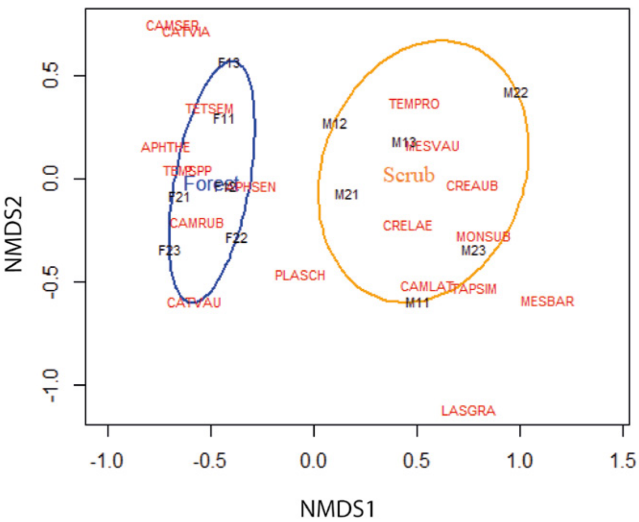

Fig. 3.– Non-metric multidimensional scaling (NMDS) ordination plot illustrating differences among sampling plots. Stress = 0.0764. Abbreviations represent species names mentioned in Table 1. M represents scrub transects with their yellow ellipsoid, and F represents forest transects with their blue ellipsoid.

Fig. 3.– Gráfico de ordenación por escalamiento multidimensional no métrico (NMDS) que ilustra las diferencias entre las parcelas de muestreo. Stress = 0.0764. Las abreviaturas representan los nombres de las especies mencionadas en la Tabla 1. M representa los transectos de matorral con su elipsoide amarillo, y F representa los transectos forestales con su elipsoide azul.

ecosystems. The Haouzia scrub exhibited higher diversity, with 13 recorded species compared to 11 species in Chiadma's forest. The Shannon and Simpson diversity indices were also higher in the natural ecosystem (5.909 and 4.035, respectively) compared to the exploited forest (3.499 and 2.222, respectively). Non-metric multidimensional scaling (NMDS) analysis demonstrated complete separation between the two surveyed ecosystems (Fig. 3, stress=0.0764).

The analysis of the relative abundance of recorded species in the study area revealed that *Aphaenogaster senilis* was the most abundant species, accounting for 49.36% of the total individuals, followed by *Tapinoma simrothi* at 17.66%. In the Haouzia scrub, *T. simrothi* was the most abundant species, with 217 recorded individuals, representing 34.94% of the relative abundance, followed by *A. senilis* at 33.5% and *Temnothorax productus* at 6.12%. In the Chiadma forest, the most abundant ant species was *A. senilis*, accounting for 65.12% of the total individuals, followed by *Cataglyphis viatica* at 10.08% and *Aphaenogaster theryi* at 9.12% (Table 1).

The analysis revealed that among the 19 identified species, only 7 were associated with specific habitats. *Camponotus serotinus* (IndVal=0.592, p<0.001) and *Aphaenogaster theryi* (0.548, p<0.001) were strongly associated with "forest" habitat, whereas *Tapinoma simrothi* (0.608, p<0.001), *Crematogaster auberti* (0.516, p<0.001), *Temonothorax productus* (0.465, p<0.001), *Monomorium subopacum* (0.387, p=0.003), and *Messor vaucheri* (0.342, p=0.017) were associated with scrub habitat.

Discussion

The fauna of terrestrial invertebrates in Morocco is estimated to be around 15,293 species, with the Arthropod phylum being dominant, comprising 94.8% of the total species (Franchimont & Saadaoui, 1998; Quatrième Rapport National sur la Biodiversité, 2009). It is worth noting that insects account for approximately 75% of the arthropod fauna, and the myrmecofauna includes 242 species, including 15 non-native ants (Taheri & Reyes-López, 2018, 2023). However, the catalog of ants in the province of El-Jadida consisted of only 7 species, namely *Dorylus fulvus* (Westwood, 1839), *Aphaenogaster theryi* Santschi, 1923, *Linepithema humile* (Mayr, 1868), *Tetramorium bicarinatum* (Nylander, 1846), *Tetramorium caldarium* (Roger, 1857), *Paratrechina longicornis* (Latreille, 1802), and *Cataglyphis vaucheri* (Emery, 1906) (Cagniant, 2006, 2009; Taheri & Reyes-Lopez, 2018). However, this list has been enriched in this study by the discovery of 14 new species for the province, bringing the total number of Formicidae in El Jadida to 24 species. Among the 7 species previously documented in the literature, *A. theryi* and *C. vaucheri* are the only ones that were captured in this study, while the rest (except *D. fulvus*) are invasive alien species that were found in public gardens within the city (Taheri & Reyes-Lopez, 2018). Out of all the ant species captured, 31.57% are endemic to Morocco, indicating that the coastal ecosystem of the province of El Jadida shows some resilience to the effects of human activity and requires special and urgent attention from managers. This coastal area consists of dunes, scrub, and exploited forests with high myrmecological diversity that deserve to be preserved. Contrary to our initial predictions, these Moroccan endemic ant species were found not only in the natural scrub of Haouzia, but also in the exploited forest of Chiadma.

Aphaenogaster theryi is an endemic species of Morocco, typified by its distribution in the Atlantic coastal regions in Sidi Ayech, Maâmora, El Jadida, Settat, but also in the Atlas of Beni Mellal (Cagniant, 1996b). Twenty-nine individuals were captured in the Chiadma forest. Its capture in this reforested area confirms its persistence in the province of El Jadida. *Camponotus serotinus* is endemic to Morocco, and is known to be frequent in the coastal region from the Tangier peninsula to the foothills of the Atlas Mountains (Cagniant, 1996a). During our surveys, we have captured a total of 57 individuals in the Chiadma forest, which confirms its presence along the Atlantic coast of Morocco. *Cataglyphis vaucheri* has been previously documented in regions from Essaouira to Tan Tan (Cagniant, 2006). It has also been reported in coastal dunes south of Rabat at the mouth of Sous, in anthropized stations towards the interior as far as Marrakech, in the north of Agadir, and in Chichawa (Cagniant, 2009). In 2001, it was also encountered in El Jadida (Cagniant, 2009). Our recent capture in both study sites confirms its continued existence in the region of El Jadida despite different natural and anthropogenic conditions and disturbances that may have occurred between 2001 and 2022. This suggests the resilience of this species to changing environmental conditions in the area. Furthermore, we have captured 19 individuals of the Moroccan endemic species *Messor vaucheri.* This species is documented along the southern Atlantic coast of the country, specifically in Essaouira, Agadir, Tan-Tan, Tarfaya, and Laayoun, inhabiting coastal dunes and consolidated sands at altitudes ranging from 100m to 120m (Délye & Bonaric, 1973; Cagniant & Espadaler, 1997; Cagniant, 2006). Our discovery of this species in the Doukkala region has expanded its known range further north in Morocco and at a lower altitude of 10 m. *Temnothorax productus* is another Moroccan endemic species that we were able to capture in the BEIS of Haouzia. This species has been documented in three specific locations along the Atlantic seaboard, namely Essaouira, Agadir, and Mirleft, as reported by Cagniant (2006). Our capture of the species in the El Jadida region has expanded its known distribution area along the Atlantic coast to include an additional locality further north.

Plantations can be a solution for preserving native biodiversity if the activity is not dedicated to replace natural vegetation cover (Baguette *et al*., 1994; Gjerde & Saetersdal, 1997; Brockerhoff *et al.* 2008). When reforestation is used as a means of repairing ecosystems and landscapes disturbed by humans, it can represent an opportunity to support native biodiversity in ecosystems degraded by grazing, anthropization and pollution, although at lower abundances (Brockerhoff *et al.,* 2008). Da Silva *et al.* (2019), based on the comparison among 40 natural and anthropogenic forests in Portugal, showed that the biodiversity of the anthropogenic sites (reforested or invasive groves) was lower than in natural sites, which is consistent with our results. The Haouzia scrub ecosystem is naturally inhabited by *Juniperus phoenicea* and the pine trees present in the area are a result of reforestation efforts carried out by the Department of Water and Forests to stabilize the sand. The capture of endemic ant species in the Chiadma forest may be due to the considerable resistance and resilience of this group compared to others; as noticed in previous studies (Whitford *et al.,* 1999). The plantation of exotic species can disrupt connectivity among the different parts of ecosystems (Brockerhoff *et al.,* 2008), which requires land managers to select the species to be planted in the natural environments to favor biodiversity. The introduction of exotic plant species into natural environment has been observed to modify the populations of insects and birds, as it alters the structure of the stands and changes the nature and composition of branches and leaves that are available for consumption (Le Tacon *et al*., 2001). The introduction of eucalyptus trees could have detrimental effects on the local natural environment, including changes in soil properties leading to soil degradation, decline in groundwater levels, and subsequent reduction in biodiversity (Ping & Xie, 2009). For instance, studies conducted in southern Brazil have shown that the replacement of natural habitats with eucalyptus plantations has resulted in significant negative impacts on herpetofauna diversity (Saccol *et al*., 2017). Eucalyptus plantations, along with other types of tree plantations, have been a topic of ongoing debate when it comes to their impact on the conservation of natural biodiversity. Martello *et al*. (2018) provided evidence that managed eucalyptus plantations significantly reduce both taxonomic and functional diversity of ant communities, resulting in taxonomic and functional homogenization at the landscape level of reforested forests. In simpler terms, this study showed that both managed and unmanaged eucalyptus plantations lead to a decrease in functional diversity and an increase in similarity among ant communities, ultimately resulting in functional homogenization. This suggests that eucalyptus plantations can have negative effects on ant biodiversity, potentially leading to a loss of ecological diversity in reforested areas. Furthermore, research conducted by Goded *et al*. (2019) has shown that eucalyptus plantations cannot fully replace native forests, as they support different grass species and only a subset of the bird species found in native forests. Our observation of a reduced ant diversity in the

Chiadma forest is consistent with the adverse impacts attributed to eucalyptus plantations. Nonetheless, the long-term response of native ant species to these effects remains uncertain, and their resilience should be assessed with periodic surveys.

Conclusion

Our study highlights the remarkable ability of coastal habitats in El Jadida province to withstand the negative effects of deforestation, increased touristic pressure, and eucalyptus reforestation. Despite the significant differences in myrmecological diversity between the more diverse natural scrubland of Haouzia and the less diverse reforested area of Chiadma, the resilience capacity of ant communities remains noteworthy and deserves further monitoring efforts. Specific and urgent management programs are needed to preserve this fragmented ecosystem along the Moroccan Atlantic coast, with conservation measures that support its unique faunal richness. Futures studies employing additional sampling methods such as Berlese extraction, soil washing, etc., may unveil new species, particularly hypogeous species, providing further insights on the composition and structure of entomological communities in the region, as well as on ecological succession processes.

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