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Presented by :

Haithem Messaoudi ***Ahmed Rezaikia***

Title

First Data on Terrestrial Isopods of Chelia-Ouled Yagoub National Park

*Master's thesis publicly defended on 22/ 06/ 2025, b*efore the jury composed of:

Mrs. Dounia Dib
MCA, University of Khenchela, President

Mrs. Cherifa Berkani
MCA, University of Khenchela, Examiner

Mr. Mehdi Badis
MCB, University of Khenchela, Supervisor

Mrs. Imane Benchana
Ph.D Student, University of Tunis El Manar, Co-supervisor

Academic year 2024/2025

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Dedication

To the ones who gave us life, love, and unwavering support, our dear fathers, our first source of pride, guidance, and strength.

To the ones whose love knows no limits,
Our beloved mothers, the endless fountains of tenderness and sacrifice.

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Abstract

Terrestrial isopods are key components of soil ecosystems, actively participating in organic matter decomposition and nutrient cycling. Their ability to serve as bioindicators makes them valuable for assessing soil quality, yet they remain poorly studied in Algeria, particularly in forested habitats. This study represents the first systematic assessment of terrestrial isopod diversity in the Ouled Yagoub forest massif. Conducted in autumn 2024, it focused on four distinct forest types: cedar, mixed pine, pure pine, and burned pine. A stratified quadrat sampling approach was employed to ensure coverage of microhabitat variation across these sites. A total of 229 specimens were collected and preserved in alcohol, then identified with a stereomicroscope. Preliminary results revealed the presence of five isopod species belonging to the families *Porcellionidae*, *Armadillidiidae*, and *Armadillidae*, with notable differences in species composition and abundance between forest types. These findings underline the ecological importance of the Aurès mountain forests in maintaining soil biodiversity. They highlight the need for broader studies on soil macrofauna in Algerian forest ecosystems and lay a foundation to extend this or any other similar studies. This research also reinforces the value of isopods as ecological indicators in Mediterranean forest environments, particularly under increasing anthropogenic and climatic pressures.

Keywords: Algeria, Bioindicators, Forest biodiversity, Mediterranean forests, Soil fauna, Terrestrial isopods.

Résumé

Les cloportes terrestres sont des composants clés des écosystèmes du sol, participant activement à la décomposition de la matière organique et au cycle des nutriments. Leur capacité à servir de bioindicateurs les rend précieux pour l'évaluation de la qualité des sols, mais ils demeurent peu étudiés en Algérie, en particulier dans les habitats forestiers. Cette étude représente la première évaluation systématique de la diversité des cloportes terrestres dans le massif forestier d'Ouled Yagoub. Réalisée en automne 2024, elle s'est concentrée sur quatre types de forêts distincts : cédraie, pinède mixte, pinède pure et pinède brûlée. Une méthode d'échantillonnage par quadrats stratifiés a été utilisée pour assurer une couverture représentative des variations de microhabitats sur l'ensemble des sites. Un total de 229 spécimens a été collectés et conservés dans de l'alcool, puis identifiés à l'aide d'un stéréomicroscope. Les résultats préliminaires ont révélé la présence de cinq espèces de cloportes appartenant aux familles *Porcellionidae, Armadillidiidae,* et *Armadillidae* avec des différences notables dans la composition et l'abondance des espèces entre les types de forêts. Ces résultats soulignent l'importance écologique des forêts de l'Aurès dans le maintien de la biodiversité du sol et mettent en évidence la nécessité d'études plus larges sur le macrofaune édaphique dans les écosystèmes forestiers algériens, tout en constituant une base pour étendre cette recherche ou d'autres études similaires. Cette recherche renforce également la valeur des cloportes en tant qu'indicateurs écologiques dans les forêts méditerranéennes, notamment face aux pressions anthropiques et climatiques croissantes.

Mots-clés : Algérie, Biodiversité forestière, Bioindicateurs, Faune du sol, Forêts méditerranéennes, Isopodes terrestres.

ملخص

تُعدّ القشريات متساوية الأرجل البرية من المكوّنات الأساسية في النظم البيئية للتربة، حيث تساهم بشكل فعّال في تحلل المادة العضوية ودورة العناصر الغذائية. وتُظهر قدرتها على العمل كمؤشرات حيوية أهميتها في تقييم جودة التربة، ومع ذلك فإنها لا تزال غير مدروسة بشكل كافٍ في الجزائر، خصوصًا في المناطق الغابية. تمثّل هذه الدراسة أول تقييم منهجي لتنوّع القشريات البرية في الكتلة الغابية لأولاد يعقوب. أُجريت الدراسة سنة 2024، وركّزت على أربعة أنواع مختلفة من الغابات: غابة الأرز، الصنوبر المختلط، الصنوبر النقي، وغابة الصنوبر المحترقة. استُخدم أسلوب المعاينة بواسطة مربعات متدرجة لضمان تغطية التباين في المواطن الدقيقة عبر هذه المواقع. تم جمع 229 عينة وحفظها في الكحول، ثم تم تحديدها باستخدام المجهر التشريحي. كشفت النتائج الأولية عن وجود خمس أنواع من القشريات البرية تنتمي إلى عائلات الكربسيات، أرماديليديدا، أرماديلا. مع اختلافات ملحوظة في تركيبة الأنواع وكثافتها بين أنواع الغابات المختلفة. وتُبرز هذه النتائج الأهمية البيئية لغابات جبال الأوراس في الحفاظ على التنوع الحيوي للتربة، وتؤكد الحاجة إلى دراسات أوسع حول الحيوانات الارضية الكبيرة (العيانية) في النظم البيئية الغابية الجزائرية، كما تُشكّل أساسًا لتوسيع هذه الدراسة أو دراسات مماثلة. كما تثبت أيضًا من قيمة القشريات متساوية الأرجل البرية كمؤشرات بيئية في الغابات المتوسطية، خاصةً في ظل التغييرات البشرية والتغيرات المناخية المتزايدة.

الكلمات المفتاحية : التنوع البيولوجي الغابي؛ الجزائر؛ الحيوانات الأرضية في التربة؛ القشريات متساوية الأرجل البرية؛ المؤشرات الحيوية؛ غابات البحر المتوسط.

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List of Abbreviations

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% → Percent

°C → Degree Celsius (temperature unit)

µm → Micrometer (unit of length, 10^–6 m)

a.s.l.→ Above sea level

AHP → Analytic Hierarchy Process (multi-criteria decision technique)

BNEDER→ Bureau National d'Etudes pour le Développement Rural (National Bureau of Studies for Rural Development, Algeria)

C → Constancy Index (proportion of samples containing a species)

cm → Centimeter (unit of length)

cm^3 → Cubic centimeter (unit of volume)

cmol+/kg → Centimole of charge per kilogram (cation-exchange capacity unit)

DNA → Deoxyribonucleic Acid (genetic material)

FAO → Food and Agriculture Organization of the United Nations

FSA → Simple Fisheries Stock Assessment (R package)

g → Gram (unit of mass)

g/cm^3 → Gram per cubic centimeter (bulk density unit)

g/kg → Gram per kilogram (soil component concentration unit)

GIS → Geographic Information System (spatial analysis tool)

Ha → Hectare (10,000 m^2; unit of area)

IUCN → International Union for Conservation of Nature

kg → Kilogram (unit of mass)

kg/m^3 → Kilogram per cubic meter (density unit)

mm → Millimeter (unit of length)

NE → Northeast (direction)

pH → Potential of hydrogen (acidity/alkalinity measure)

Python → Computer programming language

RFI → Relative Frequency Index (occurrence metric)

RFI → Relative Frequency Index (occurrence metric)

SW → Southwest (direction)

UNEP → United Nations Environment Programme

WCMC → World Conservation Monitoring Centre (UNEP-WCMC)

Introduction

Woodlice (Oniscoidea), known more commonly as pillbugs or sowbugs, represent the singular most impressive evolutionary success within the entire arthropod lineage. Terrestrial isopods, evolved from marine stock originally, have themselves been well substantiated as having successfully invaded land more than 300 million years ago in the Carboniferous period - far ahead of the earliest known dinosaurs (Schmalfuss, 2003). The evolutionary transition from aquatic to terrestrial habitat involved extraordinary adaptations, starting with the production of a water-repellent cuticle composed of calcified plates and included the development of pseudotracheae - special respiratory structures that function as primitive lungs (Hornung, 2011). Woodlice represent a finite set of adaptations that now allow them to contend with the regulatory challenges of water balance in the process of breathing atmospheric oxygen, thereby concurrently solving the two challenges that low periodicity consistently deters most crustaceans from abandoning their aquatic lifestyle (Wright & Ting, 2006).

The global diversity of woodlice is staggering, with over 3,700 species reported as existing in nearly every terrestrial habitat, with the exceptions of the permanent icecaps and driest deserts (Schmalfuss, 2003). They illustrate their ecological mobility in a species such as *Armadillidium vulgare*, which has adapted to live under human habitation across the globe, versus habitat specialists such as the Tyrrhenian endemic Helleria brevicornis, which is only found in a few Mediterranean forest communities (Taiti et al., 2021). One of the most interesting of these behaviors is conglobation (rolling into a perfect sphere), which has multiple functions including water retention (up to 34% reduction in evaporation), defense against predation, and thermoregulation (Schmalfuss, 1998). Given their ecological success and diversity.

Woodlice, as important detritivores of terrestrial ecosystems, exhibit multiple valuable roles in nutrient cycling and soil formation. Their feeding behaviour contributes to accelerating the decomposition process both through physical disruption of plant tissues and through chemical alteration, by way of digestive enzymes (Zimmer & Topp, 2002). David and Handa (2010) showed that woodlice are capable of digesting approximately 10% annual input of leaf litter in temperate forests, and some woodlouse species are highly specialized - some woodlice select leaves infected with fungus, and others consume only particular plant species. This selective feeding affects the implication of microbial communities and nutrient release dynamics in forest soils (Hassall et al., 1987). In addition, and especially important is the woodlice effect on humification - the gut passage of plant tissues increases the surface area of organic debris by as much as 15 times, thereby enabling microbial colonization and subsequent degradation into stable humus (Zimmer, 2002).

Apart from decomposing organic matter, woodlice also provide essential ecosystem services such as soil detoxification, and their role as a microbial vector is no less significant. Hopkins' (1989) experimental investigations showed that some species of woodlice can sequester heavy metals such as lead and cadmium in specialized glands within the midgut, effectively cleansing the contaminated soil environment. The guts of woodlice function as migrant incubators for beneficial bacteria and fungi, which are spread throughout the soil profile (Paoletti et al., 2007). This microbial distribution promotes nutrient cycling, specifically nitrogen and phosphorus, making these crustaceans unsung heroes of soil fertility.

Unfortunately, these ecological services are increasingly threatened. Urbanization will decrease woodlice diversity by 40-60% by fragmenting habitats and changing microclimatic factors (Vilisics et al., 2012). Climate change predictions suggest that Mediterranean species will lose a further 15-30% of their habitat by 2050 due to increased aridity (Cardoso et al., 2020).

Woodlice are surprisingly understudied overall and in Algeria in particular, where no large-scale biodiversity studies have been carried out (Caruso et al., 2020; Benchana et al., 2025). This is especially noteworthy given the biogeographical context of the area located at the intersection of Saharan and Mediterranean ecoregions, which is likely to represent unique and possibly endemic woodlice communities. In North African forests, such as the Ouled Yagoub massif, the situation is particularly concerning, as they have received very little scientific interest. This study addresses these significant knowledge gaps by systematic examination of woodlice assemblages in an unexplored forest system, yielding baseline data essential to conservation planning within a climate change framework.

In this context, this study aims to:

- Identify, for the first time, the species of woodlice (Oniscoidea) present in the Ouled Yagoub forest massif.
- Assess the influence of soil type on the occurrence of these terrestrial crustaceans.
- Analyze the distribution of different species across the forest types within the massif.

Bibliographic Synthesis

Chapter I: Chelia-Ouled Yagoub Park

1. The role of national parks in biodiversity conservation

National Parks are the world's largest protected areas (Chape et al, 2003). They are categorized under Category II of the IUCN protected area categories. National Parks are created to protect the ecological integrity of one or more ecosystems for present and future generations (Moses et al, 2013).

Conservation is the main goal of national parks. The parks, woods, and vegetation offer numerous significant environmental advantages, such as sheltering all terrestrial organisms and preventing climate change and global warming through carbon storage. Additionally, forests play a significant role in regulating the distribution and intensity of rainfall at the local and regional levels. In addition to providing millions of people with clean water, food, and other necessities, forests also have aesthetic, therapeutic, and recreational benefits (Alemu, 2016).

2. General overview of Chelia-Ouled Yagoub National Park

The Ouled Yagoub National Forest is North Africa's largest forest, and it has just been declared a national park (Figure 1) (Beghami et al., 2012). The area was designated a national park in 2021. The main objective of this regulatory framework is to ensure the sustainable development of natural resources, particularly the national forest heritage (Badis, 2023).

It is situated in the province of Khenchela in northern Algeria. The spatial distribution of this forest has a highly varied topography, with a mountainous nature marked by a series of small and irregular ridges. It is located 17 km from the Chelia Cedar Forest and forms a rectangle that is 13.5 km long and 6.5 km wide, with the same SW-NE orientation (Chafai et al., 2023).

Forestland in this large area serves as an indispensable ecological function reserve supporting flora that occurs only in North Africa, including the Atlas Cedar *Cedrus atlantica*, Aleppo Pine *Pinus halepensis*, Holm Oak *Quercus ilex*, Oxycedrus Juniperus *Juniperus oxycedrus*, and Wild Ash (*Fraxinus dimorpha*) (BNEDER 2010). Dense and transparent cedar forests, mixed cedar and oak forests, Aleppo pine forests, prickly juniper, scrub oak, wild ash, lawns, and mountain pastures are some types of forest stands (Beghami et al., 2012).

Figure 1: View of the Ouled Yagoub National Park, illustrating the forested mountainous landscape. (Photo: Messaoudi and Rezaikia, November 2024).

2.1. Forest occupation and land cover

The Chelia – Ouled Yagoub National Park has a forest area of 18,078 hectares. It is dominated by xeric cedar forests, which are the southernmost in North Africa (32% of the park's total forest area). There are also agricultural fields, scrublands, and forested grasslands. Its topography is defined by a series of narrow, discontinuous ridges with high slopes of more than 25% (Chafai et al., 2016). Altitudes range from 1,200 to 2,326 m, with the highest point recorded at Ras Keltoum (BNEDER, 2010).

The park represents four dominant categories of forests (Badis, 2023):

- **Pure Cedar woodland:** This is a dense, uniform woodland dominated by Atlas Cedars, *Cedrus atlantica*. It is located at the highest parts of the mountains, with elevations ranging from 1,950 to 2,326 meters.
- **Holm Oak Cedar woodland:** This is a mixed woodland dominated by Atlas Cedars and Holm Oaks *Quercus ilex*. It is located at altitudes ranging from 1,700 to 1,950 meters.
- **Mixed Cedar Forest:** This is a very heterogeneous forest dominated by

Atlas Cedar, with associated vegetation cover of Aleppo Pine *Pinus halepensis*, Holm Oak, Dimorphic Ash *Fraxinus dimorpha*, and Oxycedrus Juniperus *Juniperus oxycedrus*. This forest is located at altitudes varying between 1,450 and 1,700 m.

- **Pine and oak forests:** Two pure forests occupy the lower altitudes between 1,100 and 1,450 m. They are composed of thermophilic plant species, notably Aleppo pine and holm oak.

2.2. Climatic conditions

The data available at the El Hamma meteorological station, located 15 km from the study area, as well as those published by Chafai (2016), show the dominance of a general Mediterranean-type climate. At the local scale, the projection of the available data on the Emberger climatogram indicates that the park area is characterized by different bioclimatic stages that follow an altitudinal gradient ranging from the semi- arid climate with cool winters in the lower altitudes, to the cold humid stage on the summits, passing through the cool and cold sub-humid climate (Badis & Hamdi, 2022).

The average monthly rainfall varies from 0 to 128 mm, with an annual total of 522.6 mm. The coldest month is February (1.3°C), while the hottest is July (36.6°C). The relative humidity of the air increases during the cold and wet seasons between December and January (highest value 73%), while the minimum value is in July (30%) (Badis, 2023).

The highest wind speeds were recorded in November, February, and June (165.6 km/h). In August, the sirocco wind from the south dominates and causes young plants to dry out. Storms are common throughout the year, particularly between May and October, when the soils are bare and dry, increasing erosion (BNEDER, 2010).

2.3. Biodiversity in the park

The Chelia – Ouled Yagoub National Park is distinguished by its great floristic diversity, which includes pure and mixed cedar forests, a pine forest, and thorny xerophyte scrubland. These formations are endemism hotspots, with a large number of rare species and threatened taxa. The examined park accounts for 15% of the national floristic richness, with 468 plant species, including 27 indigenous to North Africa, 17 natives to Algeria, 11

Algerian-Moroccan, and 3 Algerian-Tunisian. Half of these taxa have Mediterranean biogeographic origins (BNEDER, 2010).

The avifauna of the park includes a total of 115 bird species, or 28.32% of the national ornithological richness; all phenological seasons combined. It is composed of 66 sedentary species, 38 summer nesting species, 7 wintering species, and 4 passing migrants (Badis, 2023). Biogeographically, the Mediterranean category is the best represented with 39 species (or 34% of the total) and which derives from the hot and semi-arid regions of the plains and mid-mountains of the Mediterranean, Europe, and Southwest Asia (Blondel et al., 1978). In addition, 33 species (29%) belong to the boreal category, with 29 Palearctic species and 4 Paleo-montane species. Finally, 16 species are of European origin, 12 Euro-Turkestani, 8 Holarctic, and 6 from the Old World (BNEDER, 2010).

The park is home to bird species endemic to the Maghreb region, such as the Levaillant's Woodpecker *Picus vaillantii*, the Moussier's Redstart *Phoenicurus moussieri*, the Atlas Warbler *Sylvia deserticola*, and the Maghreb Magpie *Pica mauritanica*. Other species are endemic to all of North Africa, such as the Gambra Partridge *Alectoris 9aurian* and the North African Tit *Cyanistes teneriffae* (Badis, 2023). There are also 42 species protected nationally by Decree No. 83-509 of 20 August 1983 and the Order of 15 January 1995, relating to protected non-domestic animal species. At the international level, certain species are listed by the African Convention on the Conservation of Nature and Natural Resources (Algiers Convention 1968) at the level of Annexes A and B, and by the Washington Convention on International Trade in Endangered Wild Animals in 1975 (BNEDER, 2010).

The region's wild animals include 33 species (30.55% of the national total), seven orders, 18 families, and 27 genera (Kawalski & Rzebik–Kowalska, 1991). Among these taxa, 11 species are protected at the national or international level, including the Striped Hyena *Hyaena hyaena*, the Porcupine *Hystrix cristata*, and the Greater Horseshoe Bat *Rhinolophus ferrumequinum*, which are on the International Union for Conservation of Nature's Red List (BNEDER, 2010). Throughout the Aurès region, Chiro and Blanc (1997) counted 41 species of avian and ophidian species of Mediterranean (20 species), Saharan (19), and tropical (2) origin. Among these taxa, 14 are protected at the national level and two at the international level. Only the Moorish tortoise *Testudo graeca* is included in the IUCN Red List (BNEDER, 2010).

3. Forest Biodiversity

3.1. General definition and importance of forest biodiversity

Forest biodiversity refers to the variety and variability of all life forms found within forest ecosystems, including trees, understory vegetation, soil organisms, and fauna of all sizes. Forests represent some of the most biologically rich terrestrial ecosystems on Earth, functioning as critical providers of ecosystem services such as carbon sequestration, oxygen production, water regulation, and erosion control (FAO, 2020). In Algeria, forest ecosystems—particularly in the Aurès Mountains, including Chelia and Ouled Yagoub—are shaped by Mediterranean climatic influences and altitudinal gradients, creating ideal conditions for rich biodiversity (Badis & Hamdi, 2022).

The ecological uniqueness of these Algerian forests stems from their biogeographic positioning, where the Mediterranean, Saharan, and European regions intersect (Quézel & Médail, 2003). The combination of geological complexity, climatic variability, and human influence creates mosaics of microhabitats that support diverse communities. These include cedar, oak, and pine, pure and mixed forests, along with extensive shrub and herbaceous layers. Such forest types are especially sensitive to anthropogenic disturbances like logging, grazing, and wildfires (Benhouhou et al., 2013).

We chose to conduct our research in this region because of its strategic ecological value and the lack of detailed faunal data, especially concerning soil macrofauna. As forests worldwide face increasing threats from climate change and land-use change, understanding biodiversity at all trophic levels becomes imperative for sustainable forest management and conservation planning.

3.2. Faunal diversity in forest ecosystems: macroinvertebrates and detritivores

Soil macroinvertebrates, particularly detritivores, are some of the most ecologically important organisms in forest ecosystems. They play an essential role in processes of decomposition, nutrient cycling, and soil structure enhancement. Forest litter is composed of decaying previously living matter (fallen leaves, wood and detritus from those), and it is a very rich habitat for detritivores and decomposers, containing a wide range of organisms such as earthworms, springtails (*Collembola*), millipedes (*Diplopoda*), and terrestrial isopods (*Isopoda: Oniscidea*) (Lavelle et al., 2006).

Detritivores play a fundamental role in maintaining forest soil health. Through their feeding activities, they fragment organic matter, stimulate microbial activity, and facilitate mineralization. This creates a biologically active soil layer that supports plant growth and affects above-ground biodiversity. In our study context, the dense litter layers observed in the humid forest plots offered prime microhabitats for such fauna, suggesting a positive link between litter richness and faunal abundance (Lavelle et al., 2006).

In the Chelia and Ouled Yagoub forests, changes in faunal diversity were observed across altitudinal and moisture gradients, with moister and less disturbed zones harboring a higher density and diversity of macroinvertebrates. This confirms observations from other Mediterranean forests, where biodiversity hotspots often correlate with habitat stability and structural complexity (Decaëns et al., 2006).

3.3. Role of biodiversity in soil health and ecosystem functioning

Soil biodiversity, particularly of macro-decomposers, plays a central role in regulating essential ecological processes such as organic matter decomposition, nutrient cycling, and the maintenance of soil physical structure. In forest ecosystems, the interactions between biotic and abiotic components result in feedback mechanisms that influence primary productivity, carbon storage, and resilience to disturbance (Brussaard et al., 2007).

The presence and activity of diverse detritivore communities in our study plots directly reflected soil condition and habitat quality. Rich assemblages of decomposers indicate high organic input and moisture retention, both of which are hallmarks of stable forest ecosystems. Furthermore, such biodiversity supports trophic interactions, offering prey for amphibians, reptiles, and birds (Brussaard et al., 2007)

Our research adds to the growing body of evidence emphasizing the ecological necessity of soil fauna for the functioning of forest ecosystems. Despite their critical importance, soil organisms are often underrepresented in conservation strategies. In regions like the Aurès Mountains, where baseline ecological data remain scarce, documenting and understanding soil biodiversity is an essential step toward integrated forest management.

Chapter II: Terrestrial Isopods

1. General introduction to Oniscidea (Terrestrial Isopods)

1.1. Definition of Oniscidea

Oniscidea, scientifically known as terrestrial isopods or woodlice (Figure 2), is a suborder of fully terrestrial crustaceans, meaning they live exclusively on land. In contrast to aquatic taxa, Oniscidea have modified their morphology and physiology to accommodate terrestrial habitat environmental conditions. In fact, they have developed ventilatory structures known as pseudotracheae, enabling gas exchange in air, and developed a multitude of behavioural and physiological adaptations to reduce loss of water (Broly et al., 2013).

Terrestrial isopods are important to ecosystems in multiple ways. The breakdown of organic matter by terrestrial isopods is beneficial ecologically and increases soil development in terrestrial environments. Furthermore, terrestrial isopods are consumed by many different predators. The evolutionary success of terrestrial isopods is related to their ability to take advantage of several environments, including leaf litter, decaying wood, and other urban environments (Carew, 2000).

Figure 2: Terrestrial isopod observed in forest soil in Ouled-Yagoub forest, Khenchela, Algeria (Photo: Messaoudi and Rezaikia, November 2024)

1.2. Importance of Oniscidea in terrestrial ecosystems

Oniscidea play a critical role in the functioning of ecosystems. As detritivores, they expedite decay processes by breaking up organic materials, making nutrients more available to microbes and plants (Loureiro et al., 2006). Their feeding activity improves soil aeration and structure, which enhances water infiltration and diversity of microbiological habitats (Sfenthourakis & Taiti, 2015). Furthermore, they are bioindicators of soil quality due to their sensitivity to pollutants such as heavy metals and pesticides.

2. Taxonomy and Classification

Oniscidea is a part of the class Malacostraca, order Isopoda, and suborder Oniscidea. Multiple families in this suborder have unique morphological adaptations to life on land (Schmalfuss, 2003). Below is their taxonomic hierarchy (Schmalfuss, 2003; Sfenthourakis et al., 2014)

- **Kingdom:** Animalia
- **Phylum:** Arthropoda
- **Subphylum:** Crustacea
- **Class:** Malacostraca
- **Order:** Isopoda
- **Suborder:** Oniscidea

Infraorders and major superfamilies:

- Tylomorpha (primitive terrestrial forms), Microcheta (intermediate forms)
- Crinocheta (the most advanced and widespread terrestrial isopods)

Notable families

- *Armadillidiidae:* Characterized by the ability to conglobate (roll into a ball) as a defense mechanism (Taiti & Ferrara, 1996).
- *Porcellionidae*: Contains common species with well-developed body armor and

high adaptability to urban environments, often used in ecological studies (Hornung, 2011).

- *Trichoniscidae:* Represents smaller species often found in moist microhabitats; some species are adapted to cave environments (Sfenthourakis & Taiti, 2015).
- *Ligiidae:* One of the least specialized families, often retaining semi-aquatic tendencies (Broly et al., 2013).

3. Morphological characteristics of terrestrial isopods

The morphology of terrestrial isopods is the primary basis for their identification and classification. Most classification schemes rely on external morphological characters viewed under a stereomicroscope (and sometimes without one!). These characters are typically stable and statistically significant at the species level and are easily or generally used on dichotomous keys (Schmalfuss, 2003; Hornung, 2011; Taiti & Ferrara, 1996).

Terrestrial isopods exhibit a body plan that is characteristic of crustaceans, with adaptations for terrestrial life. Their body is dorsoventrally flattened and segmented, ranging in size from about 5 to 20 millimeters long, and is divided into three general tagmata: the head (cephalon), the thorax (pereon), and the abdomen (pleon) (Figure 3) (Schmalfuss, 1984).

The head has a pair of compound eyes, a pair of antennae, and mouthparts. Oniscideans have two pairs of antennae, although only the second pair is obvious; the first is only a sensory organ that is reduced. Their mouthparts include mandibles with molar and incisor processes, maxillulae, and maxillae adapted for scraping and processing detritus (Schmalfuss, 1998; Hornung, 2011).

The pereon is made up of 7 segments (the first part of the thorax), or pereonites, with each one having a pair of walking legs (pereopods). The pereopods are essentially identical and used for movement. The top of each segment is covered by a hard plate, a pereonite, to provide structural protection (Brusca et al., 2016).

The pleon has five distinct segments, and the terminal segment, called the telson, is flanked by uropods. In Oniscidea, pleopods (underdeveloped appendages on the pleon) are flattened and modified into respiratory structures called pleopodal lungs, which are capable of gas exchange in a terrestrial environment. The pleopods also provide support for water retention, which is vital for resisting desiccation, particularly in arid environments (Wright & Ting, 2006; Hornung, 2011).

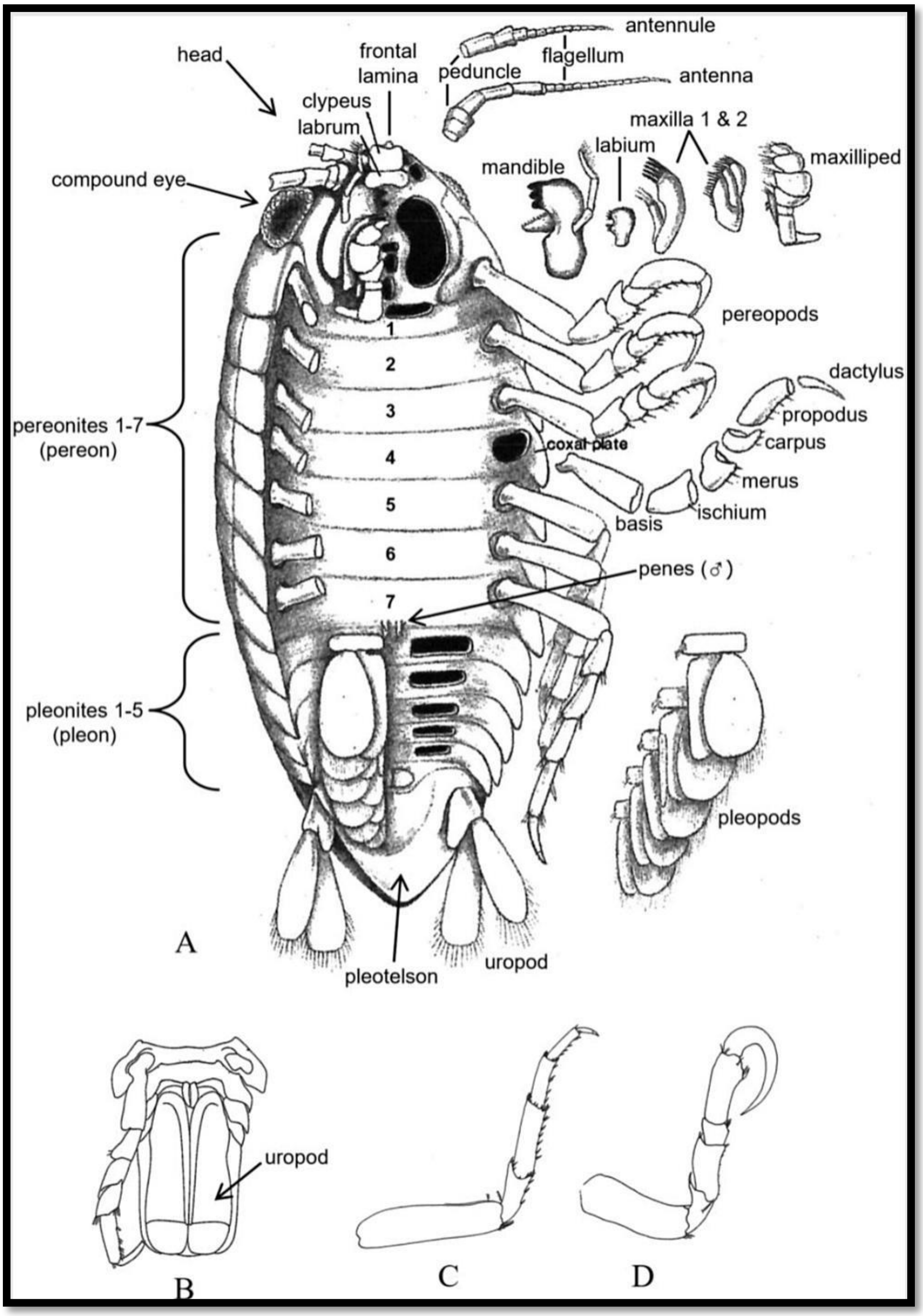

Figure 3: A Generalized isopod body plan (modified after Kensley and Schotte 1989: fig. 2). B. Ventral view of valviferan pleon and pleotelson showing opercular uropods (after Poore and Lew Ton 1993: fig. 25). C example of ambulatory pereopod (after Brusca 1983a: fig. 11 G). D example of prehensile pereopod (after Brusca 1983a: fig. 11F)

4. Historical context

4.1. Evolutionary history of Oniscidea

The transition of terrestrial isopods serves as a case study in the ability of crustaceans to adapt to terrestrial life. Isopods began in the marine realm in the Carboniferous period (c. 300 million years ago) and then transitioned to life on land (Broly et al., 2013). The evolution of Oniscidea is inextricably linked to the Order Isopoda, including marine and freshwater species. The transition to land involved a gradual evolution of many morphological and physiological traits from an aquatic environment to a physical environment, including changes to respiratory structures and features that promote water retention (Lins et al., 2017).

Fossil evidence indicates that the oldest terrestrial isopods were found in the Mesozoic era and include fossilized specimens exhibiting some characteristics associated with modern Oniscidea (Schmalfuss, 2003). Furthermore, molecular phylogenetic studies have corroborated that Oniscidea evolved from marine ancestors, and the family Ligiidae occupies the intermediate state between aquatic and fully terrestrial (Sfenthourakis & Taiti, 2015).

Fossilized early terrestrial isopods are an important part of the story of their evolution. The oldest fossils with terrestrial adaptations are from the Jurassic period (~ 160 million years ago) (Schmalfuss, 2003). The Jurassic fossils show thickened exoskeletons and modified forms of pleopods, and as such, represent functional shifts that could indicate the transition from marine to terrestrial life.

Paleontological evidence has recently shown that more than one taxon of Oniscidea has seemingly evolved in parallel and differentiated from each other in many locations. Based on fossils from Europe and North America, it seems that isopods must have evolved into terrestrial conditions at different times (Taiti & Ferrara, 1996). That is, it seems that the selective pressure for moving from aquatic to terrestrial life was so strong that they evolved in parallel efficiently.

4.2. Adaptations that facilitated the transition to terrestrial habitats

The transition from aquatic to terrestrial habitats produced large selective pressures on isopods, resulting in important evolutionary adaptations:

- **Respiratory adaptations:** The evolution of pleopodal lungs (pseudotracheae) enabled Oniscidea to breathe air efficiently while reducing water loss (Hornung, 2011).
- **Exoskeletal modifications:** The waxy cuticle found in many species, such as *Armadillidium vulgare*, minimizes desiccation (Taiti & Ferrara, 1996).
- **Behavioral adaptations:** Many terrestrial isopods exhibit photonegative behavior (avoiding light) and prefer humid microhabitats to reduce dehydration (Paoletti & Hassall, 1999).
- **Reproductive changes:** Unlike their aquatic relatives, terrestrial isopods have direct development, meaning they bypass a free-swimming larval stage, which reduces their dependence on water bodies (Lins et al., 2017).

5. Geographical distribution

5.1. Global distribution of Oniscidea

Terrestrial isopods are distributed from the tropics to desert ecosystems and from Asia to Cape Horn (Schmalfuss, 2003). The distribution of isopods is related to climate, available habitat, and historical biogeographic events. Comparison at a global scale indicates that isopoda diversity is greatest in warm, humid regions with sufficient water supply (Hornung, 2011).

Schmalfuss (2003) examined over 3,700 species of terrestrial isopods, representing 35 different families. These species were predominantly abundant either in Mediterranean climates, tropical rainforests, or temperate woodlands. The numbers in extreme deserts, or at high altitudes, are underrepresented, due to their desiccation (Sfenthourakis & Taiti, 2015).

5.2. Diversity hotspots

Oniscidea have several major diversity hotspots corresponding to the Mediterranean Basin, tropical areas, and some islands (Sfenthourakis et al., 2014). These regions provide high species richness because of stable climatic conditions and complicated habitat structure. Major diversity hotspots are:

- **Mediterranean basin:** High species richness due to long-term climate stability and habitat heterogeneity (Sfenthourakis & Taiti, 2015).
- **Neotropical region:** Presence of unique genera adapted to high humidity and complex forest ecosystems (Schmalfuss, 2003).
- **Southeast Asia:** Rich biodiversity, including many undescribed species, particularly in leaf litter and cave habitats (Taiti & Ferrara, 1996).
- **Islands:** High endemism due to geographic isolation and unique evolutionary pressures (Schmalfuss, 2003).

5.3. Endemic Terrestrial Isopods of the Maghreb Region

There are a number of terrestrial isopod species that are considered endemic to the Maghreb, highlighting an intriguing biogeography of North African ecosystems. For example, the desert woodlouse *Hemilepistus reaumuri* can be found in Algeria and Saharan areas of North Africa, and is particularly well-known for its burrowing abilities, the formation of family-based nests, and its ability to survive in the driest habitats for crustaceans (Linsenmair, 1989; Broly et al., 2013).

There is also the species *Porcellio variabilis,* which is also endemic to this region (Medini & Charfi, 1998a), more specific to low-temperature diurnal range habitats (Benchana et al., 2025). In the same genus, *Porcellio simulator* is more tolerant and can be found in a dry environment (Medini & Charfi, 1998b; Benchana et al., 2025). Belonging to the *Armadillidiidae* family, *Armadillidium tunisiens* is a recently discovered species, whose distribution is exclusively restricted to Tunisia (Hamaïed et al., 2008).

6. Interactions with the Environment

6.1. Contribution to nutrient cycling and decomposition of organic matter

Terrestrial isopods have an important role in nutrient cycling through decomposition, primarily of detritus components like leaf litter and decaying plant matter (Zimmer, 2002). Their feeding activity contributes to the organic material decomposition process, of which the isopods add to the breakdown of organic matter and possibly increase its bioavailability for microbial decomposers (David & Handa, 2010).

There are many examples of the impact of Oniscidea being measured in terms of litter decomposition. For example, Hassall et al. (1987) showed that Oniscidea were a significant factor in the release of nitrogen and phosphorus while decomposition occurred, which in turn increases the demand for plant nutrient availability, namely nitrogen and phosphorus. Moreover, Zimmer (2002) provided evidence that when Oniscidea fed on leaf litter, it stimulated microbial activity by the extraction of previously hidden inner leaf tissue from subsequent bacterial and fungal colonization.

Isopods also affect soil organic matter formation by mixing decomposed material with mineral particles. Their fecal pellets are important in developing soil structure, which preserves aeration and water (Souty-Grosset et al., 2005). In ecosystems with a high presence of isopods, litter decomposition rates are faster, and soil fertility supports plant growth (David & Handa, 2010).

6.2. Microbial interactions

- **Fungi:** Oniscidea often ingest fungal spores, aiding in their dispersal and influencing decomposition processes (Zimmer, 2002).
- **Bacteria:** Certain gut bacteria help isopods digest cellulose-rich plant material, enhancing nutrient assimilation (Souty-Grosset et al., 2005).
- **Soil microbial diversity:** Increased isopod activity correlates with higher microbial diversity, as their feeding and burrowing create heterogeneous microhabitats (David & Handa, 2010).

6.3. Predation and symbiotic relationships within soil ecosystems

It is not unexpected that hard-shelled terrestrial isopods can be consumed by many predators. These predators consist of spiders, centipedes, birds, and amphibians (Souty-Grosset et al., 2005). Some predators, like carabid beetles, have in some cases specifically evolved to eat isopods, especially when they show a defensive response (David & Handa, 2010).

Symbiotic interactions also play a role in Oniscidea ecology:

- **Parasites:** Some isopod species are hosts to parasitic fungi (Laboulbeniales), which affect their survival and reproduction (Loureiro et al., 2006).

- **Commensal bacteria:** Isopods harbor bacterial symbionts that aid in nitrogen fixation and digestion (Zimmer, 2002).
- **Mite associations:** Certain mites live on isopods, either as commensals or parasites, impacting their energy balance (Hassall et al., 1987).

7. Factors influencing distribution and abundance

7.1. Climate

The distribution and density of terrestrial isopods populations is strongly dependent on climate, and mainly humidity and ambient temperature which influence how physiologically fit they are (Chown & Nicolson, 2004; Benchana et al., 2025) Climate change could also negatively affect the Oniscidea due to alterations in humidity and temperature which may affect the range of potentially available area (Hornung, 2011).

- **Humidity:** Obviously, water availability plays a key factor in limiting the geographical ranges of isopods. In Mediterranean geographical areas, for example, the local populations in dry seasons concentrate in shaded microhabitats or damp microhabitats (Souty-Grosset et al., 2005).
- **Temperature:** Oniscidea can be killed by extreme temperatures. Most species are found in environments between 10°C and 25°C (Loureiro et al., 2006). Extremely high temperatures increase water loss, and extreme cold pulls down metabolic rates and slows reproduction rates. Most temperate region species hibernate in soil crevices during winter (Hassall et al., 1987).
- **Seasonality:** There are seasonal densities of Oniscidea, with spring and autumn reproduction and activity periods correlated with a peak of moisture availability (David and Handa, 2010; Benchana et al., 2025).

7.2. Humans

Urbanization and alterations in land-use practices have transformed the distribution of isopods dramatically. Habitat destruction or fragmentation reduces habitat availability, declines specialist species, and provides favorable habitats for more generalist species that can adapt to disturbed niches (Souty-Grosset et al., 2005).

- **Deforestation and agriculture:** Land clearing reduces the availability of leaf litter and moisture-retaining habitats, leading to species declines (David & Handa, 2010).
- **Pollution:** Heavy metal contamination, pesticides, and industrial pollutants affect isopod physiology and reproductive success (Loureiro et al., 2006). Some species accumulate toxic elements, making them useful bioindicators (Hopkin, 1990).
- **Urban habitats:** Urban areas have many artificial microhabitats (e.g., gardens, walls, basements) that provide habitat for adaptable species, such as *Porcellionides pruinosus* (Hornung, 2011), therefore decreasing isopod diversity. Urban pollution would probably account for the overall lack of diversity (Souty-Grosset et al., 2005).

8. Oniscidea as Bioindicators

Terrestrial isopods are often utilized as biological indicators of ecosystem condition due to their sensitivity to changes in soil conditions, such as pollution levels or habitat degradation. In addition, they rely on stable microclimatic conditions, making them good organisms for detecting ecosystem disturbances (Paoletti & Hassall, 1999; Dallinger et al, 1992). The presence and abundance of terrestrial isopods, along with their physiological response under specific conditions, enable estimations of soil quality, pollution (i.e., acceptable levels), and habitat stability (Hopkin, 1990).

The presence of terrestrial isopods represents the biological realm of myriapod and insect diversity, reflecting larger ecological and evolutionary patterns. Terrestrial isopods can act as potential indicators in studies of biogeography and conservation (Sfenthourakis et al, 2014). Possible future uses include using isopod-based bioindicators as part of standard soil health assessments, as well as in future global protocols for monitoring soil health (David & Handa, 2010).

Material And Methods

1. Study Site

The study was conducted in the Ouled Yagoub National Forest (Aurès Mountains, eastern Algeria) in the province of Khenchela. Its area is about 296.6 km2 (29,000 hectares) and it occupies part of the Aurès Mountains (Lakhdari et al., 2024). The topography of the region is highly varied. The landscape is dominated by steep slopes, narrow valleys, and a series of small, irregular ridges. These geomorphological features produce a heterogeneous terrain and provide for many different microhabitats. It is considered an ecologically important zone due to its diversity of vegetation species and altitudinal gradients. The elevation above sea level (a.s.l.) in the study area is from approximately 1200 m to 2326 m.

To investigate the diversity and spatial distribution of terrestrial isopods (Oniscidea), four types of forest were selected (Figure 4), each representing different ecological conditions: (1) a cedar forest with predominant tree growth of Cedrus atlantica; (2) a pine mixed forest with Pinus halepensis and other broadleaf species; (3) a pine pure forest largely of Pinus halepensis; and (4) a burned forest that had been previously affected by wildfire. These forest types were chosen to reflect variations in vegetation structure, canopy cover, and soil conditions.

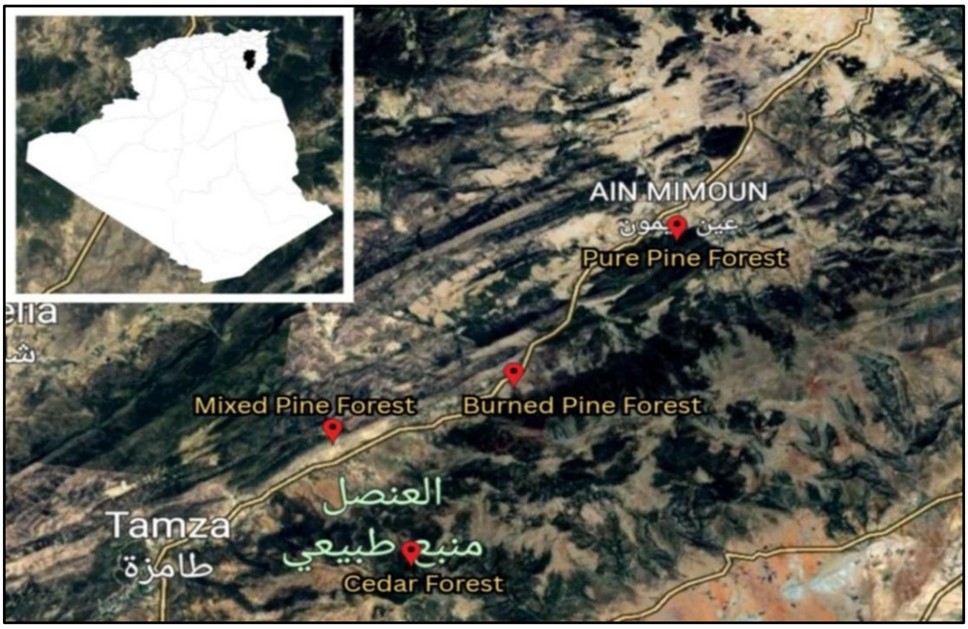

Figure 4: Satellite view of the four sampling sites in Ouled Yagoub National Park.

1.1. Burned Forest

This burned forest site (Figure 5), located at an altitude of approximately 1309 meters and positioned at coordinates 35.366917°N, 6.916645°E, represents an area recently affected by wildfire. The fire drastically transformed the original vegetation and soil structure, leaving behind a landscape dominated by sparse undergrowth, charred tree trunks, and a significant reduction in canopy cover. Litter accumulation is minimal due to disrupted decomposition processes. The site falls within a semi-arid bioclimatic stage with cool winters, receiving around 594 mm of annual rainfall, and experiencing temperatures ranging from 0.9°C in winter to 35.8°C in summer. The soil is typically dry, exposed, and prone to erosion and temperature fluctuations, making it a challenging habitat for soil invertebrates. This disturbed environment serves as a contrasting model for studying species resilience and recolonization after environmental stress.

Figure 5: Burned pine forest sampling site in the Ouled Yagoub forest (Photo: Messaoudi and Rezaikia, November 2024).

1.2. Cedar Forest

This site is (Figure 6), located at an altitude of approximately 1572 meters, with vegetation primarily composed of Atlas cedar (Cedrus atlantica) and Holm oak (Quercus ilex), forming a mixed canopy that provides considerable shade and organic litter. The area falls within the sub-humid bioclimatic stage with cool winters, receiving an average annual rainfall of 672 mm and experiencing temperatures ranging from 0.15°C to 34.5°C. The forest floor is covered with a thick layer of decomposing organic matter, offering a favorable microhabitat for soil invertebrates. The dense canopy reduces sunlight exposure and helps maintain soil humidity, which may support a more stable and diverse soil fauna. The sampling point within this forest is located at the coordinates 35.328402°N, 6.885288°E.

Figure 6: Sampling site in the cedar forest of Ouled Yagoub (Photo: Messaoudi and Rezaikia, November 2024).

1.3. Mixed Pine Forest

This forest site (Figure 7) is situated at an average altitude of 1429 meters and is characterized by a mix of Aleppo pine (Pinus halepensis) and Holm oak (Quercus ilex). The vegetation structure offers a moderately shaded understory with a relatively rich layer of litter and organic matter. The area falls under the semi-arid bioclimatic stage with cool winters, receiving an average annual rainfall of 672 mm, and temperatures ranging between 0.15°C and 34.5°C. These environmental conditions support a dynamic soil ecosystem, where moisture retention and vegetation heterogeneity may favor diverse soil fauna communities. The sampling location in this forest was recorded at the coordinates

35°20'45"N, 6°52'20"E.

Figure 7: Sampling site in the mixed pine forest of Ouled Yagoub (Photo: Messaoudi and Rezaikia, November 2024).

1.4. pure pine forest

Located at an average altitude of 1095 meters, this site (Figure 8) is dominated by a relatively homogenous stand of Aleppo pine (Pinus halepensis). The vegetation structure provides moderate canopy coverage, with a well-defined litter layer composed mainly of pine needles, contributing to slightly acidic soil conditions. This forest falls within the semi-arid bioclimatic stage with cool winters, receiving approximately 594 mm of annual precipitation. Temperature variations range from 0.9°C to 35.8°C, creating conditions that may influence soil moisture availability and organic decomposition rates. The homogeneity of the plant cover contrasts with mixed or disturbed habitats, offering insight into species preferences for more stable environments. The coordinates for this sampling site are 35.4103576°N, 6.9545723°E.

Figure 8: Sampling site in the pure pine forest of Ouled Yagoub (Photo: Messaoudi and Rezaikia, November 2024).

Table 1: Environmental Characterization of Ouled Yagoub Forest

Forest	Altitude (m)	Dominant vegetation	Bioclimatic Stage	Rainfall (ml)	T° (min–max) (c°)
Cedar	1572	Atlas Cedar + Holm Oak	Subhumid with cool winters	672	0,15 – 34,5
Mixed pine	1429	Aleppo Pine + Holm Oak	Semi-arid with cool winters	672	0,15 – 34,5
Pure pine	1095	Aleppo Pine	Semi-arid with cool winters	594	0,9 – 35,8
Burned pine	1309	Undergrowth	Semi-arid with cool winters	594	0,9 – 35,8

2. Field Work

2.1. Sampling

To conduct a comprehensive study of terrestrial isopod communities across different habitat types, four sampling campaigns were carried out during November, December 2024. Each campaign targeted one of the four forest types present in the Ouled Yagoub Forest. In each of these forest types—burned pine forest, cedar forest, mixed pine forest, and pure pine forest—a fixed sampling station was established based on the representativeness of the site and its accessibility.

In each sampling station, five 1 × 1 meter quadrats (Figure 9) were distributed randomly in parts ecologically representative of that forest type. Microhabitat selection attempted to cover a variety of local conditions (shade, litter cover, moisture) in order to obtain a more dependable picture of the isopod population and its variability. Quadrats were tagged and geolocated for spatial consistency and ease of access on repeat visits.

Figure 9: Quadrat (1 × 1 m) used for sampling at a Ouled Yagoub Forest site (Photo: Messaoudi and Rezaikia, November 2024).

Each site was visited between three and four times, depending on logistical constraints and weather conditions. The multiple visits ensured temporal replication and increased the probability of detecting species that may be more active or visible at different times. All sampling was conducted during daylight hours and under relatively stable climatic conditions to minimize variability due to temperature or humidity shifts that could influence isopod surface activity.

During each visit, we searched each quadrat for visible isopods. The collection was done by hand for a standard duration of 30 minutes per quadrat. We carefully turned over stones, decaying wood, and leaf litter to detect invisible and well-covered individuals while minimizing habitat disturbance.

To support further ecological interpretation, soil samples were collected from each quadrat immediately after isopod collection. Using a hand shovel (Figure 10), approximately 500 grams of soil were removed from a depth of 5 to 10 cm, placed in labeled plastic bags, and transported to the laboratory for granulometric analysis.

Figure 10: Hand shovel used for collecting soil samples during terrestrial isopod sampling in Ouled Yagoub Forest (Photo: Messaoudi and Rezaikia, November 2024).

The fieldwork was made possible through a combination of transportation methods. Most of the campaigns were carried out using our vehicles, allowing efficient access to the forest sites. On one occasion, due to vehicle unavailability, the site was accessed by motorbike. This logistical detail, while minor, reflects the adaptability and determination of the research team in ensuring data collection continuity across all designated sampling locations.

2.2. Conservation

Following the in-situ collection of terrestrial isopods and soil, extreme care was taken for the preservation of the environmental and biological material to ensure that its integrity would not be lost in the course of subsequent laboratory analysis. Proper preservation was essential for proper taxonomic identification as well as valid soil characterization.

Immediately after collection, terrestrial isopods were placed in labeled plastic containers for each quadrat and forest type (Figure 11). In the field, specimens were temporarily stored in 90% ethanol to initiate the fixation process. This high concentration ensured the rapid penetration of tissues, preventing enzymatic degradation and preserving delicate morphological structures that are critical for species-level identification. Each vial was marked with detailed information, including forest type, quadrat number, date of collection, and geographic coordinates, ensuring clear traceability throughout the study.

Figure 11: Specimen vials containing preserved terrestrial isopods collected from Ouled Yagoub Forest (Photo: Messaoudi and Rezaikia, November 2024).

Once transported to the laboratory, the specimens were transferred from 90% to 70% ethanol. This change is a standard practice in biological preservation: while 90% ethanol is effective for fixation, 70% is more suitable for long-term storage, as it prevents over-dehydration of soft tissues while still preventing microbial activity. The vials were sealed tightly and stored in a cool, dark room to avoid ethanol evaporation and light-induced degradation. The labeling system was maintained precisely throughout this process, allowing for systematic archiving and ease of access during later identification sessions.

In parallel, soil samples collected from each quadrat were preserved in clearly labeled plastic bags to prevent cross-contamination (Figure 12). Also, they were allowed to air-dry at room temperature. This natural drying method preserved the soil's textural properties without altering its composition. This standard method allowed for the quantitative assessment of the relative proportions of sand, silt, and clay.

Figure 12: Soil samples collected from various Ouled Yagoub Forest sites for granulometric and ecological analysis (Photo: Messaoudi and Rezaikia, November 2024).

All storage containers, whether for specimens or soil samples, were organized in a dedicated workspace with proper environmental controls. The careful conservation of these materials was fundamental for ensuring data quality in both the biological and Soil-based analyses that followed.

Through the implementation of strict conservation protocols, this phase of the research made it possible for the biological samples to retain their diagnostic characteristics and for soil properties to remain indicative of field conditions. Such preparations thus made proper laboratory testing possible and enabled the overall scientific integrity of the research.

3. Laboratory

3.1 Identification

The identification of terrestrial isopod specimens was carried out in the laboratory using a Leica MS5 stereomicroscope. This task was conducted by our co-supervisor, Dr. Imane Benchana, at the Research Laboratory of Diversity, Management, and Conservation of Biological Systems at the University of Tunis El Manar, Tunisia.

Species determination was based on recognized morphological identification keys, with particular reference to Vandel (1962). In addition, comparative examinations were carried out using three terrestrial isopod collections: Dr. Benchana's reference collection, focused on specimens from Algerian oases, Pr. Medini-Bouaziz's collection, encompassing species from across Tunisia, and North African specimens housed in the collections of the National Museum of Natural History in Paris, France.

In some of the determinations, she had to examine very small morphological features to determine whether organisms belonged to different species, especially when the species had similar overall morphology. In some cases, she relied on relatively minor distinguishing features, such as the shape of pleopod VI or the construction of an antenna, or lateral and medial lobes, where one had to carefully rotate and view the specimen in the best light and with magnification. The high level of precision and intensity required her to be extremely careful to ensure that she was not misidentifying specimens by missing these fine structures, which sometimes contributed to specimens taking longer to examine and classify.

Figure 13: Stereomicroscope setup with terrestrial isopod specimens for identification and comparison (Photo: Benchana I, February 2025).

3.2. Soil analysis

To gain better information on the environmental parameters regulating Oniscidea distribution and diversity, soil samples were collected at each of the study sites during the field campaign. The samples were transported to the laboratory for granulometric analysis, which was carried out using a " sieve shaker « with meshes from 4 mm to 125 µm (Figure 14). This method allowed us to determine the distribution of soil particle sizes, which plays an important role in soil texture and structure, key factors that influence the habitat suitability for soil-dwelling organisms such as terrestrial isopods.

In addition to the granulometric analysis, the SoilGrids online platform was used to acquire more information regarding the soil characteristics at each location. The geographical coordinates of the sampling locations were inputted, and the platform provided probabilistic estimations of soil parameters using global digital soil mapping data. Some parameters that were utilized include organic carbon density, soil organic carbon stock, bulk density, clay content, and coarse fraction proportion. These parameters are important to help understand the soil's physical and chemical properties that could affect the presence and distribution of the Oniscidea species.

Figure 14: Sieve shaker used for granulometric soil analysis (Photo: Messaoudi and Rezaikia, January 2024).

Table 2 (A): Summary of SoilGrids data results for sampling sites in Ouled Yagoub Forest.

Forest	**Organic carbon density (kg/m³)**	**Soil organic carbon stock (g/kg)**	**Bulk density (g/cm³)**	**Clay content (g/kg)**	**Coarse fragments (g/kg)**
Cedar	4.98	401.8	1.24	124.4	243.0
Mixed pine	3.35	251.8	1.33	137.2	245.0
Pure Pine	3.82	287.4	1.33	137.0	251.0
Burned Forest	4.81	382.0	1.26	128.4	242.0

Table 2 (B): Summary of SoilGrids data results for sampling sites in Ouled Yagoub Forest.

Forest	Sand (g/kg)	Sand (g/kg)	Silt (g/kg)	Vol. water at -10 kPa (%)
Cedar	404.4	404.4	348.8	341.2
Mixed pine	436.8	436.8	322.4	348.0
Pure Pine	432.8	432.8	318.4	347.0
Burned Forest	430.4	430.4	340.0	360.0

Table 2 (C): Summary of SoilGrids data results for sampling sites in Ouled Yagoub Forest.

Forest	Vol. water at -1500 kPa (%)	Cation exchange capacity (cmol+/kg)	Nitrogen (g/kg)	Soil organic carbon (g/kg)
Cedar	143.6	185.2	405.8	450.4
Mixed pine	153.0	178.0	217.0	243.0
Pure Pine	139.0	168.0	240.0	288.0
Burned Forest	138.0	186.0	370.0	431.0

4. Data Analysis

4.1. Ecological indicators

Indicators are meant to inform us simply and quickly about something of interest. They provide information about conditions, and eventually about changes and trends. Like economic indicators, environmental indicators are needed because it is not possible to monitor everything (National Research Council, 2000).

Ecological indicators may be used to quantify the condition of the environment, to provide an early warning indicator of change in the environment, or to determine the cause of an environmental problem. Ideally, the set of indicators should capture key information about the structure, function, and composition of the ecological system (Dale et al., 2001).

Ecological data graphs and visualizations were created using the Python programming language. This tool was used to generate figures illustrating species richness, diversity indices, and the relationship between environmental variables and isopod distribution. Its use allowed for consistent and precise representation of the study's analytical results.

4.1.1. Species richness

Species richness (s) can be described as the number of a given taxon in the chosen assemblage (Magurran, A. E. 2004).

4.1.2. Relative frequency

The Relative Frequency Index (RFI) is an ecological metric that expresses how often a species appears in a set of samples relative to other species. It is used to assess species distribution and community structure in ecological surveys (Kent, M, 2012).

$$\mathrm{RFI} = \frac{\text{frequency of species}}{\text{total frequency of all species}} \times 100$$

Frequency of a species: Number of samples (plots/quadrats) where the species occurs.

Total frequencies: total number of times all species appear across plots.

4.1.3. Constancy index

The Constancy Index (C) expresses the percentage of sampling units (quadrats or plots) in which a species occurs (Braun-Blanquet, J, 1932). Ecologist Josias Braun-Blanquet introduced constancy classes to interpret this percentage:

- If a species appears in 1–20% of the plots: → It is considered rare in the study area (Constancy Class I).

- If a species appears in 21–40% of the plots: → It is considered occasional (Constancy Class II).
- If a species appears in 41–60% of the plots: → It is considered frequent (Constancy Class III).
- If a species appears in 61–80% of the plots: → It is considered common (Constancy Class IV).
- If a species appears in 81–100% of the plots: → It is considered constant or very frequent (Constancy Class V).

4.1.4. Shannon index

The Shannon-Weaver index (H') measures the uncertainty regarding the membership of a species in a population (Scherrer, 2007). H' expresses the proportion of each species and has the advantage of being independent of the sample size. H' is established according to the Formula (M. Diédhiou et al 2014):

$$\mathbf{H' = -\sum_{i=1}^{s} \frac{n_i}{N} \times \ln\left(\frac{n_i}{N}\right)}$$

ni is the population of species i, and N is the species richness. H' is greater as the species richness is high. H' = 0 if all individuals in the population belong to a single species. H' is maximum when all individuals are distributed equally (J. J. FARAWAY, 2004).

4.1.5. Simpson diversity index

Simpson described an index of diversity, which is a measure of the concentration of species (DeJong, 1975). Its numerical values increase as diversity decreases (Risser & Rice 1971). A standard version of Simpson's index provides a value on a probability scale from 0.0 to 1.0 in ascending order with increased diversity (DeJong, 1975).

$$\mathbf{D} = \mathbf{1} - \frac{\sum_{i=1}^{s} \boldsymbol{n_i}(\boldsymbol{n_i} - \mathbf{1})}{\mathbf{N}(\mathbf{N} - \mathbf{1})}$$

Here, S = the number of species, ni = the number of individuals of the species, and N = the total number of individuals in the sample (DeJong, 1975). The equation gives the probability that two individuals, chosen independently and at random from a population, will be from different species. Hurlbert (1971) renamed this index the "probability of interspecific encounter".

4.1.6. Pielou's fairness index

Pielou's fairness index often accompanies the Shannon index; it allows measuring the distribution of individuals within species. E (fairness index) is the ratio of observed diversity (H') to maximum diversity (H' max) (Chitti, L, et al., 2023).

$$E = H'/H\text{max}$$

H max corresponds to the diversity of a population where all taxa present have the same relative abundance. Its value is between 0 and 1; individuals are equally distributed among the species when its value is equal to 1 (Chitti et al., 2023).

When the fairness value tends towards 0, it means that the species in the environment are not in balance with each other, but there is a certain dominance of one species over the others. If, on the other hand, the value tends towards 1, it means that the species are in balance with each other (Barbault, 1981).

4.1.7. Hill index

The Hill diversity index is a measure of proportional abundance that allows H' and D to be associated (Grall et al., 2003).

$$\text{Hill} = \frac{1}{\text{D}} \left(\text{e}^{\text{H}'}\right)$$

with (1/D) the inverse of the Simpson index and (eH') the exponential of the Shannon index. The closer the index approaches the value 1, the lower the diversity (Dona, 2023).

4.2. Forest comparison

To examine the variability of abundance and species richness across the four forest types, we first assessed whether each dataset was normal by conducting the Shapiro-Wilk normality test. Both abundance ($W = 0.709$; $p < 0.01$) and species richness ($W = 0.688$; $p < 0.01$) data were non-normal; accordingly, as such we proceeded with the non-parametric Kruskal-Wallis test along with Dunn's post hoc test when significant results were observed. Because this is a preliminary study, we set the significance level at $\alpha = 0.1$ to lessen the chance of missing biologically significant trends. All statistical analyses were completed in RStudio v4.3.3 using the FSA, dplyr, and ggplot2 packages.

Results

1. Global Data

A total of 229 specimens of terrestrial isopods, representing five species, were collected from the four different forest types in the Ouled Yagoub Forest. These species include *Porcellio variabilis*, *Porcellio laevis*, *Porcellionides pruinosus*, *Armadillidium officinalis,* and *Armadillidium sulcatum*. The distribution of these specimens varied notably across the different forest environments, reflecting differences in microhabitat conditions, vegetation structure, and potential food availability.

In the burned forest, only two species were encountered. *Porcellio variabilis* was the most abundant, with 29 individuals, accounting for 12.7% of the total isopod specimens collected across all forest types. A single specimen of *Armadillidium officinalis* was also found in this forest type, representing 0.4% of the total isopod specimens.

The cedar forest harbored a slightly higher diversity, with three species recorded. *Porcellio variabilis* again dominated with 37 individuals, corresponding to 16.2% of the overall sample. *Armadillidium sulcatum* was represented by 7 individuals (3.1%), while *Armadillidium officinalis* was found in very low numbers, with only 1 specimen (0.4%).

The pine mixed forest exhibited the highest overall isopod abundance and species richness, with all five species represented. A total of 135 individuals were collected in this forest type, which corresponds to 59% of all isopods sampled. *Porcellio variabilis* was again the most numerous with 77 individuals (33.6%), confirming its dominance and ecological flexibility. *Porcellio laevis* was the second most abundant, with 44 specimens, making up 19.2% of the total specimens' number. *Porcellionides pruinosus* contributed 11 individuals (4.8%), while *Armadillidium officinalis* and *Armadillidium sulcatum* were recorded in much lower numbers, with 2 and 1 specimen(s) respectively (0.9% and 0.4%).

In contrast, the pine pure forest had the lowest diversity, with only a single species recorded. *Porcellio variabilis* was again present with 19 individuals, which represents 8.3% of the total isopod fauna. None of the other species were found in this forest type.

In summary, *Porcellio variabilis* was by far the most widespread and dominant species, accounting for 162 out of 229 specimens, or 70.7% of the total isopod population. *Porcellio laevis* and *Porcellionides pruinosus* were found exclusively in the pine mixed forest, representing 19.2% and 4.8%, respectively. The other two species were all less abundant: *Armadillo officinalis* (4 specimens, 1.75%), *Armadillidium sulcatum* (8 specimens, 3.5%), and were mostly confined to the cedar and pine mixed forests (Figure 15).

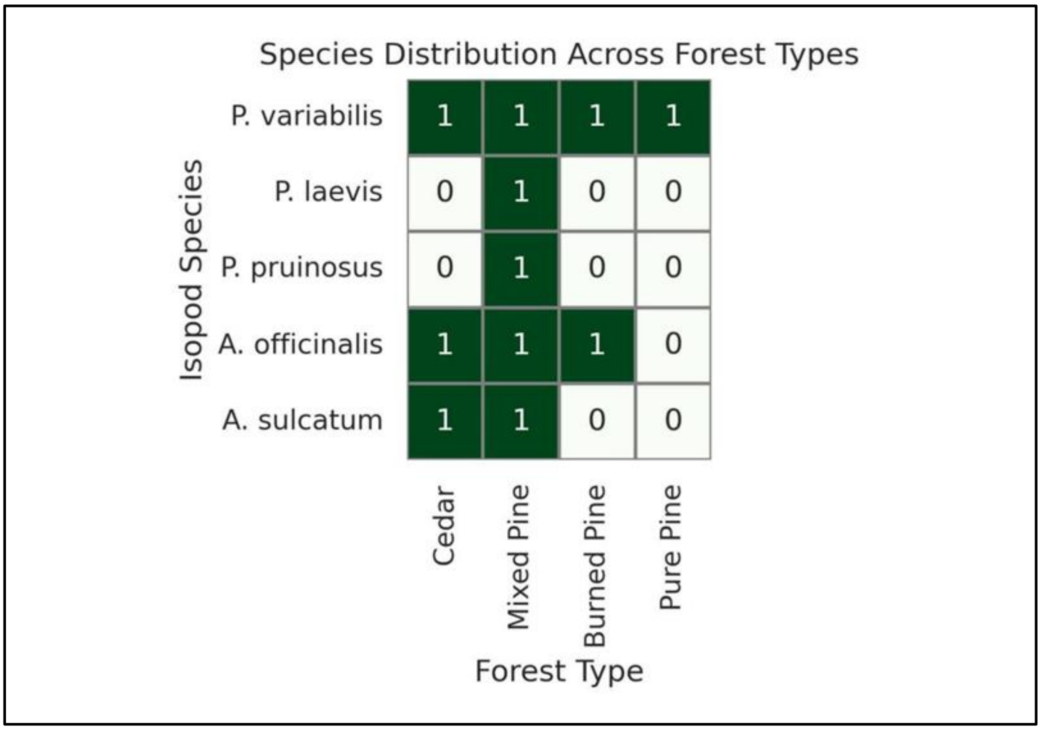

Figure 15: Habitat-specific presence of terrestrial isopods

These results demonstrate substantial variation in isopod community composition based on forest type and habitat features such as vegetation complexity, soil characteristics, and the history of disturbance. *Porcellio variabilis* dominated and had the largest range among the species, displaying its ecological plasticity, while the relatively rarer abundance of other species, particularly *Porcellio laevis* and *Porcellionides pruinosus* in pine mixed forest, indicates specific habitat preferences. Overall, the pine mixed forest was the most diverse and favorable habitat for terrestrial isopods. In comparison, pure pine and burned forests were lower in diversity, which is most likely the result of environmental factors causing stress and micro-habitat heterogeneity being limited.

2. Found Species

In total, five species of terrestrial isopods have been recognized from the samples collected at the four forest types in the Ouled Yagoub Forest. Each species represents a different morphology, habitat, and ecological role within the forest ecosystems. In the next section, we will provide a detailed account of each of the species, along with a discussion of its diagnostic characteristics, known geographical distribution, and ecological notes based on field observations and literature.

2.1. *Porcellio variabilis*

2.1.1. Morphological Description

Porcellio variabilis is a medium-sized terrestrial isopod belonging to the family *Porcellionidae* (Figure 16). Morphologically, it exhibits a dorsoventrally flattened body with a rough-textured exoskeleton. The species is characterized by its variable coloration, typically ranging from gray to brown, which aids in camouflage within its natural habitat. Notably, the species displays sexual dimorphism, with males possessing distinct morphological features such as the shape of the seventh pereopod and pleopods, which are critical for accurate identification (Medini-Bouaziz et al., 1998).

Figure 16: *Porcellio variabilis* (Photo: Benchana I)

2.1.2. Geographical Distribution

This species is endemic to the Maghreb region of North Africa, with confirmed occurrences in Tunisia, northern Algeria, and Morocco. Its distribution is primarily associated with Mediterranean-type ecosystems. In Tunisia, populations have been documented in various regions, including Béja and Chaambi, indicating a relatively wide distribution within suitable habitats (Medini-Bouaziz et al., 2006; Benchana et al, 2025).

2.1.3. Ecology

Porcellio variabilis typically inhabits open environments, often found under stones in grasslands and scrublands. It exhibits a preference for xeric habitats, demonstrating adaptability to arid conditions. The species is primarily nocturnal, seeking shelter during the day to avoid desiccation. Its ecological role includes the decomposition of organic matter, contributing to nutrient cycling within its ecosystem (Medini-Bouaziz et al., 2006).

Reproductively, *Porcellio variabilis* is iteroparous, capable of producing multiple broods during its reproductive period. Studies conducted in Béja, Tunisia, have shown that the species has a seasonal reproduction pattern, with breeding activity occurring from February to October, followed by a sexual rest phase during November, December, and January. Fecundity varies seasonally, with females producing between one to three broods per year. The gestation period ranges from 14 to 34 days, decreasing with successive broods. Energy allocation to reproduction also diminishes across broods, indicating a strategic investment in early reproductive efforts (Medini-Bouaziz et al., 2015).

2.2. *Porcellio laevis*

2.2.1. Morphological Description

Porcellio laevis is a large terrestrial isopod that can attain lengths of up to 20 mm (Figure 17) (Schmalfuss, 2003). The dorsal surface of *P. laevis* is smooth and glossy, in contrast to the granulation exhibited by many other *Porcellio* species (Vandel, 1973). The body itself is broadly oval and slightly flattened, as is common in this family, which facilitates rapid movement (Hornung, 2011). Males have long, spear-tipped uropods that are long enough to extend beyond them (Schmidt, 2008). The antennae have two articles in the flagella (Vandel, 1973). The cephalon has conspicuously large lateral lobes, and the cuticular eyes have more than twenty ommatidia (Taiti & Ferrara, 1996). The first pereon epimera have a concave hind margin, and the pleon epimera are broad enough to extend beyond the lateral margins of the pereon, collectively forming a rounded-edge lateral outline with the pereon (Schmalfuss, 2003). The telson is semicircular with concave lateral sides. Importantly, *P. laevis* is not capable of rolling into a ball, a characteristic that distinguishes it from some other terrestrial isopods (Vandel, 1973; Hornung, 2011).

Figure 17: *Porcellio laevis* (Photo: Benchana I)

2.2.2. Geographical Distribution

Porcellio laevis was initially described as being native to the Mediterranean area, but as of today, it has a cosmopolitan distribution that is largely attributed to its dispersal by humans (Hornung, 2011). *P. laevis* has been introduced to temperate and subtropical areas worldwide, including Europe, North Africa, the Americas, Australia, and parts of Asia (Schmalfuss, 2003). In North Africa, including Algeria and Tunisia, *Porcellio laevis* is commonly found in peri-urban environments, gardens, and cultivated landscapes (Medini-Bouaziz et al., 2006; Hornung, 2011).

2.2.3. Ecology

Porcellio laevis exhibits ecological flexibility and is often found in moist organic environments (Hornung, 2011). It also occurs under stones, leaf litter, logs, and compost heaps of decaying plant matter, where it lives as a detritivore (Zimmer, 2002). It plays an important role in nutrient cycling, feeding on decaying tissues that contribute indirectly to the food web by breaking down organic matter into forms that higher trophic levels can use (Lavelle et al., 2006). In addition, *Porcellio laevis* is known to be capable of bioremediation of contaminated soils and has been studied for its capacity to tolerate and accumulate heavy metals (Zimmer, 2002).

2.3. *Porcellionides prunosis*

2.3.1. Morphological Description

Porcellionides pruinosus is a small to medium-sized terrestrial isopod, ranging from 5–12 mm (0.2–0.5 in) in length (Figure 18). The main diagnostic characteristic for *Porcellionides pruinosus* is its "pruinose," or frosted, appearance. This frosted appearance is due to small, waxy epicuticular spheres located on the cuticle of the animal (Hornung, 2011). When viewed under the right light, these microstructures produce a silvery or bluish sheen. Furthermore, these small spheres are formed during the premolt stage (Vittori et al., 2020) and have been shown to increase hydrophobicity, which may provide an advantageous adaptation to terrestrial life. The body is segmented with a recognizable exoskeleton, which is presumably made of a calcium-based element during cuticle development. In addition, the antennae are long, slender, and two flagellar articles can be distinguished from the peduncle material (Hornung, 2011).

Figure 18: ***Porcellionides pruinosus*** **(Photo: Benchana I)**

2.3.2. Geographical Distribution

Porcellionides pruinosus is a synanthropic, cosmopolitan species. Although it was first described from the Mediterranean basin, and is a native species to that area, it has become globally distributed through human-mediated transport. Populations of *Porcellionides pruinosus* are widely established across Europe, North and South America, Asia, Africa, and Australia. This species is often found in disturbed habitats, including greenhouses, compost piles, agricultural soils, gardens, and areas adjacent to human settlements. Its distribution illustrates its broad ecological tolerance, allowing this species to survive in many different environments. (Schmalfuss, 2003; Hornung, 2011).

2.3.3. Ecology and Habitat Preferences

From an ecological perspective, *Porcellionides pruinosus* is an extraordinarily adaptable detritivore, feeding primarily on decaying plant matter and organic detritus, which are extremely important as key players in nutrient cycling and decomposition processes in soil ecosystems. It can be found in damp environments; however, due to its relatively waxy cuticle, it tolerates a degree of dryness. *Porcellionides pruinosus* can be commonly encountered in areas covered with leafy litter, stones, and logs, and frequently occurs in gardens, backyards, composts, or agricultural environments. The species is prolific, as it can produce multiple generations of individuals under favourable conditions (i.e., with plentiful food resources). Females carry fertilized eggs in a marsupium until they hatch. *Wolbachia*, intracellular endosymbionts, have been reported in studies and may represent an important factor in the reproductive biology of *Porcellionides pruinosus*. (Zimmer, 2002; Hornung, 2011; Cordaux et al., 2001).

2.4. *Armadillidium officinalis*

2.4.1. Morphological Description

Armadillo officinalis is a relatively large terrestrial isopod, growing up to 20 mm in maximum length (Figure 19). It has a convex, oval body, uniformly grey or slate-colored (Montesanto, 2018). A notable characteristic of this species is its ability to roll into a perfect ball (conglobation) for a defensive response, a trait that is adaptive for the family *Armadillidiidae* (Schmalfuss, 2003). The dorsal surface is smooth to slightly granulated, and the head has well-developed lateral lobes that do not exceed the anterior margin of the first pereonite. The telson is triangular and rounded at the apex, while the uropods are short and not discernible dorsally. The males can be distinguished by modifications of the seventh pereiopod, and pleopod morphology is used in taxonomic identification. (Montesanto, 2018; Schmidt, 2008).

Figure 19: ***Armadillo officinalis*** **(Photo: Benchana I)**

2.4.2. Geographical Distribution

The native range of this species includes southern Europe and North Africa, and it has been introduced to other areas, including some parts of Central Europe and the Mediterranean basin. It is particularly common in warm, temperate climates near warm temperate areas, especially the western Mediterranean. Its natural range includes Spain, France, Italy, Greece, Algeria, Tunisia, and Morocco (Schmalfuss, 2003). In North Africa, including Algeria, *Armadillo officinalis* has been observed in coastal and inland habitats, especially where there is some humidity and vegetation (Montesanto, 2018).

2.4.3. Ecology

Typically, *Armadillo officinalis* can be found in moist microhabitats, including habitats under stones, leaf litter, and logs, but tolerates relatively dry environments better than most isopods do (Montesanto, 2018). *Armadillo officinalis* prefers habitats containing moderate to high organic matter and is found in association with calcareous soil types. Its activity is mostly nocturnal, and it plays a role in nutrient cycling and decomposition by feeding on dead and decaying fibers of plant material. Compared to some other Oniscidea, it is adapted for desiccation and, to some extent, predation, by the joining together or conglobation movement, and its relatively thickened exoskeleton also helps it withstand predation (Montesanto, 2018).

2.5. *Armadillidium sulcatum*

2.5.1. Morphological Description

Armadillidium sulcatum is a robust, moderately sized terrestrial isopod, typically measuring from 12 to 16 mm (Figure 20). It is most easily recognized by the presence of longitudinal grooves or striations (sulci) across the tergites, which distinguish it from other *Armadillidium* species. Its shape is oval and moderately convex. Like other pill bugs, it is capable of complete conglobation to defend itself from predation. It is generally gray to dark brown with a slight sheen. The telson is triangular and has a rounded tip, and the uropods are short, inserted ventrally and, when viewed dorsally, not usually visible. Males have unique (diagnostic) morphological characters on the seventh pereiopod and the exopodite of pleopod I, which is important for a reliable identification (Schmalfuss, 2003; Schmidt, 2008).

2.5.2. Geographical Distribution

Armadillidium sulcatum primarily occurs within the western Mediterranean region of North Africa, specifically in Algeria and Tunisia, southern France, and areas of the Iberian Peninsula. In Algeria, it has been recorded from both coastal and inland sites, mainly within the context of either natural woodland habitats or Mediterranean maquis (Hamaïed-Melki et al., 2011). Compared to more cosmopolitan *Armadillidium* species, its geographical distribution appears relatively limited. It is typically assumed to be native and endemic to North African–Mediterranean ecosystems (Hamaïed-Melki et al., 2011).

Figure 20: *Armadillidium sulcatum* (Photo: Benchana I)

2.5.3. Ecology

Armadillidium sulcatum is somewhat more restricted from a distributional perspective. Ecologically, it is generally more likely to be found in humid, shaded microhabitats, such as those often found under stones, under deep litter, or beneath logs in a forested or shrubby area (Hassall et al., 2018). It is less drought-tolerant compared to *Armadillo officinalis*, and appears to be closely tied to a static microclimate, with moderate to high humidity (Edney, 1965; Edney, 1954). This species is just as capable of decomposing organic material and mineralizing nutrients in the soil of forests (Hassall & Sutton, 1977). *Armadillidium sulcatum* is likely to be more localized and less common than conglobating isopods, likely because they are more ecologically specialized (Hassall et al., 2018; Edney, 1965).

3. Ecological Distribution

The ecological distribution of terrestrial isopods, as showcased by forest type in the Ouled Yagoub forest, suggested that there were clear differences amongst species in their preference for and ability to occupy specific habitat conditions. The presence and abundance of each species varied significantly between the four sampled forest types—burned forest, cedar forest, mixed pine forest, and pure pine forest—indicating that differences in vegetation composition, microclimatic conditions, and soil characteristics were likely influencing the patterns in isopod assemblages (Boukachabia et al., 2022;

Achouri et al., 2008). For example, while *Porcellio variabilis* was observed to have a broad ecological range, occupying all types of forests, species such as *Porcellionides pruinosus* and *Porcellio laevis* showed a clear preference for more structurally complex and organically rich environments, matched with the mixed pine variant. Likewise, *Armadillo* and *Armadillidium* species were primarily found in specific microhabitats associated with suitable levels of humidity, litter depth, and protection (Boukachabia et al., 2022; Achouri et al., 2008).

Table 3: Ecological Indices of Terrestrial Isopod Communities By Forest

Site	**Richness (S)**	**Shannon (H')**	**Simpson (1-D)**	**Fairness (J')**	**Hill N_1**	**Hill N_2**	**Presence Index**
Cedar	3	0.92	0.58	0.83	2.51	2.38	60%
Mixed Pine	5	1.32	0.71	0.82	3.74	3.45	100%
Pure Pine	1	0.00	0.00	0.00	1.00	1.00	20%
Burned Pine	2	0.43	0.19	0.62	1.54	1.23	40%

Table 4: Ecological Characteristics of Terrestrial Isopods in Ouled Yagoub Forest

Species	**Distribution**	**relative abundance (total 229)**	**Sites Number**	**Relative frequency (%)**	**Constancy**
P. variabilis	North Africa	0.71	16	80%	Constant
P. laevis	Cosmopolitan	0.19	1	5%	Accidental
P. prunosis	Cosmopolitan	0.05	1	5%	Accidental
A. officinalis	Mediterranean	0.018	2	10%	Accidental
A. sulcatum	North Africa	0.03	2	10%	Accidental

The variation in ecological distribution found at the site level indicates the role that forest complexity has in maintaining terrestrial isopod diversity, and that, while the variability may be at a small scale, it is sufficient enough to likely create significant variation in community composition. We conclude this section with a discussion on the ecological preferences and distributions shown by individual species, specifically about forest type (Figure 21).

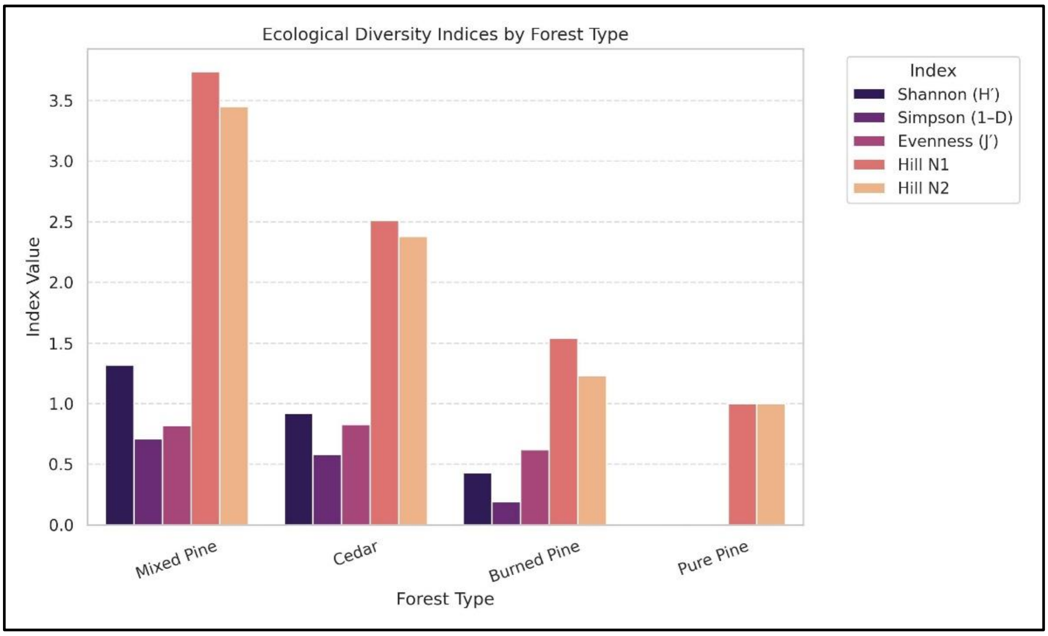

Figure 21: Ecological diversity indices across forest types.

4. Forest type effect

The assessment of spatial patterns of ecological indices across forest types was accomplished using the Kruskal-Wallis test (Figure 22).

1. **Species Richness:** There was no significant difference between the four forest types (Kruskal-Wallis H = 3.036; df = 2; $p > 0.1$).
2. **Abundance:** There was a significant difference in the abundance of terrestrial isopods among forest types (Kruskal-Wallis H = 6.348; df = 2; $p < 0.1$), and as

such, we conducted Dunn's post hoc test to assess the characteristics of this variability and the outcomes are shown in Table 5.

Table 5: Dunn's test results for isopod abundance between forest types.

Comparison	Dunn's Z	P.Value
Cedar - Mixed Pine	-1.5589311	0.11901269
Cedar - Burned	0.6719531	0.50161358
Mixed Pine - Burned	2.2308842	0.02568880
Cedar - Pure Pine	0.5644406	0.57245434
Mixed Pine - Pure Pine	2.1233717	0.03372272
Burned - Pure Pine	-0.1075125	0.91438242

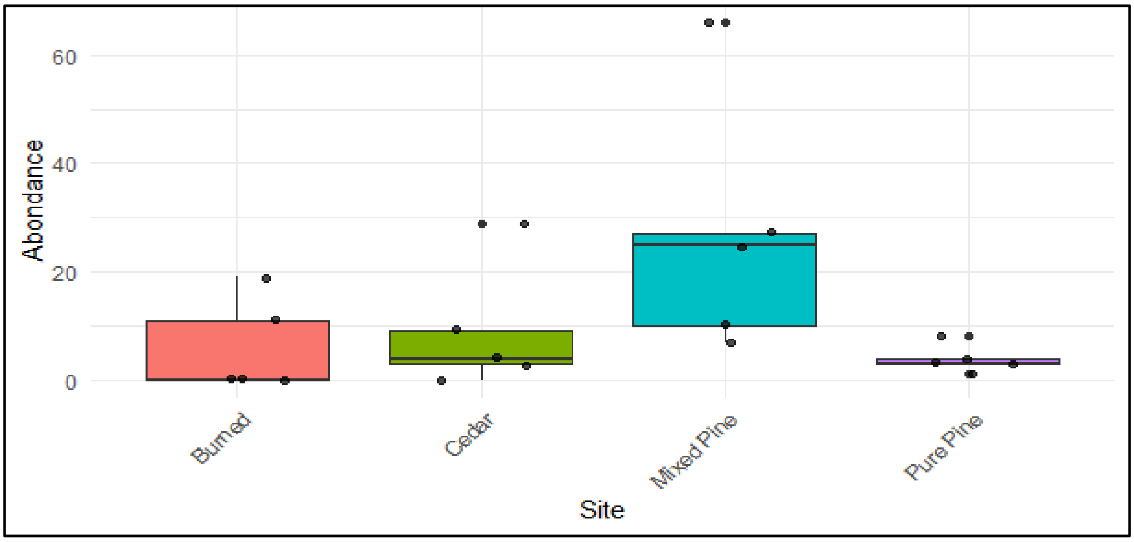

Figure 22: Abundance of terrestrial isopods by forest type in Ouled Yagoub: Boxplot illustrating inter-site variability (Kruskal-Wallis and Dunn's test).

Discussion

1. Dominance and Ecological Plasticity of *Porcellio variabilis*

The study of terrestrial isopod communities in four different forest types of Ouled Yagoub found *Porcellio variabilis*, an endemic species to northwest Africa, to be the most dominant and widespread species, making up 70.7% of all isopods collected. It occurred in all four forest types and was classified as a "constant species" (Constancy Class V), with a constancy of 80%. Its omnipresence highlights its admirable ecological plasticity, a characteristic which has been reported previously in North African populations of this species (Medini-Bouaziz et al., 2006). *Porcellio variabilis*' occupancy of both degraded (burned) and structurally intact forests (cedar and mixed pine) suggests a high tolerance to environmental stressors like a lack of litter, variability in soil moisture, and open canopy—isopod habitat variables critical for determining isopod habitat suitability (Hornung, 2011).

Porcellio variabilis made up 57% of all individuals in the mixed pine forest, with the forest having the greatest richness and microhabitat diversity of all of our study habitats. Yet, *Porcellio variabilis* also had large populations in pure pine and burned stands, which had much lower species diversity. This supports the contention that *Porcellio variabilis* is a eurytopic species, both capable of establishment in a range of microclimates and vegetation types and able to dominate in disturbed and undisturbed habitats (Medini-Bouaziz et al., 1998; Loureiro et al., 2006). Its detritivorous feeding habits likely assisted in its ability to establish in these habitats. Reproductive plasticity and physiological ability to tolerate desiccation likely accounted for the species occupying the contrasting ecological conditions (David & Handa, 2010).

2. Habitat specificity of cosmopolitan species

Unlike *Porcellio variabilis*, both *Porcellio laevis* and *Porcellionides pruinosus* were only found in the mixed pine forest. In the mixed pine forest, *Porcellio laevis* made up 19.2% of the total isopods, and *Porcellionides pruinosus* made up 4.8%. Their restricted occurrences to this forest type, with its complex canopy structure, varying litter layer composition and depth, and overall ability to retain moisture, demonstrate their reliance on habitats that are structurally and chemically rich. These attitudinal distributions are supported by earlier studies, which noted that *Porcellio laevis* is synanthropic but habitat selective when it comes to moist, organically rich substrates (Blewett et al., 2014; Medini-Bouaziz et al., 2015). Similarly, *Porcellio laevis*, while synanthropic, was restricted in habitat in this study, suggesting that it selected for the forest microclimate that would provide stable humidity and some litter depth.

The lack of these species in the cedar forest, despite being rich in organic litter, could be related to differences in soil texture, microbial communities, or disturbance regime responding to historical disturbance; thus, fine-scale environmental heterogeneity is important to the distribution of isopods. The observation of these species in a mixed pine forest also indicates these species may be effective bioindicators of microhabitat quality within Mediterranean-type forest ecosystems, similar to the conclusions of Paoletti & Hassall (1999).

3. Forest types effect

Mixed pine forest was the most favorable forest type for terrestrial isopods, considering both richness and evenness. It was the only forest type containing all five collected species, and 59% of all individuals were recorded in this forest type (135/229 individuals). The mixed pine forest also presented the highest diversity for the three metrics of diversity: Shannon ($H' = 1.32$), Simpson ($1 - D = 0.71$), and Pielou's evenness ($J' = 0.82$). The higher diversity in mixed pine forest was likely a consequence of the moderate canopy density, diverse litter composition, and balanced soil structure, which altogether directly promote microhabitats, and microhabitat heterogeneity can drive soil fauna richness (Lavelle et al., 2006).

On the other hand, the pure pine forest exhibited the lowest diversity values ($H' = 0$, $1 - D = 0$, $J' = 0$) and only hosted one species (*Porcellio variabilis*). The lack of diversity in pure pine forest is reflective of strong environmental filtering, possibly caused by the homogeneity of pine needle litter and the acidic conditions of the soil. Similar studies show that monocultures, along with low structural complexity, result in impoverished isopod assemblages due to having less food and limited microhabitats (Paoletti et al., 2007; David & Handa, 2010).

The cedar and burned forest had intermediate conditions. The cedar stand, with three species and moderate H' (0.92) and 1-D (0.58), has a relatively stable but less diverse community. The cedar stand had a relatively high organic matter content (Soil organic carbon = 401.8 g/kg) and relatively low isopod abundance, suggesting that canopy closure and litter compaction may limit isopod activity and detectability (Hornung, 2011). The burned forest was in the early stages of recolonization and revealed two species, also with low diversity indices (H ' = 0.43, 1-D =0.19), representing a transitional habitat experiencing ecological succession. Burned forests generally support generalist species tolerant to extremes in microclimate conditions and reduced habitat structure, including *Porcellio variabilis* and *Armadillo officinalis* species (Medini-Bouaziz et al., 2006).

These patterns highlight the importance of habitat complexity to support richer isopod communities and confirm previous observations that richness of forest soil macrofauna is driven by structural diversity, litter quality, and moisture availability (Decaëns et al., 2006; Brussaard et al., 2007) (Figure 23).

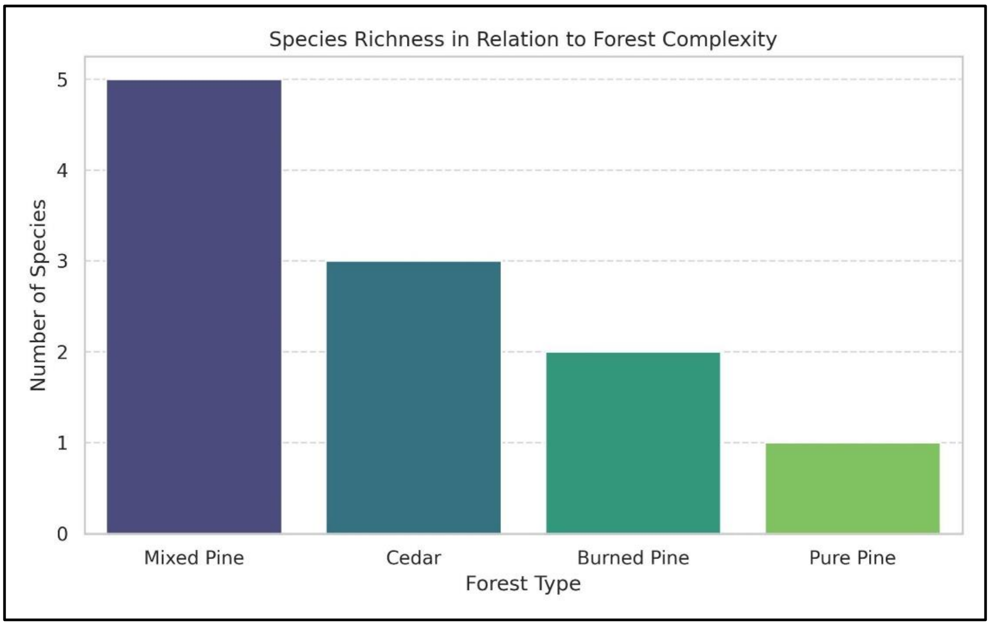

Figure 23: Forest heterogeneity and disturbance history affected isopods' diversity.

4. Soil influence

The distribution and diversity of terrestrial isopods among the various types of forest in Ouled Yagoub were related to a set of abiotic variables, including litter depth, the structure of the canopy, and soil properties such as the density of organic carbon and bulk density (Figure 24). These variables combined to create a physical and/or chemical environment that determines the availability of potential microhabitats for soil macroarthropods (Decaëns et al., 2006; Brussaard et al., 2007).

The mixed pine forest had the highest species richness (S = 5) among the forest types and had intermediate to high organic carbon density (Soil organic carbon = 251.8 g/kg), moderate bulk density (1.33 g/cm³), and a rich and variable litter layer. This combination likely promotes microhabitat diversification and stable moisture retention, especially for desiccation-sensitive taxa like *Porcellio laevis* and *Porcellionides pruinosus*. Overall, the mixed pine forest's heterogeneous vegetation, including *Pinus halepensis* and *Quercus ilex*, supports litter inputs of varied chemical complexity, thus likely impacting detritivore availability.

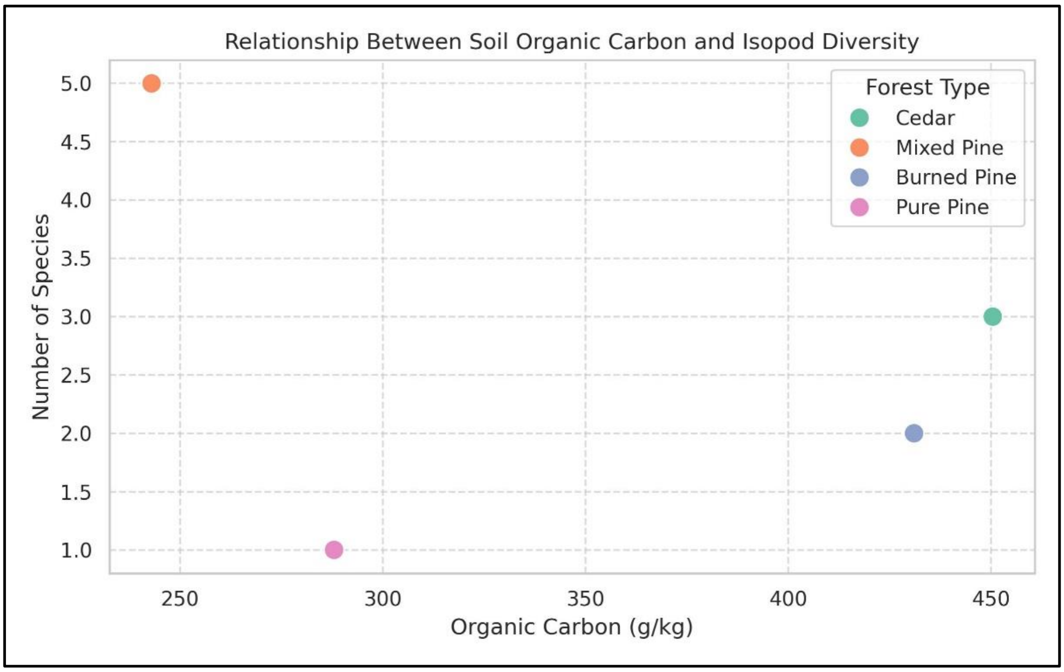

Figure 24: Relationship between soil organic carbon and isopod diversity

On the one hand, the pure pine forest, which had similar bulk density (1.33 g/cm³) and higher Soil organic carbon (287.4 g/kg), supported a single species. This indicates that the litter composition (pine needles) and structure of the canopy may create an indication of the niches available. Lavelle et al. (2006) also had similar findings, in which they concluded that microhabitat heterogeneity was more important in maintaining soil invertebrate communities than simply soil fertility.

As for the cedar forest, it presented another distinct case. This forest had the highest Soil organic carbon value (401.8 g/kg) and a moderate level of canopy closure and supported three species. The difference between the cedar forest and the other two forests could be due to the well-compacted litter layer and cooler sub-humid conditions restricting surface activity and possible detection of species (Hornung, 2011). This phenomenon has been seen in dense mountain cedar forests, in which high humidity and low temperature hinder macrofauna movement.

Despite soil organic carbon levels of 382.0 g/kg in the burned forest, the number of species (S = 2) remained low, likely due to loss of canopy, reduced litter depth, and exposure of the soil surface. Soil bulk density (1.26 g/cm³) and organic content alone were not sufficient to ameliorate the extreme microclimatic features (e.g., temperature fluctuation, erosion) that are involved in hindering recolonization by more specialized species (Blewett et al., 2014).

Considering the findings as a whole, together suggest that whilst soil parameters do affect isopod distributions, canopy complexity, and diversity of litter affect community structure in a more significant and consistent manner.

Conclusion

This research represents the first thorough ecological assessment of terrestrial isopod communities in Ouled Yagoub National Forest, which contains mixed pine, cedar, pure pine, and burned pine forest types based on structural and environmental differences. A total of 229 specimens, representing five species within three families (*Porcellionidae, Armadillidiidae,* and *Armadillidae*), were found. The key features of *Porcellio variabilis* were that it constituted more than 70% of all individuals and exhibited the most constancy. Therefore, the data confirm that *Porcellio variabilis* is sufficiently representative of a generalist detritivore with high ecological plasticity.

The mixed pine forest was the most favorable habitat, depicting the highest richness, diversity, and evenness. This site was unique in supporting generalist and specialist species, suggesting it had heterogeneity of microhabitats and was not decoupled from moderate canopy structure. The pure pine forest, on the other hand, was functionally simplified with just *Porcellio variabilis*, with zero values for the samples on all diversity indices, indicating high levels of environmental filtering and low resilience potential.

The cedar forest exhibited intermediate richness and diversity as it hosted moisture-sensitive species such as *Armadillidium sulcatum* and *Armadillo officinalis,* which likely benefited from deep organic litter and stable microclimate afforded by the forest. The burnt forest was early in successional recovery and showed low diversity with only generalist colonizers, indicating a requirement for the forest to develop canopy and litter layers to allow recolonization of specialist detritivores.

Soil data demonstrated that bulk density and organic carbon content could not fully explain community structure; rather, litter complexity, canopy architecture, and moisture content were determined to be the strongest determinants of isopod distribution. These results support the view that structural and compositional diversity are important for regulating functional soil invertebrate communities.

From a conservation standpoint, the mixed pine forest should be treated as a priority conservation area for biodiversity because it has high richness and ecological functionality. Future management strategies should attempt to describe mixed-species compositions, retain organic litter layers, and maintain canopy heterogeneity as a mechanism to manage soil macrofauna diversity. Where disturbance to monocultures has occurred, enrichment planting and the retention of woody debris can assist, and the re-colonization of more specialized taxa could be achieved.

In future studies, it would be beneficial to expand the timeline and spatial extent of sampling to incorporate seasonal dynamics and more forest plots, as well as using molecular methods of species identification and environmental DNA methods, in order to improve survey accuracy and facilitate more comprehensive soil biodiversity monitoring. Additionally, it would be useful to conduct studies that investigate trophic relationships between isopods and microbial communities in order to quantify their functional role in forest soil.

In summary, this study further highlights the ecological importance of terrestrial isopods as indicators of habitat quality and functional diversity in Mediterranean forest ecosystems when subjected to additional anthropogenic and climatic environmental pressures. By incorporating isopods into biodiversity monitoring strategies, biodiversity assessments can contribute meaningfully to forest management and conservation in North Africa.

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Appendix

First Data on Terrestrial Isopods of Chelia-Ouled Yagoub National Park

Ahmed Rezaïkia[1], Haithem Messaoudi[1], Mehdi Badis[1,2], Imane Benchana[3]
[1] Department of Ecology and Environment, Faculty of Natural and Life Sciences, Abbes Laghrour University, Khenchela 40000, Algeria.
[2] Research Laboratory of Algerian Forests and Climate Change, Higher National School of Forests, 40000 Khenchela, Algeria.,
[3]Research Laboratory of Diversity, Management, and Conservation of Biological Systems, FST, Tunis El Manar University, Tunis 2092, Tunisia.

1 INTRODUCTION

Oniscoids, also known as woodlice, are terrestrial crustaceans that play a key role in forest ecosystems. As decomposers, they actively contribute to the recycling of organic matter by breaking down plant litter and promoting soil humification.

However, despite their ecological importance, their diversity remains poorly studied in Algeria, particularly in forest environments.

In this context, this work aims to identify species of oniscoides present in the Ouled Yagoub forest massif for the first time.

2 STUDY AREA

Ouled Yagoub National Forest has just been declared a national park. It is situated in the province of Khenchela in northeastern Algeria. The spatial distribution of this forest has a highly varied topography, with a mountainous nature marked by a series of small and irregular ridges. It is located 17 km from the Chelia Cedar Forest and forms a rectangle that is 13.5 km long and 6.5 km wide, with the same SW-NE orientation (Chafai et al., 2023).

Figure 1: Cedar Forest

Figure 2: Ouled Yagoub National Park

Figure 3: Mixed Pine Forest

Figure 4: Burned Pine Forest

Figure 5: Pure Pine Forest

Table 1: Environmental Characterization Of Olued Yagoub Forest

Forest	Altitude (m)	Dominant vegetation	Bioclimatic Stage	Rainfall (ml)	T° (min – max)
Cedar	1572	Atlas Cedar + Holm Oak	Subhumid with cool winters	672	0,15 – 34,5
Mixed pine	1429	Aleppo Pine + Holm Oak	Semi-arid with cool winters	672	0,15 – 34,5
Pure pine	1095	Aleppo Pine + Holm Oak	Semi-arid with cool winters	594	0,9 – 35,8
Burned pine	1309	Undergrowth	Semi-arid with cool winters	594	0,9 – 35,8

3 MATERIALS AND METHODS

SAMPLING

. winter sampling campaigns (2024)

. Stratified sampling : Center, Edge, Outside

. Quadrat method 1m × 1m

Figure 6: 1m × 1m Quadrat

LABORATORY

. Collected specimens were preserved in 70° ethanol

. Identification under a Leica stereomicroscope.

Figure 7: Stereomicroscope

RESULTS 4

- A total of 229 isopod specimens belonging to five species were collected across four forest types in the Ouled Yagoub Forest.
- Found species were a mix from cosmopolitan, mediterranean and north African isopods, which are *Porcellio variabilis*, *Porcellio laevis*, *Porcellionides prunosis*, *Armadillo officinalis*, and *Armadillidium sulcatum*
- *Porcellio variabilis* was the most abundant and widespread, with 162 individuals (70.7%), found in all forest types.
- The pine mixed forest had the highest abundance and species richness, with 135 specimens (59%) and all five species present.
- Forest type had a significant influence on isopod diversity and abundance, with burned and pine pure forests showing reduced diversity.

Figure 8: *P. Variabilis* (Photo: Benchana I)

Figure 9: *P. Laevis* (Photo: Benchana I)

Figure 10: *P. Prunosis* (Photo: Benchana I)

Figure 11: *A. Officilanis*

Figure 12: *A. Sulcatum* (Photo: Benchana I)

Table 2: Ecological Indices Of Isopod Communities By Forest

Site	Richeness (S)	Shannon (H')	Simpson (1-D)	Faimess (J')	Hill N_1	Hill N_2	Presence Index
Cedar	3	0.92	0.58	0.83	2.51	2.38	60%
Mixed Pine	5	1.32	0.71	0.82	3.74	3.45	100%
Pure Pine	1	0.00	0.00	0.00	1.00	1.00	20%
Burned Pine	2	0.43	0.19	0.62	1.54	1.23	40%

Table 3: Ecological Characteristics Of Isopods In Ouled Yagoub Forest

Species	Distribution	abundance	relative abundance (total 229)	Sites Number	Relative frequency (%)	Constancy
P. variabilis	North Africa	162	0.71	16	80%	Constant
P. laevis	Cosmopolitan	44	0.19	1	5%	Accidental
P. prunosis	Cosmopolitan	11	0.05	1	5%	Accidental
A. officilanis	Mediterranean	4	0.018	2	10%	Accidental
A. sulcatum	North Africa	8	0.03	2	10%	Accidental

CONCLUSION 5

Our study revealed a mix of cosmopolitan and North African endemic isopods species in Ouled Yagoub forest. These results provide a first insight into the isopod fauna of these ecosystems and may serve as a foundation for future research focused on the structure, dynamics, and conservation of terrestrial isopod populations in national parks.

These results highlight the significant influence of forest type on isopod diversity and abundance. The pine mixed forest appears to offer the most suitable conditions for a diverse isopod community, whereas the burned and pine pure forests show reduced diversity, possibly due to environmental stress or habitat homogeneity.

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Mediterranean Forests: Challenges, Issues, and Solutions for Sustainable Management

ملخص

تُعدّ القشريات متساوية الأرجل البرية من المكوّنات الأساسية في النظم البيئية للتربة، حيث تساهم بشكل فعّال في تحلل المادة العضوية ودورة العناصر الغذائية. وتُظهر قدرتها على العمل كمؤشرات حيوية أهميتها في تقييم جودة التربة، ومع ذلك فإنها لا تزال غير مدروسة بشكل كافٍ في الجزائر، خصوصًا في المناطق الغابية. تمثّل هذه الدراسة أول تقييم منهجي لتنوّع القشريات البرية في الكتلة الغابية لأولاد يعقوب. أُجريت الدراسة سنة 2024، وركّزت على أربعة أنواع مختلفة من الغابات: غابة الأرز، الصنوبر المختلط، الصنوبر النقي، وغابة الصنوبر المحترقة. استُخدم أسلوب المعاينة بواسطة مربعات متدرجة لضمان تغطية التباين في المواطن الدقيقة عبر هذه المواقع. تم جمع 229 عينة وحفظها في الكحول، ثم تم تحديدها باستخدام المجهر التشريحي. كشفت النتائج الأولية عن وجود خمس أنواع من القشريات البرية تنتمي إلى عائلات الكربسيات، أرماديليديدا، أرماديلا. مع اختلافات ملحوظة في تركيبة الأنواع وكثافتها بين أنواع الغابات المختلفة. وتُبرز هذه النتائج الأهمية البيئية لغابات جبال الأوراس في الحفاظ على التنوع الحيوي للتربة، وتؤكد الحاجة إلى دراسات أوسع حول الحيوانات الارضية الكبيرة (العيانية) في النظم البيئية الغابية الجزائرية، كما تُشكّل أساسًا لتوسيع هذه الدراسة أو دراسات مماثلة. كما تثبت أيضًا من قيمة القشريات متساوية الأرجل البرية كمؤشرات بيئية في الغابات المتوسطية، خاصةً في ظل التغييرات البشرية والتغيرات المناخية المتزايدة.

Résumé

Les cloportes terrestres sont des composants clés des écosystèmes du sol, participant activement à la décomposition de la matière organique et au cycle des nutriments. Leur capacité à servir de bioindicateurs les rend précieux pour l'évaluation de la qualité des sols, mais ils demeurent peu étudiés en Algérie, en particulier dans les habitats forestiers. Cette étude représente la première évaluation systématique de la diversité des cloportes terrestres dans le massif forestier d'Ouled Yagoub. Réalisée en automne 2024, elle s'est concentrée sur quatre types de forêts distincts : cédraie, pinède mixte, pinède pure et pinède brûlée. Une méthode d'échantillonnage par quadrats stratifiés a été utilisée pour assurer une couverture représentative des variations de microhabitats sur l'ensemble des sites. Un total de 229 spécimens a été collectés et conservés dans de l'alcool, puis identifiés à l'aide d'un stéréomicroscope. Les résultats préliminaires ont révélé la présence de cinq espèces de cloportes appartenant aux familles *Porcellionidae, Armadillidiidae,* et *Armadillidae* avec des différences notables dans la composition et l'abondance des espèces entre les types de forêts. Ces résultats soulignent l'importance écologique des forêts de l'Aurès dans le maintien de la biodiversité du sol et mettent en évidence la nécessité d'études plus larges sur le macrofaune édaphique dans les écosystèmes forestiers algériens, tout en constituant une base pour étendre cette recherche ou d'autres études similaires. Cette recherche renforce également la valeur des cloportes en tant qu'indicateurs écologiques dans les forêts méditerranéennes, notamment face aux pressions anthropiques et climatiques croissantes.