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Ecology and distribution of *Uromenus dyrrhachiacus* (Karny, 1918) (Orthoptera: Tettigoniidae)

Écologie et répartition de Uromenus dyrrhachiacus *(Karny, 1918) (Orthoptera : Tettigoniidae)*

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Abstract

Uromenus dyrrhachiacus*, called Albanian Saddle Bush-cricket, is a critically endangered species that is highly localised in the Durrës region of Albania (Chobanov* et al. *2016). The aim of the study, which was carried out in 2022 and 2023, was to know its exact distribution and ecological requirements, preliminary information needed for any future conservation actions. After field sampling and a preparatory phase of the study in 2022, an intensive field survey was carried out in 2023 in the presumed and historical distribution area, but also in neighbouring regions with certain similarities. Many parameters were recorded, such as relative abundance, geological structure, dominant plants, location and distance from the sea, state of pastoralism, state of environmental degradation, etc., for the stations where the species was found as well as for the stations where the taxa was not observed. It is concluded that the species under consideration, which occurs on siliceous soils, was originally dependent on matorral-type plant formations of sclerophyllous forest with* Quercus ilex *L., in close proximity to the sea. For generations, man has altered the habitat of this region with plantations, changes in pastoral practices and, more recently, severe habitat alteration for industrial needs, urban expansion and tourist development. The species is now found only in more or less disturbed and degraded environments, which are not indicators of its ideal habitat. This must be taken into account when discussing the protection of its habitat or the implementation of mitigation measures for projects that further reduce its range.*

Keywords: Ensifera, Bradyporinae, conservation, Albania, Durrës.

Résumé

Uromenus dyrrhachiacus *est une espèce en danger critique d'extinction, très localisée dans la région de Durrës en Albanie. L'objectif de l'étude, menée en 2022 et 2023, était de connaître précisément sa répartition mais également ses exigences écologiques, informations préalables requises pour toute action de conservation future. Après un échantillonnage sur le terrain et une phase préparatoire de l'étude en 2022, une recherche intensive sur le terrain a été effectuée en 2023 sur l'aire de répartition supposée et historique mais aussi sur des régions voisines présentant certaines similarités. De nombreux paramètres ont été notés, tels que l'abondance relative, la*

Mots-clés : Ensifère, Bradyporinae, conservation, Albanie, Durrës.

structure géologique, les plantes dominantes, la localisation et la distance à la mer, l'état du pastoralisme, l'état de dégradation du milieu, etc., pour les stations où l'espèce a été trouvée ainsi que les stations où elle n'a pas été observée. Nous en concluons que l'espèce, présente sur sol siliceux, était à l'origine inféodée aux formations végétales de type matorral issues de la forêt sclérophylle à Quercus ilex *L., à proximité de la mer. Depuis des générations, l'homme a remanié l'habitat de cette région avec notamment des plantations, des pratiques pastorales qui ont évolué et plus récemment des altérations sévères des habitats pour des besoins industriels, d'extension de la ville et de développement touristique. L'espèce ne se trouve aujourd'hui plus que sur des milieux plus ou moins remaniés et dégradés qui ne correspondent pas à son habitat originel probable. Ceci est à prendre en considération pour toute discussion relative à la protection de son habitat ou à la mise en place de mesures compensatoires à des projets venant davantage réduire son aire de répartition.*

Introduction

Uromenus dyrrhachiacus was discovered by Karny (1918) near the city of Durrës in central Albania. At that time, the author defined three main areas on the coastal hills from south to north (current names in parenthesis): Shkâmb (Shkëmbi i Kavajës), Mali Durcit (Mali i Durrësit) and Porte (Portez).

This *Uromenus* species belongs to the *rugosicollis* group, the majority of those taxa live in North Africa. *U. elegans* (Fischer, 1853) is the only other *Uromenus* found in the Balkans, more precisely in southern Greece: in the Peloponnese and in Crete. It is also known from Sardinia and the western part of the Italian peninsula.

After the Karny's discovery, there was no specific mention of new observations in the literature for more than half a century. In 1996 (Fontana & Kleukers, pers. comm.), it was reported again in a bushy plant formation above the sea, west of the commercial harbour, and more recently in 2015 (Puskás & Szövényi in Heller *et al*. 2021), further north, but still within the area given by Karny in 1918. In 2022, these last two sites were destroyed. The first probably by landslides related to urbanisation above and which destroyed the original biotopes, the second by bulldozers levelling the hill to make way for a new industrial port terminal.

In order to improve our knowledge (distribution, ecology) of this species with the aim of proposing conservation measures, we decided to carry out a study in 2022 and 2023. The aim is to share with stakeholders a better vision of the situation, the threats and how to mitigate them.

In the summer of 2022, a first prospecting campaign in the field and indoor breeding were set up (Lemonnier-Darcemont *et al*. 2022). In 2023, a more extensive field campaign was carried out with the aim of understanding the relationship between its presence/absence, and its abundance if any, and the habitat characteristics of each surveyed site.

The elective habitat of this insect is located in the coastal region of Durrës, included in the Peri-Adriatic depression. The plant formations located between 15 and 100m above sea level, consist of a rather sparse herbaceous vegetation, with a predominance of woody or woody-based plants.

In the field, the first adults are found in June with a peak in early July. According to Karny (1918), some individuals can survive until at least mid-September.

In 2015, the species was listed as Critically Endangered (CR), on the IUCN Red List of Threatened Species (Chobanov *et al*. 2016).

Methods

The taxonomic references used are respectively (Cigliano *et al*. 2025) for Orthoptera and (POWO 2025) for plants.

The first survey in the summer of 2022 was designed to get an initial idea of the status of the species and its ecological requirements (Lemonnier-Darcemont *et al*. 2022) and to refine the methodology for the second year. In the majority of cases, *U. dyrrhachiacus* was found at a height of at least 50cm in the vegetation, mostly woody or woody-based. In these stations, the cover of plants over 50cm represents on average more than 50%, the rest being composed of very low woody and herbaceous plants (< 50cm). The structure of the vegetation is an important element in the ecological requirements of this insect since it needs the stems of *Spartium junceum* L., *Phragmites* sp., *Cichorium* sp., *Foeniculum vulgare* Mill. , both to reproduce and to lay eggs, and feeds readily on the parenchyma of young stems of *S. junceum, F. vulgare* and their leaves, or on the flowers of *V. agnus-castus* L. for example. The type of the soil is also important to be noted.

Study site

The study area is located in the area of Durrës, Albania, mainly in the historical known distribution of the species, but also extended to the nearest capes, to the north and to the south. The study area is shown in Figure 1.

Figure 2 shows the geological nature of the studied area extracted from https://geoportal.asig.gov.al/map/?auto=true.

This area is made up of:

- Qh is composed of clays, silts and peats, is mainly siliceous. These are mainly lagoon or estuarine deposits associated with sea level variations during the Holocene;
- Qp-h consists of sands, gravels, and silts, deposited by rivers and gravitational processes from the nearby Alpine mountains. The Durrës alluvial-proluvial formation is generally calcareous, although siliceous materials may be present locally, especially in gravitational sediments;
- N2-2rr consists of sandstones and conglomerates, indicating a fluvial to deltaic environment under tectonic influence. It is mainly calcareous although locally siliceous elements may be present;
- N2-1h is associated with more recent marine or lacustrine environments. Soils are of sedimentary origin, mainly siliceous, rich in sandstone and clay, with the presence of siltstone;
- N1-3m is associated with the marine events of that time. The soils are of sedimentary origin, mainly siliceous, rich in sandstone and clay, with the presence of evaporites;
- N1-2s is mainly calcareous. It may contain siliceous inclusions, but calcium carbonate dominates.

This region is subject to a Mediterranean climate with mild, wet winters and hot, dry summers, with certain microclimates accentuated by the influence of the Adriatic Sea.

The species is located exclusively in the meso-Mediterranean vegetation belt (Quézel & Médail 2003). Its elective biotopes are located between 10m and 100m altitude, close to the sea (≤ 1km). These are matorral-type plant formations originating from the sclerophyllous forest of *Quercus ilex*, more or less degraded and disturbed, as shown by the dominance in most of the sites of plants well adapted to these environments: *Dittrichia viscosa* L., *Scolymus hispanicus* L., *Onopordum* sp., *Eryngium* sp., *Cichorium* sp., *Asphodelus* sp.,

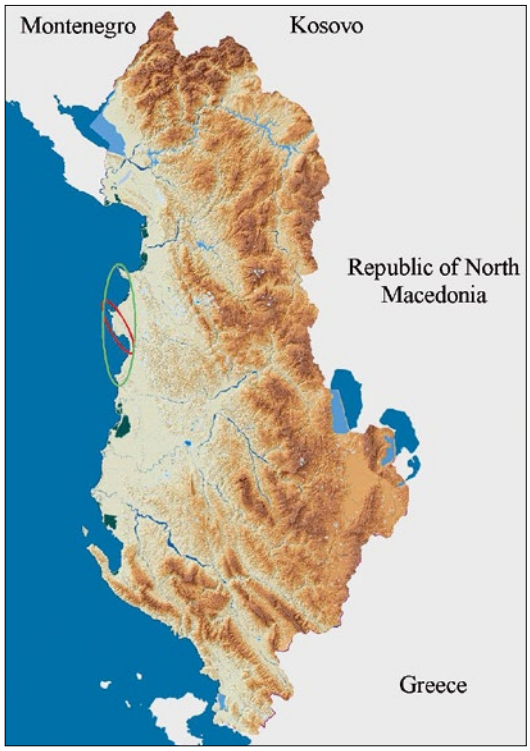

Figure 1 – Map of the study area. The red ellipse covers the historical localities and the green ellipse encompasses the study area.

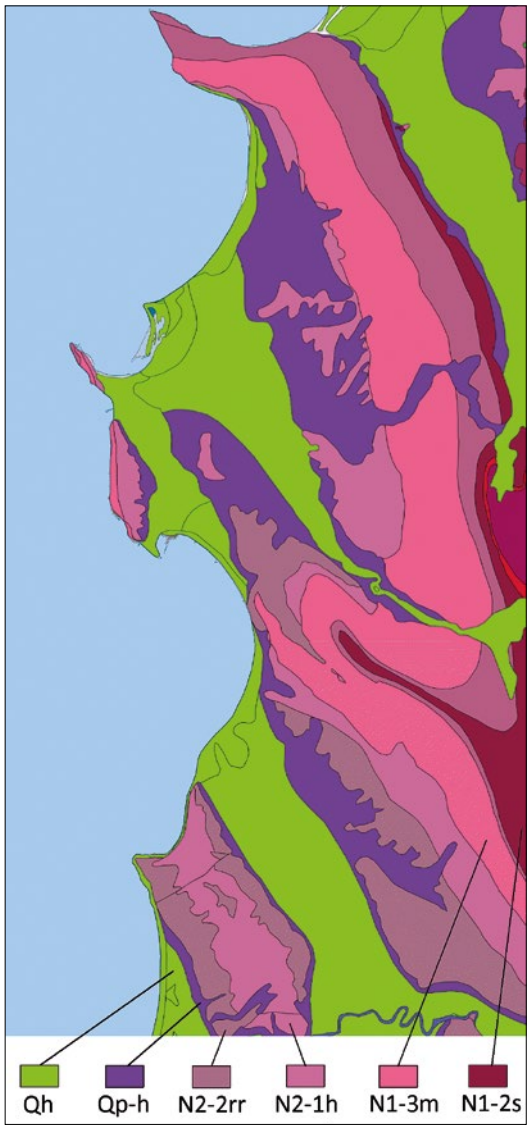

Figure 2 – Geology of the area. Qh = Quaternary Holocene swamp-lacustrine formation, Qp-h = Quaternary formation (Pleistocene and mainly Holocene), N2-2rr = Middle Pliocene (Neogene) formation (Rrogozhina) associated with the erosion of the Alpine mountains and variations in sea level, N2-1h = Helmesi Formation of the Lower Pliocene (Neogene) age, N1-3m: Messinian Formation of the Upper Miocene (Neogene) age, N1-2s = Neogene formation that covers the lower to middle Miocene.

Foeniculum vulgare, and *Spartium junceum*. For each surveyed site, the main plants taller than 50cm are reported.

A global view of the structure of the vegetation is also recorded, in most cases using a drone, a dji Mavic Pro with a 1/2.3" 12 Mpix, 26mm CMOS camera (78.8° angle of view).

Sampling

The main challenge was to target suitable sites in order to optimise our research time and answer as many questions as possible about the current status of the species. For this purpose, a precise preparation was necessary, using satellite maps (Google Earth®) to locate potentially suitable habitats and also open topographic maps to optimise our access time to the selected localities. In addition, adjustments were made after direct observation of the soils, the composition of the plant structure, and in some cases, the modification by human activities. All the targeted localities were studied, except for private and military areas. The setback concerns only the access to the military area of the Portez cape, which was not allowed.

At each site, sampling without collection was carried out by one or more observers following random transects without overlap. Specimens were adult or subadult, easily distinguished by the colour of the head near the pronotum (blue for adults and black for subadults) and by more discernible tegmina for adults (Figure 3).

U. dyrrhachiacus is found at a height of at least 40cm in the vegetation and is therefore relatively easy to find. In order to compare the relative abundance of the species between sites, we normalised the measurements by providing: number of individuals seen per 30 minutes and per observer. In this way, the results can be compared regardless of the time elapsed and the number of observers involved.

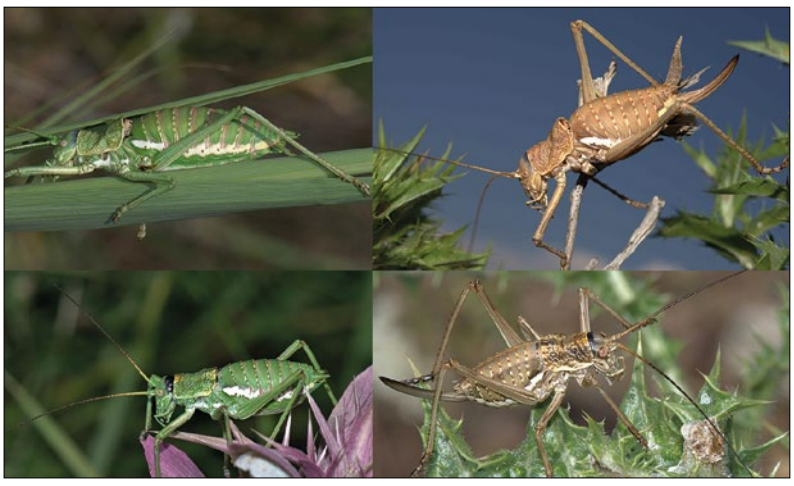

Figure 3 – Uromenus dyrrhachiacus male (left) and female (right), adult (up) and sub-adult (down).

Data analysis

Statistical analysis was carried out using Excel and XLStats. The aim of the statistical analysis was to identify which of the variables recorded at each site could provide enough significant information to be considered as valid covariates for predicting the relative abundance of the species. This could inform future advice on the management of the species' habitats and mitigation plans in the eventuality of future threats.

Results

The results including all the variables recorded are shown in Table 1.

The presence is also shown on a map in Figure 4.

The EOO (IUCN 2012) is about 35km² and gives an idea of its former range, at least before the city expanded many decades ago. The historical and current sites of Uromenus dyrrhachiacus belong to only two geological formations dated to the Neogene, i.e., ≤ 10 millions years ago: N1-3m and N2-1h.

The distribution of the species is divided into three distinct subpopulations:

– the main subpopulation is located on both sides of the chain of hills located north of Durrës. The distribution area is small but the species can be locally abundant in some spots, especially in the middle near a pass (Spitallë). The threat is the destruction of the hills (soil collected and displaced by a noria of trucks) currently in the northern part, near the new port, and in the southern part, near the city;
– the subpopulation of Portez, in the north of the new port is isolated and could disappear (work also on the ground of this area) if it is absent of the military area;
– a subpopulation in the south of Durrës still exists but in a very restricted area. This population is threatened with extinction due to the urbanisation of the area.

These three areas match with the three areas mentioned by Karny in 1918. The Figure 5 shows the biotopes of these three distinct areas. Now the area between the three subpopulations has been definitively urbanised or destroyed and is no longer suitable for the species.

The species is absent from the other capes, in the north and in the south of Durrës, despite some similarities in the biotope (type of soil, composition of plants). Between these areas, the entire coastline has been used and modified by human activities for construction and tourism.

Of the 21 other variables analysed, including 15 plants and 4 parameters of vegetation structure, the data analysis aimed to exclude variables that did not provide significant information to predict the presence of *Uromenus dyrrhachiacus*. We reduced the selected variables as long as at least 85% of the variability in relative abundance could be predicted by these selected variables. The fewer variables we keep, the easier it is to communicate conservation actions to stakeholders and to conduct mitigation studies. As a result, 6 of them (5 plants and the structure in mosaic) can be used as covariates (Figure 6): 5 plants (presence/absence) and the heterogeneous mosaic structure (yes/partial/no), if the site belongs to one of the two geological formations mentioned above.

The presence of *Foeniculum vulgare*, *Phragmites* sp., *Onopordum* sp. and *Eryngium* sp. positively predicts the presence and the abundance of the species. Conversely, the presence of *Cichorium* sp. has a negative effect on the prediction. The latter indicates a habitat that is too dry. At the inverse, if *Phragmites* sp. is too abundant and dense, the habitat is not suitable for *Uromenus*. With regard to the structure of the vegetation, the most important point is the mosaic of heterogeneous structure whatever the relative proportions of each category (close dense vegetation, plants higher than 50cm, others: herbs, bare soils, etc.) are within a normal distribution around their mean.

The other plants are not significant as predictors, either because they are ubiquitous, regardless of the presence or absence of *Uromenus*, such as *Spartium junceum* and *Scolymus hispanicus*, or because they do not play a role in the suitability of the habitat for the species, such as *Pistacia lentiscus* L., *Centaurea calcitrapa* L., etc. *Rubus* sp. has a positive or a negative effect depending on its

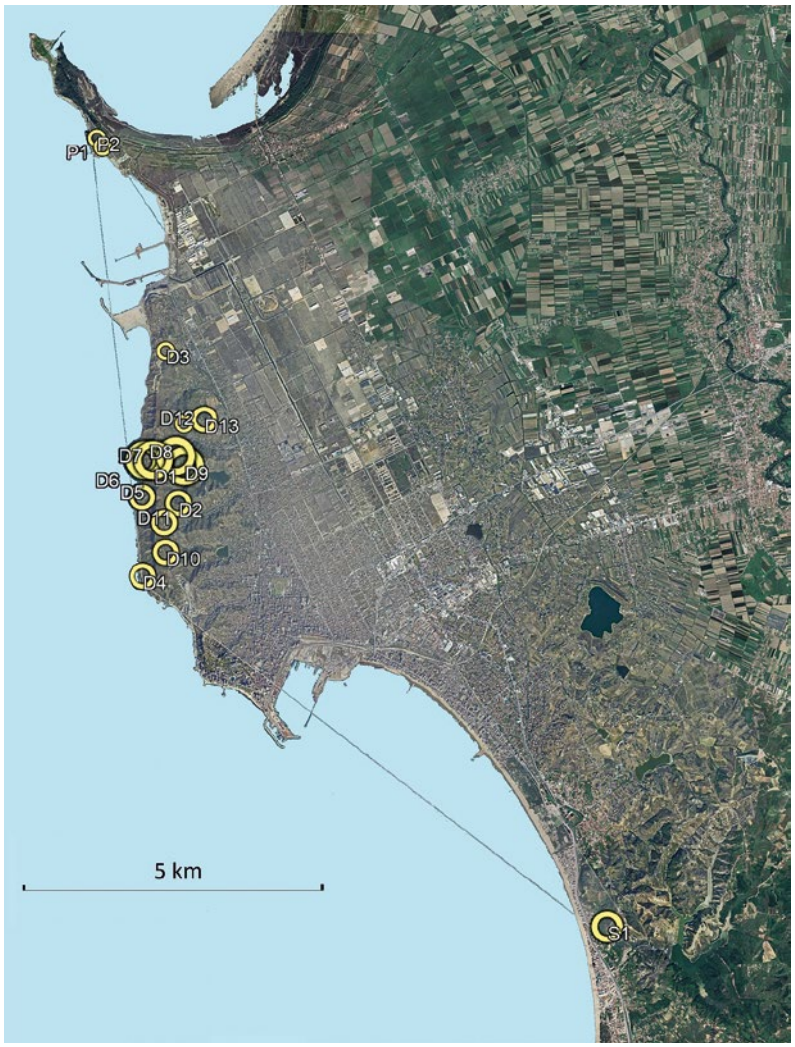

Figure 4 – Map of localities of presence and outline (grey lines) of extent of occurrence (EOO). The size of the circles reflects the relative abundance of the species.

Figure 5 – Biotopes of the 3 distinct areas. Left up: Northern area (Portez), right up: Southern area (Shkëmbi i Kavajës), down: central area composed of hills located on the north of Durrës, left: west side (sea side), right: east side.

Table 1 – All sites studied

Locality	Abundance	Location				Geology	Dominant plants (≥ 50 cm)														Structure of vegetation			
	Number of records (adults and subadults) per 30mn per observer	Latitude	Longitude	Altitude (m)	Distance from the sea (m)		Spartium junceum	Scolymus hispanicus	Foeniculum vulgare	Vitex agnus-castus	Cichorium sp.	Phragmites sp.	Onopordum sp.	Eryngium sp.	Pteridium aquilinum	Dittrichia viscosa	Pistacia lentiscus	Asphodelus sp.	Rubus sp.	Quercus ilex	Centaurea calcitrapa	Heterogenous in mosaic Yes/ Partially /No	% of closed dense vegetation	% of plants > 50 cm height	Other (herbs, soil, etc.)
Species present																								
P1	8	41.395440	19.408277	21	150	N1-3m	X	X	X	X	X			X								P	30	60	10
P2	9	41.396744	19.406976	15	177	N1-3m	X	X	X	X	X			X								P	25	70	5
D1	38	41.345151	19.422848	115	356	N1-3m	X	X	X				X		X							Y	20	60	20
D2	14	41.338587	19.428253	66	725	N2-1h	X	X			X			X								P	10	60	30
D3	8	41.362841	19.423875	48	271	N2-1h	X	X			X	X				X		X				Y	5	45	50
D4	14	41.326977	19.421057	15	60	N1-3m	X	X	X			X					X					P	10	80	10
D5	18	41.339431	19.420208	20	92	N1-3m	X	X	X			X						X				Y	10	70	20
D6	30	41.345143	19.420150	35	102	N1-3m	X	X	X			X										Y	20	65	15
D7	34	41.345198	19.420680	50	143	N1-3m	X	X	X			X										Y	10	65	25
D8	45	41.345934	19.427265	70	690	N2-1h	X	X	X			X	X		X							Y	20	65	15
D9	36	41.344430	19.429000	45	815	N2-1h	X	X	X		X	X	X		X				X			Y	25	60	15
D10	15	41.330797	19.426234	106	537	N2-1h	X	X							X				X	X	X	Y	15	75	10
D11	15	41.335435	19.425659	108	525	N2-1h	X	X							X							P	35	60	5
D12	9	41.351373	19.428448	45	760	N2-1h	X	X			X				X							Y	20	45	35
D13	13	41.352031	19.432800	53	1125	N2-1h	X	X			X		X									Y	20	55	25
S1	22	41.274358	19.521113	67	485	N1-3m	X	X	X		X		X		X				X			Y	30	40	30
Species not observed																								
R1	0	41.573457	19.479380	22	98	N2-2rr	X	X								X						N	50	10	40
R2	0	41.580897	19.454607	16	290	N2-2rr	X									X			X			N	30	20	60
D14	0	41.360884	19.428886	30	720	N2-1h	X	X	X							X						N	20	60	20
D15	0	41.354171	19.423724	85	330	N2-1h									X							N	70	20	10
D16	0	41.335375	19.420046	19	64	N1-3m						X										N	80	10	10
D17	0	41.334124	19.425149	126	488	N2-1h	X	X							X				X			P	30	20	50
D18	0	41.326539	19.430616	76	500	N2-1h	X	X							X							P	15	70	15
S2	0	41.280351	19.521724	97	755	N1-3m	X	X	X		X											P	40	35	25
S3	0	41.267720	19.531784	80	1180	N1-3m	X	X			X			X		X						P	20	50	30
K1	0	41.176504	19.480849	65	560	N2-2rr	X	X		X		X			X				X			N	50	40	10
K2	0	41.166942	19.483502	105	780	N2-1h	X				X		X			X						P	10	30	60
K3	0	41.146074	19.473055	125	990	N2-1h	X	X			X											N	10	20	70
K4	0	41.139322	19.452541	45	950	N2-2rr	X	X				X				X						N	50	30	20
K5	0	41.149925	19.490417	98	1910	N2-2rr									X	X			X			P	40	30	30
K6	0	41.164454	19.488782	75	1260	N2-2rr		X							X	X						N	50	30	20

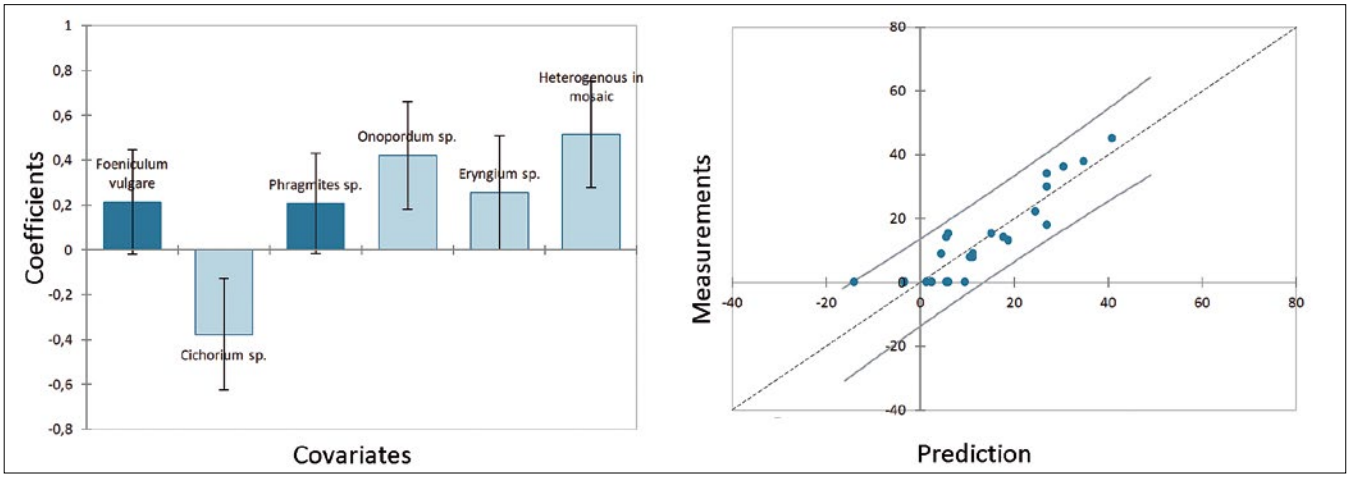

Figure 6 – Identified covariates of the relative abundance of* Uromenus dyrrhachiacus*. Light blue means p-value < 0.05, Darker blue means p-value < 0.07.

abundance and density, so this variable cannot be used with presence/absence only.

We found that *Saga natoliae* Serville, 1838 was generally present in biotopes suitable for *Uromenus dyrrhachiacus*, and more frequently where the Albanian Saddle Bush-cricket was also abundant.

In natura, along the summer, the population size decreases relatively quickly (about 40% per fortnight), probably due to the natural predation and the increasingly dry biotope.

Discussion

It should be noted that the central area, where the *Uromenus dyrrhachiacus* is relatively abundant has not always been a natural habitat. In the past, there were olive groves and vineyards on the slopes of the hill, which were cultivated in a traditional way, preserving wild flowers and bushes between these agricultural areas. More than 20 years ago (according to elderly inhabitants), there was a fire and cultivation of this part of the western side of the hills was abandoned.

We can assume that the original habitat of the species was a matorral type formation of holm oak (*Quercus ilex*), probably adjacent to wetlands (abundant before the strong human influence on this region and marsh drainage), which could explain the affinity of the species with *Phragmites*.

Today, the species is found in environments that have been more or less radically altered by human activity (soil movement, fires, plantations, overgrazing by cattle, etc.). It seems to have adapted to the pioneer vegetation, characteristic of these modified environments, allowing it to complete its life cycle. The mosaic structure of the vegetation, with the presence of numerous groves of woody or ligneous vegetation, is an important factor that allows it to survive in its new habitats and, in particular, to protect itself from predators and the extreme heat of summer.

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Mycoendophytes des fruits et graines immatures et mûrs de *Pistacia atlantica* de daya El Gouffa, Laghouat, Algérie

Mycoendophytes of immature and mature fruits and seeds of Pistacia atlantica, *from daya El Gouffa, Laghouat, Algeria*

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Résumé

Pistacia atlantica *est l'une des rares espèces ligneuses des régions arides d'Algérie. Cet arbre est particulièrement connu pour sa résistance aux conditions climatiques défavorables, ce qui est en grande partie dû à l'arsenal microbien qu'il possède. Il établit des relations symbiotiques avec un microbiome, dont la forme la plus connue est l'association avec les champignons endophytes. Ces derniers offrent à leur hôte une protection multiple face aux stress environnementaux. Le présent travail consiste à isoler et à caractériser la communauté fongique endophyte associée aux graines et fruits du pistachier de l'Atlas de la daya d'El Gouffa, dans la région de Laghouat, pour deux phases de maturation des fruits. L'échantillonnage a concerné dix sujets âgés de* P. atlantica. *Vingt fruits ont été prélevés pour chaque sujet. Au laboratoire, la graine est séparée du fruit et les deux parties sont mises en culture séparément sur milieu PDA, à température ambiante, pendant deux mois. Après purification et identification des isolats fongiques, nous avons observé des fréquences de colonisation des graines et des fruits immatures de 57 % et 43 % respectivement, tandis que pour les graines matures, la fréquence de colonisation était de 48,5 %, et celle des fruits mûrs de 93,5 %. Quatorze genres fongiques ont été recensés. La majorité des mycoendophytes isolés appartiennent au phylum des Ascomycota.* Cladosporium *et* Coniothyrium *dominent au niveau des graines et des fruits immatures, tandis qu'*Aspergillus *et* Eurotium *prédominent au niveau des graines et des fruits mûrs. Le cortège fongique associé aux fruits et graines varie en fonction de leur stade de maturation.*

Abstract

Pistacia atlantica *is one of the rare woody species found in the arid regions of Algeria. This tree is best known for its resistance to adverse climatic conditions. This is due to its microbial arsenal. It forms symbiotic relationships with a microbiome, the best known form of which is the association with endophytic fungi. The latter provides their host with multiple forms of protection against environmental stress. The aim of this study was to isolate and characterise the endophytic fungal community associated with the seeds and fruits of the Atlas pistachio tree in the El Gouffa daya in*

Mots-clés : mycoendophytes, *Pistacia atlantica*, graines, fruits, biodiversité, zone aride.

Keywords: mycoendophytes, *Pistacia atlantica*, seeds, fruit, biodiversity, arid zone.

the Laghouat region, for two phases of fruit ripening. Sampling was carried out on 10 old trees of P. atlantica. *Twenty fruits were collected from each plant. In the laboratory, the seed was separated from the fruit and the two parts were cultured separately on PDA medium at room temperature for two months. After purification and identification of the fungal isolates, we obtained colonisation frequencies for immature seeds and fruits of 57 % and 43 % respectively, while for mature seeds the frequencies were 48.5 % and for ripe fruits 93.5 %. Fourteen genera of fungi were identified. The majority of the isolated mycoendophytes belongs to the phylum Ascomycota.* Cladosporium *and* Coniothyrium *are the two dominant genera in seeds and unripe fruits.* Aspergillus *and* Eurotium *dominate seeds and ripe fruits. The fungal community associated with fruits and seeds changes according to their stage of ripeness.*

Introduction

Les mycoendophytes sont des micro-organismes non pathogènes ; ils vivent à l'intérieur des tissus végétaux sans exercer d'impact négatif sur la plante hôte. Ce groupe de champignons établit une association mutualiste avec diverses espèces végétales et colonise la flore de différents écosystèmes, tels que les forêts xériques, arctiques, tempérées, tropicales, les prairies, les terres cultivées et les savanes (Rashmi *et al*. 2019 ; Alam *et al*. 2021). Ces symbiotes très diversifiés sont un élément essentiel du micro-écosystème végétal et font partie de leur microbiome (Wen *et al*. 2022). Par cette interaction symbiotique, les champignons endophytes procurent à leur partenaire une protection permanente contre les différents stress abiotiques et biotiques. Ainsi, ils donnent une meilleure performance dans des périodes et des conditions de sécheresse, de salinité, de températures élevées et de faible disponibilité des nutriments (Lata *et al*. 2018 ; Khare *et al*. 2018).

Les zones arides constituent le biome terrestre le plus répandu sur terre, représentant environ 40 % de la superficie totale des terres émergées de la planète (Cherlet *et al*. 2018), et sont caractérisées par de faibles précipitations, des températures élevées et un air sec, ce qui rend difficile la survie des plantes (Tchakerian 2015). *P. atlantica* est l'un des rares arbres encore présents dans la région aride d'Algérie (Smail-Saadoun 2005) ; il est à la fois producteur et protecteur (Monjauze 1982). Cette essence est connue notamment pour sa résistance aux conditions climatiques très rudes de la région d'étude, caractérisée principalement par de faibles précipitations, des températures très élevées et une période de sécheresse annuelle très longue (Limane *et al*. 2014). Cet arbre est capable de s'adapter aux différentes conditions climatiques et cela permet son utilisation dans les programmes de reforestation, afin de remplacer des espèces forestières exigeantes en eau (Ifticene-Habani & Abdoun 2018). On le trouve depuis le cœur du Sahara jusqu'aux marges du bioclimat humide (Quézel & Médail 2003). Cet arbre constitue un patrimoine forestier très particulier ; il est utile pour la production à la fois fruitière et ligneuse et sa présence contribue à la diversité de l'écosystème steppique, ce qui en fait une espèce importante en Algérie (Benaradj *et al*. 2015). La majorité des recherches sur *P. atlantica* se sont concentrées sur ses aspects botaniques et écologiques. Rares sont les études menées sur son microbiome associé. Concernant le microbiome fongique, nous pouvons citer les travaux de Zareb et Smail-Saadoun (2020, 2021) et Mechiah *et al*. (2022), qui ont montré la présence des champignons endophytes au niveau foliaire et racinaire de cet arbre.

Dans le présent travail, notre intérêt s'est porté sur le microbiome fongique associé aux fruits et graines du pistachier de l'Atlas. Ces fruits sont utilisés depuis longtemps par les populations locales à des fins culinaires et médicinales (Guenane *et al*. 2015). Les champignons endophytes sont connus pour la synthèse de métabolites secondaires favorisant le développement des fruits et stimulant la germination des graines. De plus, ces mycoendophytes, transmis de la plante mère à la descendance *via* les graines par transmission verticale, sont nécessaires à la croissance de la nouvelle plantule (Faddetta *et al*. 2021). Shahzad *et al*. (2018) signalent que l'environnement interne d'une graine change au fur et à mesure de sa maturation, modifiant par conséquent sa composition en endophytes. L'objectif de notre travail était de mettre en évidence la diversité et l'évolution des mycoendophytes colonisant les fruits et les graines de *P. atlantica* de daya El Gouffa, dans la région de Laghouat en Algérie, sur deux périodes différentes : au début de la fructification (mai 2019) et à la maturité des fruits (septembre 2019).

Matériel et méthodes

Zone d'étude

C'est dans la région de Laghouat, située à 400 km au sud d'Alger, que s'est déroulé l'échantillonnage, et plus précisément dans le site de daya El Gouffa, qui se trouve à 80 km au sud de la ville de Laghouat (figure 1). Les dayas sont des dépressions de faible amplitude qui, dans les régions endoréiques du Maghreb, parsèment la surface rigide des plateaux souvent protégée par un calcaire lacustre ou une croûte pédologique. Ce sont des dépressions fermées, et elles renferment des eaux douces favorables à la végétation. Ces caractéristiques expliquent pourquoi les dayas sont occupées par une végétation herbacée et arborescente (Agabi, 1995). La daya El Gouffa est de type jeune, loin de l'action anthropique, colonisée principalement par *P. atlantica* et *Ziziphus lotus*. Son altitude se situe entre 900 et 1 000 m, avec une latitude nord de 33°29' et une longitude est de 02°13'. La station d'étude se place dans l'étage bioclimatique aride et se caractérise par une période sèche de 11 mois par an (Limane *et al*. 2014).

Figure 1 – Position géographique de la région d'étude (d-maps.com).
Figure 1 – Geographical position of the study region (d-maps.com).

Échantillonnage

La récolte a concerné 200 fruits complets immatures et 200 fruits complets mûrs en bon état phytosanitaire, issus de 10 sujets femelles sains et âgés de *P. atlantica* (figure 2). Les fruits complets immatures ont été récupérés au mois de mai 2019, ce qui correspond au début de la fructification, alors que les fruits complets mûrs sont récoltés au mois de septembre 2019 sur les mêmes individus et dans la même daya. L'échantillonnage a été effectué de manière aléatoire et les fruits récupérés ont été mis dans des sacs en papier et conservés dans une glacière jusqu'à leur mise en culture au laboratoire.

Figure 2 – Positionnement des sujets échantillonnés au niveau de daya El Gouffa.
Figure 2 – Position of the subjects sampled at daya El Gouffa.

Désinfection superficielle et mise en culture

Les fruits complets ont subi une stérilisation superficielle pour éliminer les microorganismes épiphytes, suivant le protocole de Helander et *al*. (1994), modifié comme suit : un traitement à l'éthanol (95°) pendant deux minutes, suivi d'un traitement à l'eau de Javel (NaOCl, 12°) pendant trois minutes, puis un second traitement à l'éthanol (95°) pendant

trente secondes. Entre les trois traitements, des rinçages à l'eau distillée stérile ont été réalisés. Ensuite, les fruits complets ont été séparés en deux parties à savoir : 1) le fruit proprement dit : le péricarpe et 2) la graine. Un total de 800 fruits et graines stérilisés en surface ont été placés aseptiquement dans des boîtes de Pétri, à raison de 5 unités par boîte, contenant un milieu PDA (potato-dextrose-agar), additionné d'un antibiotique (amoxicilline) à large spectre d'inhibition, pour éviter la croissance bactérienne. L'incubation a été réalisée à température ambiante entre 24 °C et 27 °C pendant deux mois.

Identification des isolats fongiques

L'identification des mycoendophytes recensés au niveau des fruits et graines de *P. atlantica* a été réalisée morphologiquement suivant les caractéristiques macroscopiques des cultures, tels que la couleur, la texture, la taille, la forme des colonies et la vitesse de croissance (rapide, modérée ou lente), et selon les critères microscopiques, par des observations entre lame et lamelle sous microscope optique, afin de visualiser la structure des hyphes, la forme et la couleur des différentes conidies et spores, en se basant essentiellement sur les clés d'identification établies par Kiffer & Morelet (1997), Kidd *et al*. (2016) et celle de Dufresne & Saint-Germain (2018). Cette identification à l'échelle morphologique est limitée au niveau du genre. Ainsi, les structures qui n'ont pas été identifiées et les mycéliums stériles sont mentionnés (SNI).

Paramètres analysés

Fréquence moyenne de colonisation (FC %)

Afin de mesurer le taux d'infection ou de colonisation fongique au niveau des sujets échantillonnés, nous avons adopté la méthode de Fisher et Petrini (1987) suivante :

$$FC\ (\%) = (N_c / N_t) \times 100$$

avec :

N_c : nombre de fruits ou graines colonisés ;

N_t : nombre total de fruits ou graines mis en culture.

Abondance fongique (%)

Les abondances des différents genres fongiques isolés sont calculées selon la formule suivante :

$$A\ (\%) = (N_g / N_t) \times 100$$

avec :

A : abondance des genres fongiques ;

N_g : nombre de fois où le genre est recensé chez le même sujet ;

N_t : nombre total de fruits ou graines colonisés chez le même sujet.

En utilisant le logiciel Stat Box 6.40 (Agrosolutions), des analyses de variances (ANOVA) ont été effectuées pour les variables analysées. Une analyse en composantes principales (ACP) a été réalisée, afin de distinguer la répartition des genres fongiques identifiés et de faire ressortir les différents groupes selon la maturité des fruits et graines. Enfin, une matrice de corrélation a été élaborée dans le but de mettre en lumière les corrélations existantes entre les mycoendophytes inventoriés.

Résultats

Fréquence de colonisation

À partir des 800 échantillons cultivés sur PDA, répartis entre fruits et graines immatures et mûrs, et après une incubation de deux mois, nous avons enregistré un développement fongique dans 484 unités. Les fréquences de colonisation au niveau de chaque sujet de *P. atlantica* et selon la répartition des fruits et des graines, immatures et mûrs, sont montrées dans le tableau 1.

Concernant les fréquences de colonisation fongique obtenues, le groupe des fruits mûrs a enregistré la plus forte fréquence moyenne d'infection en endophytes avec 93,5 %. Le test de normalité montre que ces fréquences de colonisation ont une distribution normale, car 70 % des valeurs moyennes sont incluses dans l'intervalle $[x \pm \sigma]$.

L'analyse de variance des fréquences de colonisation ne montre aucune différence significative entre les graines immatures et mûres ($p = 0{,}63$), ni entre les graines immatures et les fruits immatures ($p = 0{,}26$). En revanche, des différences significatives ont été observées entre les graines et les fruits

mûrs (p = 0,000018), et entre les fruits immatures et mûrs (p = 0,00095). Il existe une différence significative entre les fréquences de colonisation des graines (immatures et mûres) et des fruits (immatures et mûrs) (p = 0,000066).

Taxonomie des mycoendophytes recensés

Au total, quatorze genres fongiques ont été identifiés à partir des différents échantillons analysés de *P. atlantica*. 86,51 % des mycoendophytes isolés appartiennent au phylum des Ascomycota, 3,83 % au phylum des Zygomycota et 9,63 % des champignons endophytes n'ont pas été identifiés et sont désignés SNI (figure 3).

Les genres identifiés dans cette étude sont les suivants : *Acremonium, Alternaria, Aspergillus, Aureobasidium, Chaetomium, Cladosporium, Coniothyrium, Eurotium, Fusarium, Mucor, Penicillium, Phialophora, Phoma* et *Ulocladium*. Les abondances de ces genres au niveau des fruits et graines immatures et mûrs de *P. atlantica* sont mentionnées dans le tableau 2.

Le genre le plus abondant chez les graines immatures est *Cladosporium* avec 40 %, suivi par *Coniothyrium* (15,74 %), *Penicillium* (15,73 %) et *Aspergillus* (12 %). Les genres les moins représentés sont : *Mucor* (6,66 %), *Phialophora* (5,33 %), *Fusarium* (3 %) et *Alternaria* (1,53 %). Les fruits immatures sont aussi colonisés en grande partie par *Cladosporium* (33,01 %), ainsi que par *Coniothyrium* (13,35 %) et *Phialophora* (11,01 %). Les mycoendophytes les moins représentés sont : *Acremonium* (10 %), *Mucor* (8,66 %), *Aspergillus* (8,2 %), *Penicillium* (5,23 %), *Ulocladium* (5 %), *Alternaria* (3 %) et *Aureobasidium* (2,5 %).

En dehors des mycoendophytes non identifiés (SNI) qui représentent 33,55 % des abondances fongiques calculées, *Aspergillus* et *Eurotium* sont les deux genres dominants parmi les champignons endophytes recensés et identifiés chez les graines mûres, respectivement 27,33 % et 20,96 %. Le reste des champignons recensés sont *Cladosporium* (11,11 %), *Chaetomium* (3,7 %) et *Penicillium* (3,33 %). Quant aux fruits mûrs, ils sont colonisés majoritairement par *Aspergillus* (73,02 %), suivi par *Eurotium* (9,46 %). *Cladosporium* (7,5 %), *Alternaria* (2,5 %) et *Phoma* (2,5 %) sont les moins présents dans ce groupe.

Tableau 1 – Fréquences de colonisation fongique (FC %) au niveau des dix sujets de *P. atlantica*.

Table 1 – Fungal colonization frequencies (FC %) in ten* P. atlantica *plants.

Sujets	FC % Graines		FC % Fruits	
	immatures	mûres	immatures	mûrs
1	40	0	80	100
2	75	60	75	100
3	65	50	65	100
4	50	50	55	100
5	25	50	20	85
6	65	75	45	100
7	25	50	40	100
8	5	75	100	75
9	5	50	15	75
10	75	25	75	100
Moyenne (x)	43	48,50	57	93,50
Écart type (σ)	27,10	22,24	27,20	10,81
Erreur Standard	8,57	7,03	8,60	3,42

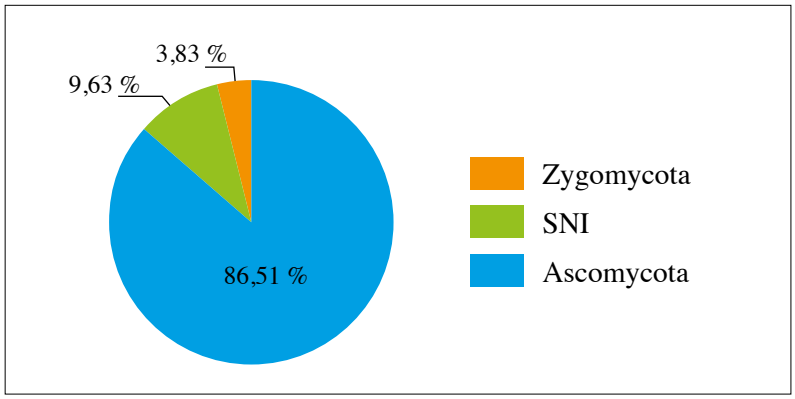

Figure 3 – Phyla de l'ensemble des genres recensés.

Figure 3 – Phyla of all recorded genera.

Cladosporium et *Aspergillus* sont présents dans les différents échantillons et pour les deux périodes d'échantillonnage, au début de la fructification et à la maturité des fruits et graines.

La diversité fongique est plus importante au début de la fructification, avec onze genres contre sept genres de mycoendophytes à la maturité des fruits et des graines. Les genres *Coniothyrium, Mucor* et *Phialophora* sont recensés uniquement dans les échantillons immatures, alors que *Eurotium* colonise les graines et les fruits mûrs.

Afin de mettre en lumière les différentes interactions qui peuvent s'établir entre les mycoendophytes testés, la matrice de

Tableau 2 – Abondances (%) des genres fongiques inventoriés au niveau des sujets de *P. atlantica*.
Table 2 – Abundances (%) of fungal genera inventoried on* P. atlantica *specimens.

Genre	Phylum	% Graines		% Fruits	
		immatures	mûres	immatures	mûrs
Acremonium	Ascomycota	0	0	10	0
Alternaria	Ascomycota	1,53	0	3,00	2,50
Aspergillus	Ascomycota	12,00	**27,53**	8,20	**73,02**
Aureobasidium	Ascomycota	0	0	2,50	0
Chaetomium	Ascomycota	0	3,70	0	0
Cladosporium	Ascomycota	**40,00**	11,11	**33,01**	7,50
Coniothyrium	Ascomycota	15,74	0	13,35	0
Eurotium	Ascomycota	0	20,96	0	9,46
Fusarium	Ascomycota	3,00	0	0	0
Mucor	Zygomycota	6,66	0	8,66	0
Penicillium	Ascomycota	15,73	3,33	5,23	0
Phialophora	Ascomycota	5,33	0	11,01	0
Phoma	Ascomycota	0	0	0	2,50
Ulocladium	Ascomycota	0	0	5,00	0
SNI	/	0	**33,53**	0	5,00

Tableau 3 – Matrice des corrélations des mycoendophytes inventoriés.
Table 3 – Correlation matrix for mycoendophytes inventoried.

	Acremonium	*Alternaria*	*Aspergillus*	*Aureobasidium*	*Chaetomium*	*Cladosporium*	*Coniothyrium*	*Eurotium*	*Fusarium*	*Mucor*	*Penicillium*	*Phialophora*	*Phoma*	*Ulocladium*	SNI
Acremonium	1														
Alternaria	0,63	1													
Aspergillus	−0,49	0,12	1												
Aureobasidium	**1,00**	0,63	−0,49	1											
Chaetomium	−0,33	−0,89	−0,06	−0,33	1										
Cladosporium	0,42	0,28	−0,81	0,42	−0,49	1									
Coniothyrium	0,48	0,39	−0,77	0,48	−0,57	**0,99**	1								
Eurotium	−0,51	−0,76	0,39	−0,51	0,89	−0,82	−0,88	1							
Fusarium	−0,33	−0,11	−0,41	−0,33	−0,33	0,71	0,67	−0,51	1						
Mucor	0,72	0,52	−0,77	0,72	−0,57	0,93	**0,96**	−0,87	0,42	1					
Penicillium	−0,08	−0,11	−0,68	−0,08	−0,27	0,86	0,82	−0,57	0,95	0,62	1				
Phialophora	0,88	0,60	−0,72	0,88	−0,52	0,80	0,84	−0,79	0,16	**0,96**	0,39	1			
Phoma	−0,33	0,37	**0,96**	−0,33	−0,33	−0,64	−0,57	0,12	−0,33	0,57	−0,60	−0,52	1		
Ulocladium	**1,00**	0,63	−0,49	**1,00**	−0,33	0,42	0,48	−0,51	−0,33	0,72	−0,08	0,88	0,33	1	
SNI	−0,40	−0,87	0,08	−0,40	**0,99**	−0,61	−0,69	**0,95**	−0,40	0,68	−0,37	−0,62	0,19	−0,40	1

En gras : valeurs significatives (hors diagonale) au seuil alpha = 0,05 (test bilatéral).

corrélation de Pearson (tableau 3) donne les coefficients de corrélation des genres fongiques examinés deux à deux.

Il y a lieu de noter que toutes les corrélations significatives entre les genres de mycoendophytes sont positives. *Aureobasidium* établit deux interactions positives hautement significatives avec *Acremonium* et *Ulocladium*, avec un indice de corrélation de 1. *Coniothyrium* et *Mucor* présentent un coefficient de corrélation de 0,96, ces deux genres étant corrélés respectivement avec *Cladosporium* (0,99) et *Phialophora* (0,96). Quant aux souches non identifiées, elles

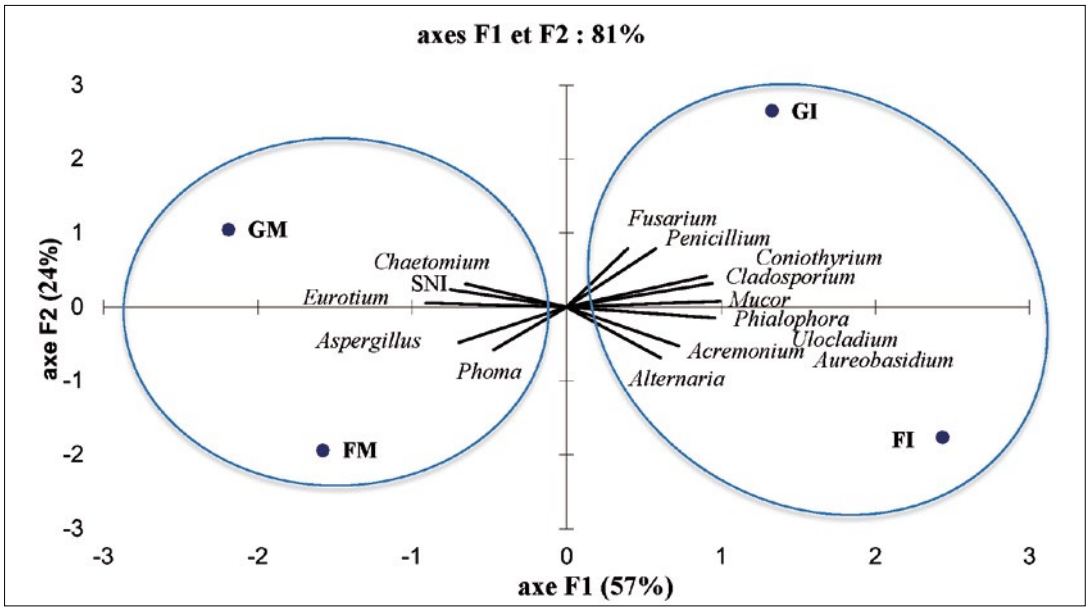

Figure 4 – Distribution des genres fongiques recensés au sein des fruits et graines de *P. atlantica*. GI = graine immature, GM = graine mûre, FI = fruit immature, FM = fruit mûr. SNI = structures non identifiées.

Figure 4 – 11Distribution of fungal genera found in the fruits and seeds of* P. atlantica*. GI = immature seed, GM = ripe seed, FI = immature fruit, FM = ripe fruit. SNI = non identified structures.

montrent des interactions avec *Chaetomium* (0,99) et *Eurotium* (0,95). Concernant les genres *Aspergillus*, *Chaetomium*, *Cladosporium*, *Eurotium*, *Phialophora* et *Phoma*, ils établissent une seule corrélation significative. Le reste des mycoendophytes (*Alternaria*, *Fusarium* et *Penicillium*) ne présentent aucune corrélation significative.

L'analyse en composantes principales (ACP) explique 81 % du phénomène, avec 57 % pour l'axe 1 et 24 % de l'inertie totale pour l'axe 2 (figure 4).

Selon cette ACP et par rapport à l'axe F1, nous pouvons distinguer l'individualisation de deux groupes différents. Le premier groupe comporte les mycoendophytes présents dans les fruits et graines matures : *Aspergillus*, *Chaetomium*, *Eurotium*, *Phoma* et SNI, avec la dominance du genre *Aspergillus*. Le deuxième groupe comprend les champignons endophytes recensés essentiellement dans les fruits et graines immatures, avec la dominance de *Cladosporium*. L'axe F2, quant à lui, sépare le cortège de champignons endophytes présents dans les graines, qu'elles soient immatures ou mûres, de celui des fruits immatures ou mûrs.

Discussion

Cette étude a mis en évidence, pour la première fois, la présence de mycoendophytes au sein des fruits et des graines immatures et matures du pistachier de l'Atlas de daya El Gouffa de la région de Laghouat en Algérie.

P. atlantica ne fait pas l'exclusivité par cette colonisation fongique, il en est de même pour plusieurs autres espèces végétales étudiées dans les régions arides et sahariennes, telles que *Phoenix dactylifera* (Mahmoud *et al*. 2016), *Schinus molle* (Rouabah *et al*. 2020), *Peganum harmala* (Ouzid 2018 ; Rouabah *et al*. 2020) et *Limoniastrum feei* (Medjeber *et al*. 2021). Par leur association symbiotique avec le végétal hôte, les champignons endophytes assurent un rôle crucial dans la réduction du stress biotique et abiotique. Ils renforcent la défense contre les herbivores et les agents pathogènes, principalement par la production de métabolites secondaires. Ces composés repoussent les herbivores et constituent une défense chimique contre les agents pathogènes, améliorant ainsi la santé générale de la plante hôte (Faeth & Fagan 2002 ; Miller *et al*. 2002). Les mycoendophytes peuvent stimuler la croissance des racines, en augmentant leur longueur et leur surface et en améliorant leur architecture. Cela permet aux plantes de bénéficier d'une plus grande quantité d'eau et de nutriments provenant du sol, renforçant

ainsi leur résistance à la sécheresse (Miranda *et al*. 2023). Ainsi, ils améliorent la survie des plantes dans les écosystèmes arides (Khan *et al*. 2011 ; Hosseyni Moghaddam *et al*. 2022).

La fréquence moyenne de colonisation enregistrée dans les fruits et les graines de *P. atlantica* est de 60,5 %, comme c'est le cas pour d'autres plantes des régions arides, telles que *Peganum harmala* qui montre une fréquence de colonisation de 56 % au niveau de ses fruits, alors que les fruits de *Schinus molle* présentent une fréquence de colonisation plus élevée à 88 % (Rouabah *et al*. 2020).

La fréquence de colonisation et la densité de la communauté endophyte au sein des végétaux changent selon la nature de la plante hôte et en fonction des conditions climatiques et édaphiques, ainsi que de l'hétérogénéité de l'habitat (Oita *et al*. 2021). El-Nagerabi *et al*. (2013) ainsi que Philippot *et al*. (2013) signalent que cette colonisation fongique est notamment influencée par plusieurs facteurs, dont le génotype de la plante hôte, les divers stress environnementaux et la présence éventuelle d'autres micro-organismes.

Le cortège fongique isolé au sein des graines et fruits de *P. atlantica* présente une diversité importante, avec quatorze genres fongiques et quelques structures non identifiées. Les mycoendophytes recensés appartiennent en majorité au phylum des Ascomycota (86,51 %). Ce dernier constitue le plus grand phylum de champignons, comprenant la gamme d'espèces la plus diversifiée en raison de son degré élevé de spécialisation, de son taux d'évolution et d'adaptabilité plus rapide et de son implication dans une variété de relations symbiotiques (Wang *et al*. 2010). Selon Arnold (2007), les champignons endophytes sont majoritairement issus des Ascomycètes. Une méta-analyse de sept études visant à identifier les champignons endophytes cultivables de diverses plantes du désert a révélé que 88,73 % des isolats appartenaient au phylum des Ascomycota. Ces constatations sont cohérentes avec les connaissances antérieures sur l'appartenance de ces symbiotes endophytes aux différents phylums fongiques (Rodriguez *et al*. 2009 ; Zhang & White 2021).

En matière de diversité fongique et de nombre d'isolats recensés au niveau de *P. atlantica*, il semble que les racines et les feuilles présentent plus de genres que les fruits et les graines. Au niveau foliaire de *P. atlantica*, Benfoddil (2015) a inventorié 24 genres fongiques, tandis que Zareb et Smail-Saadoun (2020) ont recensé 26 genres. Les racines comportent 18 genres de mycoendophytes (Mechiah *et al*., 2022). À l'exception de *Coniothyrium*, *Eurotium* et *Phialophora*, tous les genres recensés pour les fruits sont présents dans les racines et les feuilles. Il semble que ces trois genres ont une certaine préférence tissulaire pour les organes étudiés (fruits et graines). Il est évident que certains mycoendophytes sont en mesure d'infecter plusieurs espèces végétales, alors que d'autres sont plutôt spécialisés et ne colonisent qu'une gamme limitée de plantes. En outre, cette spécificité de colonisation peut également se manifester au niveau des organes de la plante hôte (Baron & Rigobelo 2022). Wang *et al*. (2022) soutiennent l'idée que la densité de la population fongique est principalement influencée par le type de l'organe végétal. En effet, ils ont trouvé une nette différence dans la composition et la richesse fongique entre la racine et la graine de *Sophora alopecuroides*, les racines étaient les plus riches et les plus diversifiées en mycoendophytes. Cette spécificité tissulaire de colonisation fongique est liée à l'organisation structurale interne et à la composition nutritionnelle et biochimique des différents tissus de la plante hôte (Lakshman & Kurandawad 2013 ; El-Nagerabi *et al*. 2013 ; Ren *et al*. 2019).

La faible teneur en mycoendophytes des graines par rapport aux autres parties de la plante hôte se justifie par leur organisation structurelle, ce sont des organes fermés et fortement protégés (Wang *et al*. 2022), ce qui pourrait affecter la transmission horizontale des champignons phyllosphériques dans les graines. Par ailleurs, ces dernières sont responsables de la transmission verticale des mycoendophytes, il est possible que ces champignons privilégient la conservation et favorisent la germination des graines dans le sol (Shearin *et al*. 2017). Faddetta *et al*. (2021) ont prouvé la transmission verticale du microbiote endophyte des graines de *Citrus limon* aux pousses et ont suggéré que ces micro-organismes ont un rôle essentiel dans la germination des graines et la croissance de cette plante. Abdelfattah *et al*. (2021) ont démontré qu'une grande partie du microbiome de la graine est transférée à la phyllosphère et aux racines de la plantule en développement. De ce fait, les semences jouent un rôle particulier en reliant une génération à l'autre et en assurant la transmission continue des endophytes (Abdelfattah *et al*. 2023).

Dans cette étude, les graines et les fruits matures sont plus infectés que les graines et les fruits immatures. Cela argumente de plus en plus l'idée selon laquelle la colonisation en mycoendophytes augmente avec le degré de maturité des tissus végétaux. La majorité des travaux menés dans ce sens affirment que la composition de la communauté fongique est influencée par le degré de croissance de l'hôte (Wang *et al*. 2022). Au niveau racinaire de *Lycium barbarum*, Li *et al*. (2022) ont confirmé que la composition en champignons endophytes était variable selon le stade de maturité. Le même constat de dépendance de l'assemblage microbien des mycoendophytes au degré de maturité a été observé pour les plants de betteraves sucrières et de petits pois (Houlden *et al*. 2008).

La distribution observée au niveau de l'ACP montre l'individualisation des genres fongiques recensés en deux groupes distincts. La diversité la plus élevée en mycoendophytes est notée au niveau des graines et fruits immatures, avec dix genres fongiques. Les graines et les fruits mûrs comportent des SNI et seulement quatre genres fongiques. D'après cette distribution, il semble que ces champignons jouent des rôles précis pendant la maturation des tissus colonisés, où ils synthétisent des substances nécessaires pour chaque phase de développement. Ce constat est en accord avec les travaux de Ju *et al*. (2024), qui montrent que la composition en mycoendophytes et la production de composés bioactifs chez *Sophora alopecuroides* varient en fonction du stade de développement des organes.

Aspergillus et *Cladosporium* sont les deux genres dominants pour l'ensemble des graines et des fruits. Ce sont des champignons communs présents dans les différentes parties de *P. atlantica*. Ils dominent au sein des feuilles échantillonnées au printemps 2016 (Zareb & Smail-Saadoun 2020). Ces endophytes sont communs à plusieurs espèces de plantes et ont été isolés à plusieurs reprises et dans différents habitats en tant que genres dominants (Bezzera *et al*. 2013 ; Zareb & Smail-Saadoun 2020). Ces deux genres sont connus notamment comme des champignons dématiés ou pigmentés capables d'accumuler la mélanine au niveau des hyphes, ce qui leur donne le pouvoir de vivre dans des environnements stressants, où ils jouent un rôle important dans la protection des plantes contre plusieurs stress biotiques et abiotiques et surtout contre les rayonnements UV (Hohl & Feldmesser 2007 ; Rodriguez *et al*. 2009). Il est certain que les végétaux vivant dans des milieux hostiles hébergent les champignons pigmentés comme élément de leur mécanisme d'adaptation à des conditions de vie extrêmes (Zareb & Smail-Saadoun 2020).

Cladosporium caractérise les échantillons immatures collectés au mois de mai. Il a été isolé chez plusieurs plantes comme le genre fongique endophyte le plus abondant, c'est le cas aussi pour les graines et les pousses de *Citrus limon* (Faddetta *et al*. 2021). Ce genre représente une source importante de gibbérellines, qui sont des hormones régulant divers processus de développement chez les plantes, y compris la sénescence des feuilles et des fruits (Salvatore *et al*. 2021). Cette production de gibbérelline contribue probablement à la maturation des fruits, ce qui explique parfaitement sa présence en tant que genre dominant dans la phase immature des fruits du pistachier de l'Atlas. La gibbérelline, appliquée au début de la floraison, stimule le processus de floraison et diminue l'abscission des fleurs et des fruits. Selon Navita (2021), la gibbérelline a un impact significatif sur le prolongement de la période de floraison et la production de fruits de tomate. Safitri & Aini (2018) ont évoqué que l'application de GA3 au début de la phase de fructification pouvait augmenter le nombre de fruits formés. En plus de produire des hormones de croissance, certaines espèces de *Cladosporium* ont montré leur potentiel en tant qu'agents insecticides contre les hémiptères, tels que les pucerons et les aleurodes (Mousavi *et al*. 2022). Les pucerons, comme l'espèce *Slavum wertheimae*, peuvent induire la formation de galles sur les bourgeons des arbres de *P. atlantica* (Sifi 2016).

À la phase de maturité des fruits et graines, le genre qui domine est *Aspergillus*. Il est connu pour prospérer dans les environnements arides grâce à sa capacité à s'adapter à différentes conditions environnementales. Il tolère divers stress tels que la sécheresse, les températures extrêmes, l'hydrophobicité et le stress oxydatif et osmotique (Paulussen *et al*. 2017). Ce genre assure un rôle déterminant dans le biocontrôle et le maintien de la santé des végétaux en produisant des molécules antimicrobiennes bioactives efficaces contre les agents pathogènes (Wang *et al*. 2022). Des études ont montré qu'*Aspergillus* peut lutter contre des maladies fruitières spécifiques. Par exemple, l'espèce endophytique *A. terreus* isolé des graines de *Phaseolus vulgaris* s'est avérée utile dans le contrôle des maladies de la fonte des semis causées par *Rhizoctonia*

solani (Abdelaziz *et al*. 2023). *Aspergillus* produit aussi de la gibbérelline qui est un type de phytohormone jouant un rôle important en facilitant la germination des graines et en favorisant la croissance des plantes (Mathur *et al*. 2022). Khan *et al*. (2011) ont démontré que l'inoculation des plants de soja par *A. fumigatus* augmente significativement la longueur et la biomasse de leurs pousses, leur surface foliaire et leur teneur en chlorophylle.

Le genre *Eurotium* colonise uniquement les fruits et graines matures. Les espèces de ce genre constituent une source importante de molécules bioactives dotées d'activités antibactériennes, d'antibiofilm et d'autres activités biologiques, en particulier celles qui sont associées à des conditions environnementales particulières (May Zin *et al*. 2017 ; Zhang *et al*. 2017). Ces champignons sont connus pour être hautement xérophiles ou halophiles, ce qui leur donne un certain degré d'adaptation aux conditions extrêmes de l'environnement (Jedidi *et al*. 2017). *E. rubrum*, *E. chevalieri* et *E. cristatum* sont quelques-unes des espèces d'*Eurotium* qui ont été explorées pour leurs métabolites. Ces champignons ont été isolés à partir d'une variété de plantes, y compris des plantes salines et alcalines, des mangroves et des algues marines (Deng *et al*. 2023). Par ailleurs, *Coniothyrium*, présent uniquement dans les fruits immatures, possède un potentiel en tant qu'agent antifongique et de lutte biologique, il présente une capacité de dégradation de la paroi cellulaire des microorganismes pathogènes. À titre d'exemple, l'espèce *C. minitans* est utilisée pour lutter contre les maladies causées par *Sclerotinia sclerotiorum* (Zhao *et al*. 2020).

De plus, il peut y avoir des relations synergiques entre les genres au sein du même groupe. Cela se confirme par la matrice de corrélations, qui montre des interactions positives significatives élevées entre les genres fongiques. Bien que les mycoendophytes possèdent de nombreuses aptitudes individuelles, il est concevable que ces champignons, lorsqu'ils interagissent les uns avec les autres et interviennent en tant que communauté, puissent remplir de nouvelles actions favorables à l'hôte, qui ne peuvent pas être repérées lorsque chaque champignon est étudié indépendamment des autres (Andreote *et al*. 2014). Ces relations synergiques observées entre les mycoendophytes isolés dans cette étude ne sont pas statiques, mais peuvent changer dans l'espace et dans le temps. À titre d'exemple, dans cette étude, *Aspergillus* a montré des corrélations positives avec *Eurotium* et *Phoma*, alors que dans d'autres études, il a montré des relations antagonistes avec ces deux genres (Strobel *et al*. 2011 ; Medjeber *et al*. 2021). Il est devenu clair que la relation spécifique entre les champignons endophytes bascule du mutualisme à l'antagonisme, en passant par la compétition, en fonction de l'habitat et selon les conditions offertes (Fontana *et al*. 2021 ; Wulandari *et al*. 2022).

La saisonnalité aussi affecte la structure et la richesse de la mycoflore, elle a un rôle dans la distribution et la dynamique des populations fongiques au sein des compartiments tissulaires des plantes hôtes (Oita *et al*. 2021). Dans le présent travail, les échantillons prélevés au mois de septembre ont donné des fréquences de colonisation plus élevées que ceux du mois de mai. Agan *et al*. (2021), dans leur étude sur *Pinus sylvestris*, ont conclu que la densité en mycoendophytes au niveau des aiguilles progresse du printemps à l'automne et en fonction de l'âge de ces dernières.

Conclusion

Les graines et les fruits de *P. atlantica* de daya El Gouffa se trouvent colonisés par les champignons endophytes. Cette association symbiotique représente un mode de vie essentiel pour cet arbre qui prospère dans les régions arides et semi-arides. Cette étude montre que la densité et la diversité fongique des fruits et graines de cette population varient en fonction du degré de maturité et de la saison. Par ailleurs, il est recommandé de mener des recherches complémentaires sur la composition en mycoendophytes du pistachier de l'Atlas dans d'autres dayas ou d'autres régions afin de pouvoir tirer des comparaisons inter-populations.

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Analyse bibliométrique des pelouses de parcours méditerranéens (Scopus, 2004-2024) : disparités Nord-Sud

Bibliometric Analysis of Mediterranean Rangelands (Scopus, 2004-2024): North-South Disparities

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Résumé

Cette étude analyse les dynamiques des recherches scientifiques menées sur les parcours méditerranéens qui sont des écosystèmes vulnérables aux changements climatiques et aux pressions anthropiques. Son objectif est de mettre en évidence les tendances, les priorités et les lacunes existantes en matière de recherche.

L'analyse de 452 articles publiés entre 2004 et 2024 dans Scopus, impliquant 2174 auteurs et 1778 mots-clés, montre que la production scientifique reste faible avant 2008 (< 10 articles/an) et atteint un pic en 2016 avec 43 publications. Les collaborations internationales représentent 43,6 % des travaux, tandis que les revues Science of the Total Environment *(IF = 17,6 en 2023) et* Agriculture, Ecosystems & Environment *(IF = 11,7 en 2023) concentrent 60 % des publications à fort impact (ayant IF > 10).*

L'Europe du Sud domine la production avec l'Espagne (362 publications), l'Italie (232) et la France (180). À l'inverse, l'Afrique du Nord reste marginale avec seulement 2,46 % des publications, réparties entre l'Algérie, le Maroc et la Tunisie. Les institutions nord-africaines contribuent à seulement 3,24 % des publications, illustrant un déficit de participation et un manque de collaborations Sud-Sud, lié à un écosystème scientifique insuffisamment valorisé et à des soutiens politiques et financiers limités.

*Trois axes de recherche dominent : les écosystèmes herbacés (*grassland*: 250 occurrences, 11 % des mots-clés), la région méditerranéenne (*mediterranean region*: 239 occurrences, 10,5 %), suivis par la biodiversité (*biodiversity*: 112 occurrences, 5 %) et l'adaptation au changement climatique (*climate change*: 76 occurrences, 3,3 %). Les dimensions socio-économiques (*governance, rural livelihoods, socio-economic factors*) sont sous-représentées (< 1 %), limitant une approche holistique de ces écosystèmes. De plus, les savoirs traditionnels et communautaires (*pastoralism, traditional knowledge, community-based management*), pourtant essentiels pour une gestion durable des parcours méditerranéens,*

Mots-clés : écosystèmes méditerranéens, pâturage extensif, gestion adaptative, biodiversité, changement climatique, collaboration scientifique.

Keywords: Mediterranean ecosystems, extensive grazing, adaptive management, biodiversity, climate change, scientific collaboration.

sont faiblement mobilisés (14,75 %), accentuant la marginalisation des perspectives locales et traduisant leur faible prise en compte dans les travaux scientifiques.

Ces résultats soulignent l'urgence d'une reconfiguration des collaborations Nord-Sud, avec un renforcement des capacités de recherche en Afrique du Nord et une meilleure intégration des savoirs traditionnels. Une approche interdisciplinaire combinant écologie, socio-économie et politiques environnementales serait essentielle pour élaborer des stratégies adaptées aux défis environnementaux croissants.

Abstract

This study examines research trends on Mediterranean rangelands, ecosystems vulnerable to climate change and anthropogenic pressures. It aims to identify key research priorities, trends, and existing gaps. Bibliometric analysis reveals an uneven distribution of scientific contributions between the northern and southern Mediterranean regions.

An analysis of 452 articles published between 2004 and 2024 in Scopus, involving 2,174 authors and 1,778 keywords, shows limited scientific output before 2008 (< 10 articles/year), peaking in 2016 with 43 publications. International collaborations account for 43.6% of studies, while high-impact journals such as Science of the Total Environment (IF = 17.6 in 2023) and Agriculture, Ecosystems & Environment (IF = 11.7 in 2023) host 60% of publications with an impact factor (IF) > 10.

Southern Europe dominates research output, with Spain (362 publications), Italy (232), and France (180) leading. In contrast, North Africa remains underrepresented, contributing only 2.46% of publications, primarily from Algeria, Morocco, and Tunisia. North African institutions account for just 3.24% of total publications, reflecting limited participation and weak South-South collaboration due to underfunded research ecosystems and inadequate policy support.

Three dominant research themes emerge: grassland ecosystems (250 keyword occurrences, 11%), Mediterranean region (239 occurrences, 10.5%), biodiversity (112 occurrences, 5%), and climate change adaptation (76 occurrences, 3.3%). Socio-economic dimensions (governance, rural livelihoods, socio-economic factors) are underrepresented (< 1%), hindering holistic ecosystem management. Additionally, traditional and local knowledge (pastoralism, traditional knowledge, community-based management of Mediterranean rangelands) – critical for sustainable practices – remains poorly integrated (14.75%), indicating its marginalization in scientific discourse.

These findings underscore the need for redefined North-South research partnerships, enhanced capacity-building in North Africa, and greater inclusion of traditional knowledge. An interdisciplinary approach integrating ecology, socio-economics, and environmental policy is essential to address growing sustainability challenges.

Abridged English Version

Mediterranean rangelands are vital ecosystems that provide essential ecological functions and socio-economic benefits. However, they face increasing threats due to climate change and human activities. This study analyzes 452 Scopus-indexed publications from 2004 to 2024 to understand research trends and identify knowledge gaps.

Research Output Disparities

The analysis reveals a significant imbalance in scientific production between the two shores of the Mediterranean. Southern European countries dominate research output, accounting for 86% of the total publications. Spain leads with 362 articles, followed by Italy (232) and France (180). In contrast, North African countries Algeria, Morocco, and Tunisia contributed only 2.46% of total publications and were involved in just 3.24% of institutional affiliations. This discrepancy reflects systemic challenges, including unequal funding opportunities, weaker research infrastructure, and limited participation in international collaborations.

Thematic Priorities and Knowledge Gaps

Research on Mediterranean grazed grasslands has primarily focused on biodiversity and ecological studies. The keyword *grassland* appears in 250 instances, underscoring the strong emphasis on vegetation dynamics and species diversity. Climate adaptation strategies, such as sustainable grazing and resilience – building, are also prominent in the literature.

However, socio-economic aspects remain critically underrepresented, appearing in less than 1% of the keywords. Similarly, traditional ecological knowledge, an essential component of sustainable land management, is weakly integrated with only 14.75% of keyword occurrences. This highlights a persistent bias toward Western scientific methodologies, overlooking local and community-driven conservation practices that have historically shaped grassland management in the region.

Collaboration Networks

Scientific collaboration patterns further illustrate the North-South divide. European countries maintain strong global partnerships, with 43.6% of studies involving international cooperation. Spain, Italy, and France are particularly well integrated into global research networks and frequently publish in high-impact journals such as "Science of the Total Environment" and "Agriculture, Ecosystems & Environment".

By contrast, North African researchers face significant barriers to collaboration. Their participation in international research networks remains limited, and South-South partnerships among African and Middle Eastern institutions are almost nonexistent. This isolation not only hampers regional scientific development but also prevents the formulation of locally adapted solutions for grassland conservation.

Implications and Recommendations

To address these disparities, targeted actions are needed to foster equitable research collaborations, integrate local knowledge, and reform structural barriers in scientific production.

Strengthening Equitable Partnerships

Promoting North-South collaboration is crucial. Increased funding for joint research projects, academic exchange programs, and capacity-building initiatives can enhance the participation of North African institutions in global scientific efforts. In parallel, strengthening South-South networks can help build regional expertise and reduce dependence on Northern research frameworks. Establishing consortia among African and Middle Eastern institutions would facilitate knowledge-sharing and foster research autonomy in the Global South.

Integrating Local Knowledge

Scientific research should incorporate traditional ecological knowledge to develop more inclusive and effective conservation strategies. Funding policies must support studies that value community-led grazing practices and local conservation efforts. Additionally, interdisciplinary approaches that combine ecological, socio-economic, and policy perspectives are essential to address the complex challenges facing Mediterranean grasslands.

Addressing Structural Inequities

Institutional reforms are necessary to create a more balanced research landscape. Equitable distribution of research funding, improved infrastructure, and greater inclusion of Southern Mediterranean researchers in international projects can help bridge the gap. Furthermore, addressing biases in academic publishing by promoting non-Western perspectives in high-impact journals will ensure a more diverse and representative body of knowledge.

Conclusion

This study highlights the urgent need to close the research divide between the Northern and Southern Mediterranean. While European institutions continue to dominate scientific production, the marginalization of North African research and the neglect of socio-cultural dimensions limit the effectiveness of conservation strategies. Bridging these gaps requires sustained efforts in equitable collaboration, the integration of traditional knowledge, and interdisciplinary innovation. By reorienting research priorities and fostering inclusive networks, the scientific community can develop more sustainable and context-specific solutions for Mediterranean grazed grasslands.

Introduction

La région méditerranéenne, reconnue comme un *hotspot* de biodiversité, s'étend sur 2 073 806 km², représentant 1,6 % de la surface terrestre mondiale. Elle abrite environ 10 % de la biodiversité végétale sur seulement 2 % de la surface terrestre (Médail & Quézel 1997). Les gradients climatiques historiques et actuels, caractérisés par une aridité croissante d'ouest en est et des enclaves désertiques localisées (Rivas-Martínez *et al.* 2017) modèlent cette diversité écologique. En Méditerranée, l'interaction entre perturbations naturelles (sécheresses, incendies) et anthropiques (pâturage extensif, brûlage contrôlé) a favorisé un taux d'endémisme exceptionnel,

illustrant une coévolution homme-nature millénaire (Barbaro *et al*. 2001 ; Vidaller *et al*. 2022).

Parmi les écosystèmes méditerranéens, les pelouses semi-naturelles pâturées – définies comme des formations herbacées permanentes maintenues par une gestion agro-pastorale traditionnelle (pâturage extensif, fauche tardive) – se distinguent par leur richesse floristique et faunistique, ainsi que par leurs fonctions écologiques multiples (Carlier *et al*. 2009).

Ces habitats se sont formés sous l'influence de cycles climatiques, d'événements paléogéographiques et d'une topographie complexe (Marion *et al*. 2010). Cependant, ces écosystèmes sont confrontés à plusieurs défis majeurs. Le surpâturage altère la composition floristique et accélère l'érosion des sols (Dutoit & Alard 1995 ; Hempson *et al*. 2022 ; Hill *et al*. 2008 ; Marion 2010 ; McNaughton 1984 ; Perevolotsky & Seligman 1998). Le changement climatique exacerbe l'aridité et menace les espèces spécialisées (Castro & Castro 2019 ; Haunschild *et al*. 2016). Par ailleurs, l'abandon progressif des pratiques agro-pastorales traditionnelles entraîne la fermeture des paysages et le déclin des espèces pionnières ou inféodées aux formations végétales ouvertes (Janišová *et al*. 2021).

Ces pressions compromettent des services écosystémiques essentiels, tels que la régulation hydrologique et la séquestration du carbone. Bien que les sols des pelouses pâturées méditerranéennes présentent des capacités de séquestration du carbone généralement inférieures à celles des forêts matures, ils peuvent stocker des quantités significatives de carbone dans les horizons superficiels, surtout lorsqu'ils sont gérés de manière extensive (Lal 2004). Comparativement aux écosystèmes arbustifs dégradés ou abandonnés, les pelouses bien gérées peuvent maintenir, voire améliorer, la stabilité du stock de carbone organique dans les sols (De Dato *et al*. 2010 ; Poeplau & Don 2013). Face à ces enjeux, des stratégies de gestion adaptative intégrant les dimensions écologiques et socio-économiques apparaissent comme urgentes (Bernués *et al*. 2014). Parmi celles-ci, on peut citer les systèmes agro-pastoraux traditionnels du Haut Atlas marocain, reposant sur la transhumance et la régulation collective des ressources (Taleb & Oualidi 2013), les *dehesas* espagnoles, où le pâturage extensif est combiné à la conservation de la biodiversité et à la production agricole (Plieninger *et al*. 2015), ainsi que les pelouses extensives de moyenne montagne en France (Massif central, Pyrénées), intégrées dans des démarches de transition agroécologique (Duru *et al*. 2015).

Néanmoins, la mise en œuvre de ces stratégies se heurte à de multiples pressions qui fragilisent ces écosystèmes (Cojocariu *et al*. 2019 ; Dutoit *et al*. 2005 ; Dutoit 1996 ; Gustavsson *et al*. 2011). Celles-ci se manifestent différemment selon les régions du bassin méditerranéen : tandis que le sud connaît une intensification des pratiques agricoles et pastorales, le nord est marqué par un abandon progressif des terres, entraînant des dynamiques contrastées de transformation des paysages, et des changements d'usage drastiques (Guarino *et al*. 2020).

Les recherches récentes sur la perte de biodiversité soulignent également un déficit important d'intégration des sciences sociales et économiques dans les études écologiques (Tan *et al*. 2023), une limite également observée dans les recherches méditerranéennes (Vlachogianni *et al*. 2012).

Bien que les analyses bibliométriques soient largement mobilisées pour évaluer les tendances de recherche en environnement (Li & Zhao 2015), leurs applications aux écosystèmes méditerranéens demeurent limitées. Cette étude s'appuie sur une analyse bibliométrique de 557 articles indexés dans Scopus entre 2004 et 2024, utilisant l'outil Bibliometrix pour cartographier les tendances scientifiques, les collaborations et les priorités géopolitiques (Aria & Cuccurullo 2017). Cette approche pourtant validée pour son exhaustivité (Mongeon & Paul-Hus 2016) est cependant restée sous-exploitée jusqu'à présent dans le contexte des pelouses méditerranéennes.

Ainsi, cette étude propose une analyse bibliométrique des recherches menées sur les pelouses de parcours méditerranéennes afin de mieux comprendre l'évolution des publications (tendances historiques) et la dynamique des recherches scientifiques (thématiques émergentes, collaborations entre chercheurs). Plus spécifiquement, elle vise à quantifier la progression temporelle des publications, à identifier les principaux contributeurs scientifiques (auteurs, institutions, revues et pays), à analyser la structuration thématique à travers les mots-clés dominants et à évaluer les disparités géographiques, notamment entre les pays du nord et du sud de la Méditerranée. Cette

étude cherche à souligner les lacunes actuelles et à encourager des approches collaboratives et interdisciplinaires favorisant une gestion durable et équitable de ces écosystèmes face aux pressions anthropiques et aux défis climatiques. Ces résultats devraient alors contribuer à orienter les futures recherches et à promouvoir une meilleure intégration des savoirs locaux et scientifiques dans les stratégies de conservation et de gestion des pelouses pâturées méditerranéennes.

Cette étude repose sur l'hypothèse que les recherches menées sur ces écosystèmes présentent des asymétries significatives, tant sur le plan géographique que disciplinaire et thématique, reflétant une concentration des efforts scientifiques dans certaines régions du nord de la Méditerranée à l'inverse d'autres espaces, notamment au sud.

Matériel et Méthodes

Requête de recherche

Cette stratégie repose sur une combinaison de termes clés et de leurs synonymes en anglais, articulés à l'aide de connecteurs logiques utilisés pour élargir (OR), restreindre (AND) ou exclure (NOT) des termes dans une recherche documentaire (appelés opérateurs booléens), conformément aux pratiques méthodologiques recommandées dans les études bibliométriques (Aria & Cuccurullo 2017 ; Zhang *et al*. 2010) pour optimiser la recherche.

La requête appliquée est la suivante : *TITLE-ABS-KEY ([“grassland” OR “semi-natural grasslands” OR “grazing land”] AND [“Mediterranean basin” OR “Mediterranean region”]) AND PUBYEAR > 2003 AND PUBYEAR < 2025 AND (LIMIT-TO [DOCTYPE, “ar”]) AND (LIMIT-TO [LANGUAGE, “English”] OR LIMIT-TO [LANGUAGE, “French”]) AND (LIMIT-TO [SRCTYPE, “j”])*.

Cette requête cible deux concepts principaux. Le premier concerne les pelouses, en utilisant les termes *grassland* (« pelouse »), écosystèmes dominés par des plantes herbacées, *semi-natural grasslands* (« pelouses semi-naturelles ») et *grazing land* (« terres pastorales »), ensemble des surfaces dédiées à l'élevage extensif, incluant les parcours et les zones de transhumance (Mosquera-Losada *et al*. 2014). Le second porte sur la région méditerranéenne, avec les termes *Mediterranean basin* (« bassin méditerranéen ») et *Mediterranean region* (« région méditerranéenne »), zone géographique stratégique, caractérisée par son climat particulier et sa riche biodiversité (Médail & Quézel 1997).

Critères de sélection

Pour garantir la pertinence et la qualité des résultats, des critères d'inclusion et d'exclusion ont été appliqués.

Les critères d'inclusion comprennent les publications publiées entre 2004 et 2024 (cette période nous a permis de couvrir vingt ans d'évolution scientifique, offrant ainsi une perspective temporelle suffisante pour analyser les dynamiques de recherche) de type *article*, les articles publiés en anglais ou en français, les articles issus de revues scientifiques. Notre analyse a porté uniquement sur les études portant sur la distribution spatiale des pelouses pâturées dans la région méditerranéenne.

Les critères d'exclusion concernent les publications hors de la période 2004-2024, les documents autres que des articles (comme les livres, chapitres ou actes de conférences), les publications dans des langues autres que l'anglais ou le français, les documents ne provenant pas de revues scientifiques et les articles qui ne traitent pas directement de la thématique des pelouses méditerranéennes.

Cette stratégie de recherche a initialement permis d'identifier 557 documents. Après l'application des critères d'inclusion et d'exclusion, 452 documents (soit 81,1 %) ont été retenus pour l'analyse bibliométrique. Les principales exclusions concernent :
– les documents n'étant pas de type « article » (518 sur 557, soit 93 %, répondaient à ce critère) ;
– les publications non rédigées en anglais ou en français (557 sur 562, soit 99 %, étaient admissibles, dont 10 en français) ; et
– les documents non publiés dans des revues scientifiques (534 sur 557, soit 95,8 %).

Le diagramme *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA) résume les étapes de cette stratégie (figure 1).

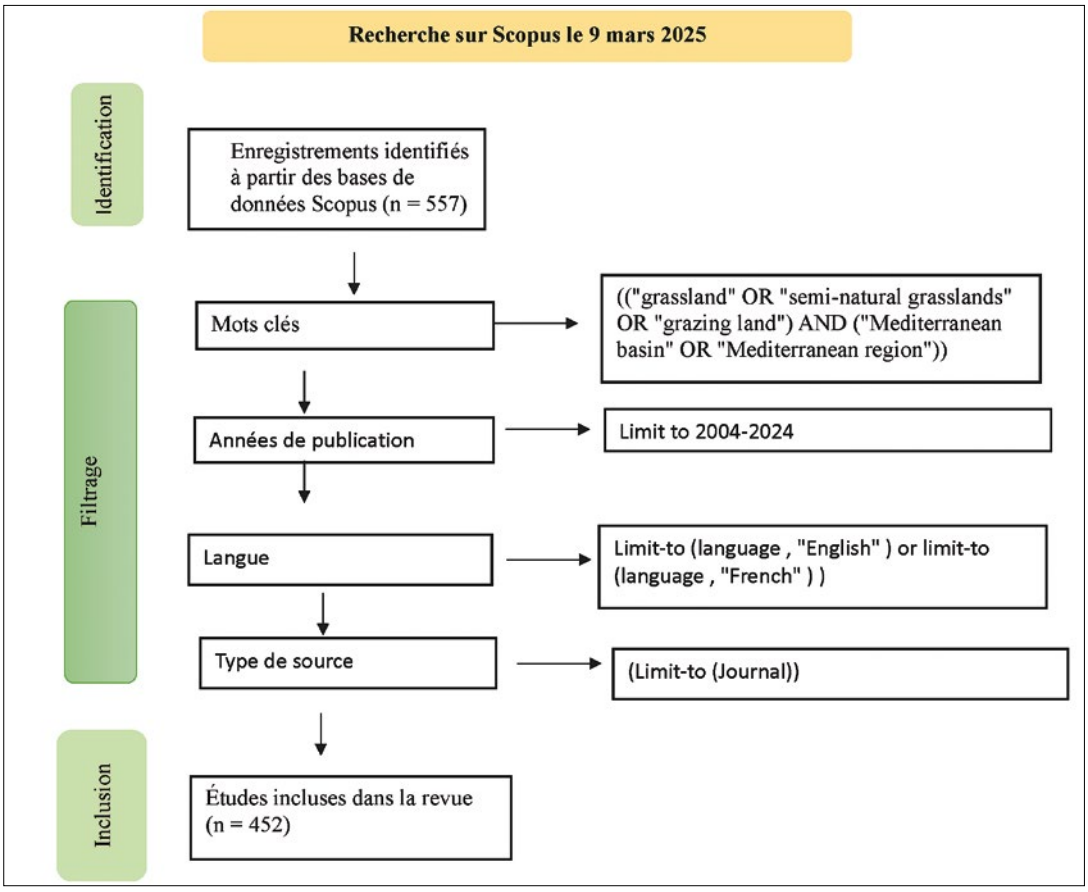

Figure 1 – Diagramme PRISMA illustrant le processus de sélection des publications scientifiques issues de la base Scopus (2004–2024).

Figure 1 – PRISMA flow diagram of the publication selection process from the Scopus database (2004–2024).

Préparation des données

Les métadonnées des 452 articles ont été extraites depuis Scopus au format BibTeX, puis importées dans RStudio à l'aide du package Bibliometrix et de son interface web interactive Biblioshiny. Cette méthodologie s'inspire des approches adoptées dans les études bibliométriques (Zhang *et al*. 2010). L'utilisation de la base de données Scopus, reconnue pour sa couverture extensive des revues en écologie et agronomie, garantit une collecte exhaustive des données scientifiques et permet une analyse des tendances et des réseaux de recherche (Baas *et al*. 2020 ; Vital Ahissou 2024).

Outils et axes d'analyse bibliométrique

Après l'importation et le nettoyage des métadonnées, une analyse bibliométrique a été réalisée à l'aide des fonctions proposées par les packages Bibliometrix et Biblioshiny dans l'environnement RStudio (Aria & Cuccurullo, 2017). L'analyse s'est articulée autour de quatre axes méthodologiques complémentaires : descriptif, relationnel, thématique et visuel.

Analyse descriptive

La fonction *biblioAnalysis* a permis de produire les indicateurs bibliométriques généraux, surtout le profil global du corpus (tableau 1), incluant l'évolution annuelle des publications, l'impact local des auteurs mesuré par l'indice H (Hirsch 2005), la productivité par pays et la répartition des publications par institutions. Ces éléments permettent d'identifier les tendances de production, les chercheurs influents, ainsi que les pays et universités les plus actifs sur la thématique.

Analyse des réseaux

La fonction *biblioNetwork* a été mobilisée pour générer différents réseaux de collaboration scientifique, à savoir le réseau de co-auteurs visualisant les connexions entre

chercheurs ayant publié ensemble et les réseaux de collaboration internationale entre pays, illustrant les flux de coopération interétatique. Ces représentations ont permis de repérer les clusters collaboratifs et les pôles scientifiques majeurs dans le champ.

Analyse thématique

L'analyse des contenus sémantiques a été réalisée à travers une analyse de co-occurrence des mots-clés, permettant d'identifier les concepts les plus récurrents dans la littérature et un réseau de co-occurrence sémantique, indiquant les relations structurelles entre thématiques dominantes. Ces analyses mettent en lumière les axes de recherche les plus explorés et les émergences conceptuelles dans le corpus.

Visualisation et interprétation

Enfin, les visualisations produites *via* Biblioshiny ont facilité la lecture des dynamiques bibliométriques observées. Elles ont permis de synthétiser les résultats de manière intuitive et interactive, renforçant l'interprétation des tendances structurelles et thématiques de la recherche sur les pelouses méditerranéennes.

Résultats

Croissance du nombre de publications scientifiques et des collaborations internationales

La production scientifique sur les parcours méditerranéens a connu une croissance annuelle entre 2004 et 2024, avec un taux de croissance annuelle moyen de 5,45 %, tel que cela est indiqué dans les statistiques bibliométriques générales (figure 2). Le nombre de publications est passé de 9 articles en 2004 à un pic de 43 publications en 2016, marquant une dynamique ascendante dans ce domaine de recherche (figure 3).

Le corpus présente également un taux élevé de collaborations internationales, représentant 43,6 % des publications avec une moyenne de 5,82 co-auteurs par article (figure 2), témoignant d'une forte culture scientifique collaborative. Ces réseaux sont structurés autour de certains auteurs comme Maestre Fernando (Espagne, H-index = 10 [corpus 2004-2024]) et Dutoit Thierry (France, H-index = 9 [corpus 2004-2024]) (figure 4). Le nombre moyen de 5,82 co-auteurs par document souligne une culture scientifique collective. La production scientifique des dix premiers pays sur les pelouses méditerranéennes (tableau 2) montre une concentration des leaderships en Europe.

Tableau 1 – Indicateurs bibliométriques généraux du corpus analysé (Scopus, 2004–2024).

Table 1 – General bibliometric indicators of the analyzed corpus (Scopus, 2004–2024).

Indicateur	Valeur
Nombre de sources (revues scientifiques)	220
Nombre d'articles	447
Taux de croissance annuel moyen	5,45 %
Nombre total d'auteurs	2174
Nombre d'auteurs d'articles rédigés individuellement	17
Taux de co-publication internationale	43,62 %
Nombre moyen de co-auteurs par publication	5,82
Nombre total de mots-clés (auteur)	1778
Durée moyenne écoulée depuis la publication	9,4 ans
Nombre moyen de citations par article	32,29

Tableau 2 – Répartition de la production scientifique des dix premiers pays sur les pelouses méditerranéennes (2004-2024).

Table 2 – Scientific output distribution of the top 10 countries in Mediterranean grassland research (2004-2024).

Pays	Production scientifique
Espagne	362
Italie	232
France	180
États-Unis	92
Portugal	84
Grèce	71
Allemagne	51
Royaume-Uni	42
République tchèque	30
Israël	25

Centralité des thèmes écologiques et faible intégration des dimensions socio-culturelles

Les mots-clés *grassland* (11 %) et *mediterranean region* (11 %) dominent le corpus analysé, suivis de *biodiversity* (5 %) et *climate change* (4 %), illustrant une concentration sur les dynamiques écosystémiques (ensemble des interactions entre les composantes biologiques, abiotiques et humaines influençant

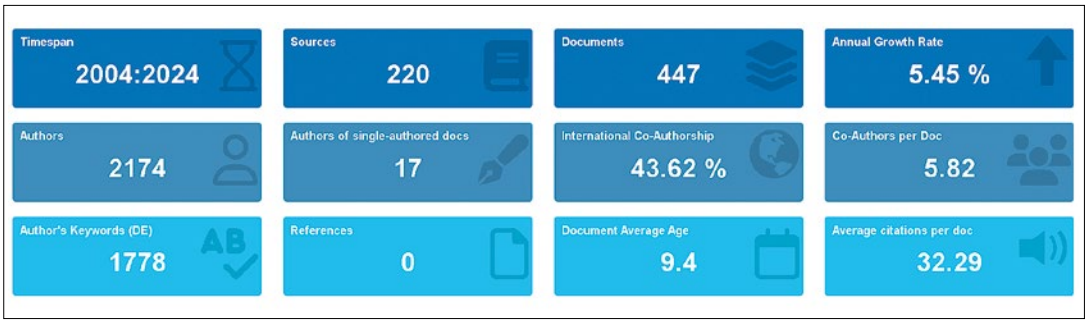

Figure 2 – Statistiques bibliométriques générales du corpus analysé sur les pelouses méditerranéennes (2004-2024).

Figure 2 – General bibliometric statistics of the analyzed corpus on Mediterranean grasslands (2004–2024).

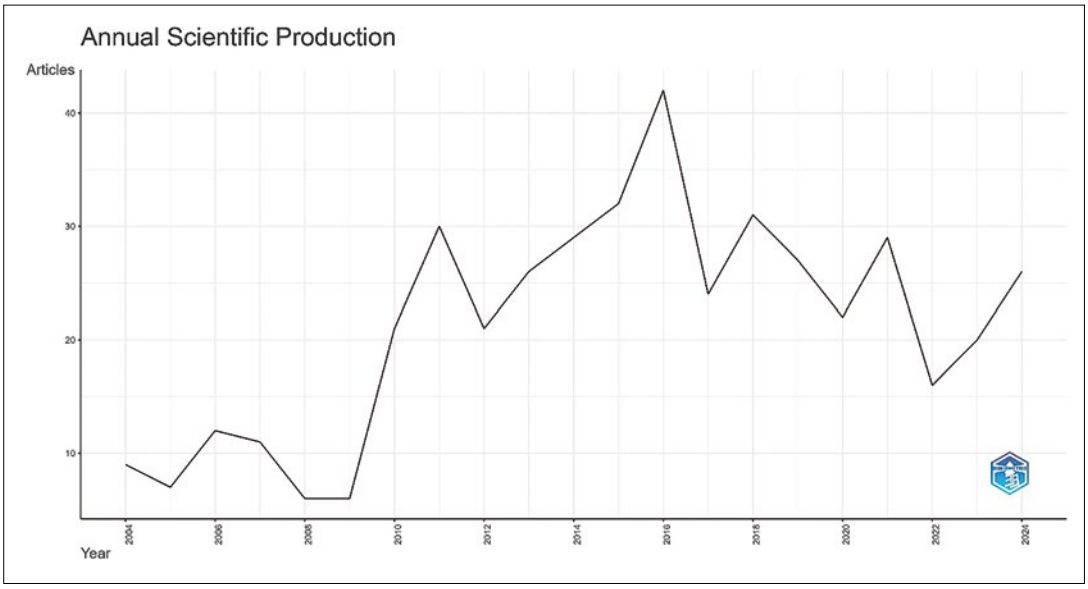

Figure 3 – Répartition annuelle des publications sur les pelouses méditerranéennes (2004-2024).

Figure 3 – Temporal distribution of Mediterranean grassland publications (2004-2024).

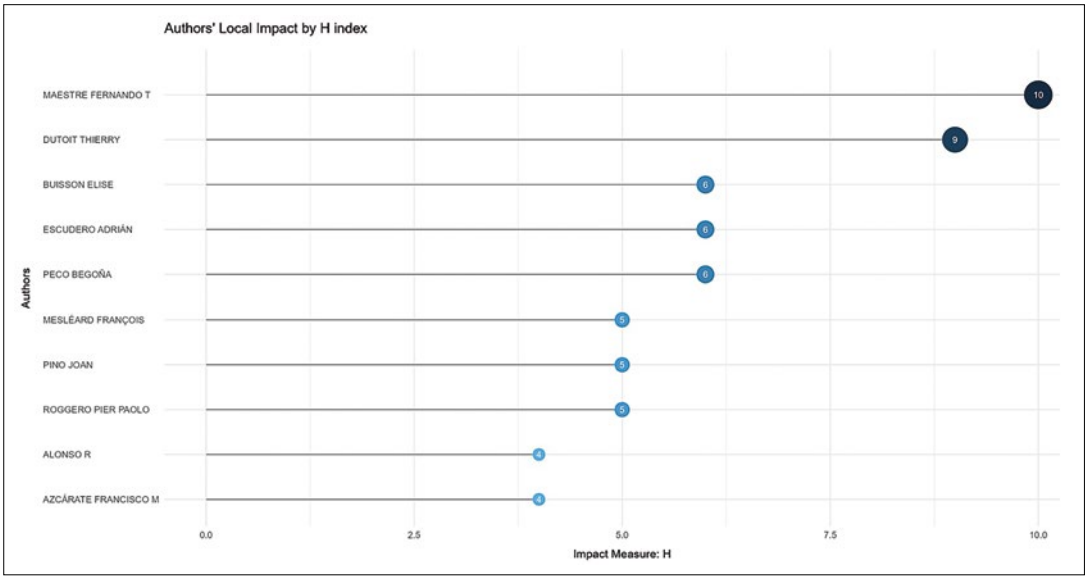

Figure 4 – Impact local des auteurs selon l'indice H dans le corpus Scopus (2004-2024).

Figure 4 – Local author impact based on H-index in the Scopus corpus (2004-2024).

Figure 5 – Répartition des mots-clés dans les publications scientifiques sur les pelouses méditerranéennes (2004–2024).

Figure 5 – Keyword co-occurrence analysis in scientific publications on Mediterranean grasslands (2004–2024).

l'évolution et le fonctionnement des écosystèmes) (figure 5 ; tableau 3).

Le réseau de co-occurrences (figure 6) est composé de plusieurs clusters thématiques distincts, illustrant la diversité des axes de recherche. Le cluster central regroupe les termes les plus fréquemment utilisés et les mieux connectés, notamment *grassland*, *Mediterranean region*, *biodiversity*, *Mediterranean environment* et *climate change*. Cela suggère que la majorité des recherches portent sur les écosystèmes méditerranéens et leur biodiversité, en relation avec les impacts des changements climatiques.

Le cluster « Écologie et gestion des écosystèmes » inclut des termes liés aux fonctionnalités écosystémiques (c'est-à-dire les processus biologiques et écologiques qui soutiennent le fonctionnement, la stabilité et les services rendus par les écosystèmes), tels que *biomass*, *ecosystem*, *forestry* et *drought*. Il met en évidence des recherches sur les dynamiques écologiques et les effets des conditions climatiques extrêmes sur les pelouses pâturées méditerranéennes.

L'absence de mots-clés liés aux dimensions sociales et économiques (par exemple *local knowledge*, *traditional knowledge*, *socio-economic impact*) montre la faible intégration des sciences sociales dans ces recherches.

Tableau 3 – Fréquence d'utilisation des 10 mots-clés principaux dans les publications scientifiques sur les pelouses méditerranéennes (2004-2024).

Table 3 – Frequency of the top 10 keywords in scientific publications on Mediterranean grasslands (2004-2024).

Mots-clés	Occurrences	Pourcentage (%)
pelouse	250	11
région méditerranéenne	250	11
biodiversité	122	5
changement climatique	83	4
écosystème	76	3
mer Méditerranée	54	2
Espagne	79	3
aride	55	2
Europe du Sud	52	2
richesse spécifique	34	2

Disparités géographiques de la production scientifique en Méditerranée

L'Europe du Sud domine la recherche avec 57,6 % des publications, dont 24,1 % pour l'Espagne seule suivie de l'Italie (15,4 %) et de la France (12,0 %). L'analyse bibliométrique révèle une forte concentration de la production scientifique en Europe du Sud, représentant 57,6 % des publications sur les pelouses pâturées méditerranéennes (tableau 3).

Les publications scientifiques sont produites dans les universités européennes et américaines, avec l'Université de Sassari (Italie) en tête (20 articles), suivie de l'Université de Californie (États-Unis) et d'institutions

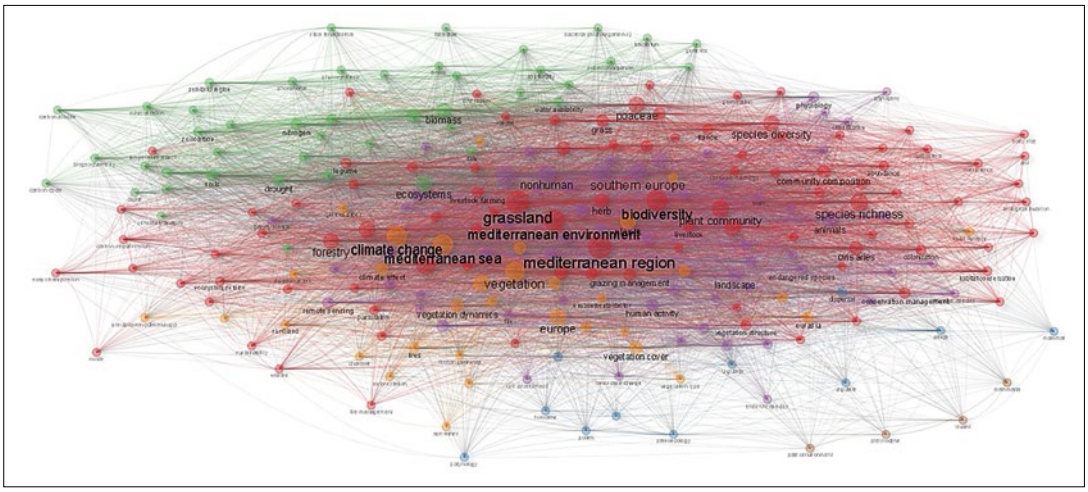

Figure 6 – Réseau de co-occurrence des mots-clés dans les publications sur les pelouses méditerranéennes (2004-2024).

Figure 6 – Keyword co-occurrence mapping (Mediterranean grasslands, 2004-2024).

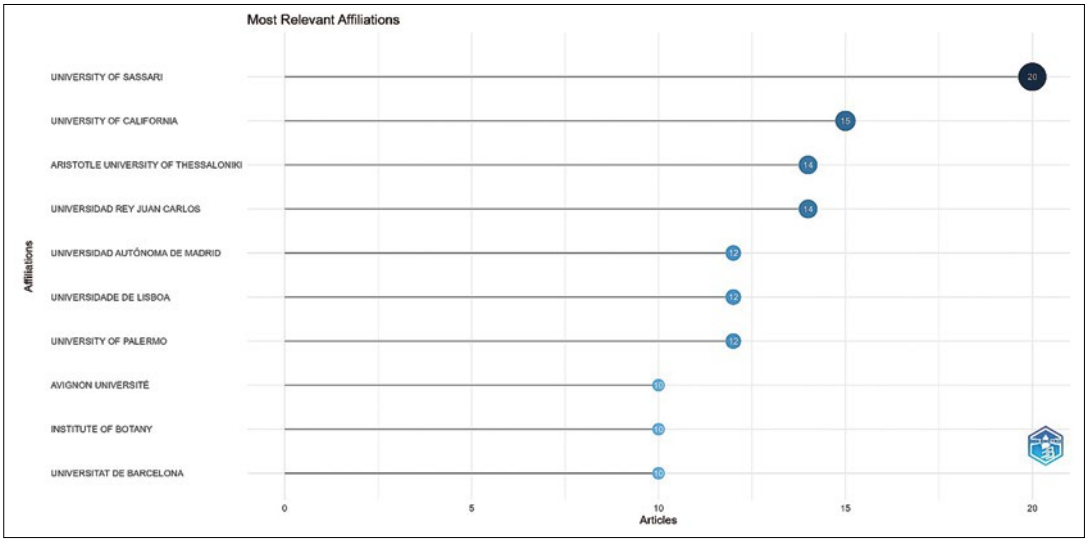

Figure 7 – Répartition des publications par université dans le domaine des pelouses méditerranéennes (2004-2024).

Figure 7 – Institutional publication output in Mediterranean grassland research (2004-2024).

Figure 8 – Réseaux de collaboration internationale entre les pays dans les recherches sur les pelouses méditerranéennes (2004-2024).

Figure 8 – International collaboration networks among countries in Mediterranean grassland research (2004-2024).

espagnoles et grecques. L'absence des universités nord-africaines met en évidence un déséquilibre dans la recherche méditerranéenne et les collaborations scientifiques (figure 7).

Les réseaux de collaboration internationale illustrent une forte interconnectivité entre les pays européens et des partenariats stratégiques avec les États-Unis et l'Australie (figure 8). Les données montrent que l'Espagne, l'Italie et la France sont fortement intégrées dans les collaborations multiples, tandis que le Portugal et les États-Unis privilégient les collaborations uniques. Cependant, une disparité Nord-Sud marquée persiste. Les pays d'Afrique du Nord restent marginalisés dans ces réseaux, avec des collaborations limitées et une faible intégration institutionnelle (figure 9).

méditerranéenne. Nardi *et al*. (2016) ont montré que 68 % des publications sur les forêts méditerranéennes proviennent d'Europe contre seulement 5 % d'Afrique du Nord. De manière similaire, Requier-Desjardins *et al*. (2024) ont mis en évidence une sous-représentation marquée de l'Afrique du Nord dans les recherches en agroécologie, représentant moins de 5 % des projets recensés. Par ailleurs, Di Matteo *et al*. (2015) ont révélé que la France, l'Espagne et l'Italie concentrent environ 80 % des financements alloués aux projets de recherche forestière dans la région méditerranéenne. Ces constats traduisent des inégalités structurelles persistantes en matière d'infrastructures, de financements et d'intégration dans les réseaux scientifiques internationaux.

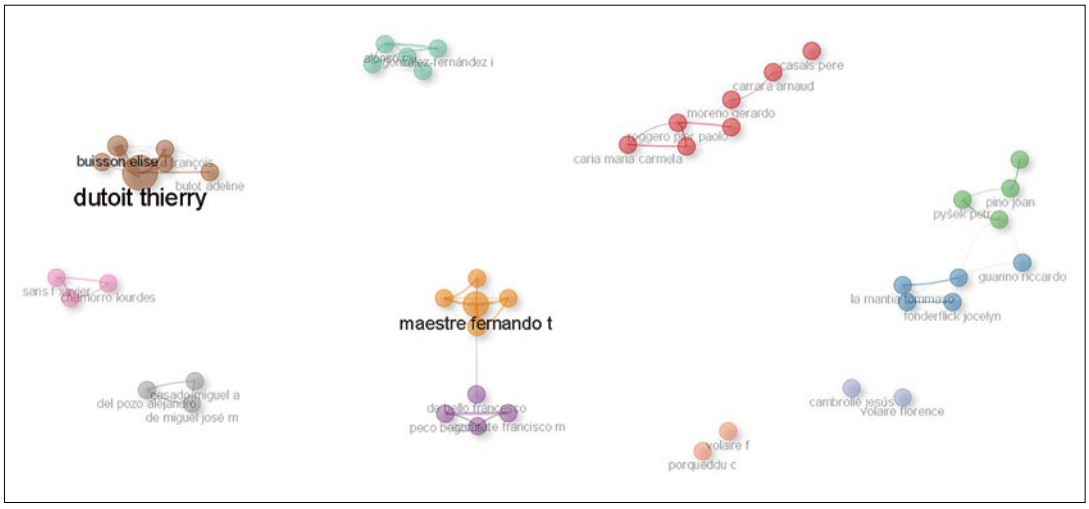

Figure 9 – Réseaux de collaboration scientifique entre auteurs du corpus analysé (2004-2024).
Figure 9 – Co-authorship network analysis (2004-2024).

Discussion

Déséquilibres géographiques dans la recherche sur les écosystèmes méditerranéens : confirmation d'une tendance structurelle

Notre analyse de 447 publications révèle une production scientifique concentrée en Europe du Sud (57,6 %), avec l'Espagne comme acteur dominant (24,1 % des travaux). À l'inverse, les pays d'Afrique du Nord, pourtant directement concernés par ces écosystèmes, ne contribuent qu'à 2,46 % des publications. Ces résultats confirment les déséquilibres Nord-Sud déjà documentés dans la recherche

Ces données convergentes suggèrent un biais structurel persistant dans la production scientifique sur les socio-écosystèmes méditerranéens, que notre étude vient confirmer pour le domaine spécifique des pelouses pastorales. Cette analyse révèle pour la première fois l'ampleur des disparités Nord-Sud dans la recherche sur les parcours méditerranéens, validant une inégalité persistante dans la production scientifique régionale internationale.

Ces résultats concordent avec ceux de Doblas-Miranda *et al*. (2014), qui notent une sous-représentation des chercheurs nord-africains dans les projets internationaux sur les écosystèmes méditerranéens, limitant l'intégration des savoirs locaux pourtant essentiels à la résilience des zones arides. Nardi *et al*.

(2016) confirment cette disparité, attribuant la dominance européenne (Sud) aux infrastructures et aux financements compétitifs (fonds attribués selon la performance et la qualité des projets scientifiques).

Les savoirs traditionnels, bien que reconnus comme pivots de la résilience écologique (leviers essentiels permettant aux écosystèmes de s'adapter aux perturbations tout en maintenant leurs fonctions et leur biodiversité), restent sous-valorisés dans les politiques de gestion environnementale (Folke *et al*. 2004) et ne constituent que 14,75 % des mots-clés identifiés.

Cette marginalisation limite l'intégration des pratiques locales (par exemple pastoralisme rotatif, pratique traditionnelle de gestion des parcours naturels où les troupeaux sont déplacés de manière cyclique entre différentes zones de pâture) dans les politiques de conservation (Reyes-García *et al*. 2019). Pourtant, des approches hybrides (par exemple modélisation satellitaire couplée aux calendriers pastoraux traditionnels), combinant science occidentale (par exemple analyse algorithmique des sols) et connaissances autochtones (par exemple techniques de rotation des troupeaux basées sur la phénologie végétale), ont démontré leur efficacité pour la gestion durable des pâturages (Fernández-Giménez & Fillat Estaque 2012).

Production scientifique et agendas mondiaux

Cette analyse bibliométrique révèle un intérêt croissant, bien que fluctuant, pour les pelouses pâturées méditerranéennes, avec une progression annuelle des publications de 5,45 % entre 2004 et 2024. Le pic observé en 2016 (43 publications) s'inscrit dans le contexte de l'intensification des agendas internationaux de conservation, notamment les objectifs d'Aichi, soulignant l'influence des cadres politiques mondiaux sur les priorités scientifiques (Garavaglia & Besacier 2017). Cette dynamique témoigne du caractère réactif de la recherche écologique face aux impulsions géopolitiques, un phénomène bien documenté dans les sciences environnementales. Par exemple, Juffe-Bignoli *et al*. (2016) soulignent que les objectifs d'Aichi ont catalysé les efforts de suivi et de publication sur les aires protégées à l'échelle mondiale.

La dominance des publications de l'Espagne, de l'Italie et de la France dans 60 % des collaborations internationales s'explique par leur exposition aux pressions climatiques méditerranéennes (aridité, canicules) et aux stress anthropiques (urbanisation, surpâturage). Ces régions, marquées par des mutations rapides des paysages, sont naturellement devenues des laboratoires d'étude de la résilience des prairies, définie dans une perspective écosystémique comme la capacité de ces milieux à absorber les perturbations, à se réorganiser et à maintenir leurs fonctions essentielles (Blondel 2010).

Priorités thématiques et lacunes de connaissance

L'analyse des mots-clés met en évidence trois axes dominants : la biodiversité, le changement climatique et la gestion durable. Le terme biodiversité apparaît 122 fois (5 % des occurrences). Par ailleurs, la prédominance du mot-clé « *climate change* » (4 % des occurrences) reflète l'urgence des enjeux climatiques, telle que soulignée par le Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC) et les accords internationaux, notamment l'accord de Paris. Ces préoccupations sont particulièrement marquées dans les *hotspots* méditerranéens, où la fragmentation des habitats et la vulnérabilité des espèces constituent des défis majeurs (Merzaux 2023). Cependant, cette focalisation environnementale occulte les dimensions socio-économiques, pourtant cruciales pour une conservation holistique, globale, interdisciplinaire et intégrant les aspects écologiques, sociaux et économiques. Par exemple, les études sur les pratiques pastorales clés dans la structuration des pelouses restent rares, malgré leur rôle dans la lutte contre l'érosion des sols et le maintien de paysages ouverts (Oteros-Rozas *et al*. 2013 ; Plieninger *et al*. 2015).

La faible représentation des thématiques liées à la gouvernance et aux savoirs traditionnels accentue les lacunes existantes, limitant l'intégration de dimensions socio-culturelles essentielles dans les stratégies de gestion de ces écosystèmes. Ces lacunes freinent l'élaboration de stratégies de gestion adaptées aux contextes locaux. Si les travaux de Lambdon *et al*. (2008) ont permis des avancées significatives dans la compréhension des relations biomasse-biodiversité, leur approche reste essentiellement biophysique, négligeant les réalités sociales et culturelles (Maestre *et al*.

2009). Cette dissociation entre dynamiques écologiques et contextes humains pourrait mener à des politiques de conservation inadaptées, particulièrement en Méditerranée méridionale. Le cas du Maghreb illustre ce décalage : l'abandon des systèmes agropastoraux, lié à une marginalisation économique, entraîne une homogénéisation des paysages et une érosion des savoirs locaux (Lyons *et al*. 2023). Pourtant, cette dynamique reste insuffisamment quantifiée, alors qu'elle constitue un levier clé pour comprendre les trajectoires de transformation des pelouses semi-naturelles.

Leadership institutionnel et dynamiques collaboratives

Les institutions occidentales, comme l'Université de Sassari (Italie) ou l'University of California-Davis (États-Unis), dominent les réseaux de recherche grâce à des approches transdisciplinaires mêlant agronomie, écologie et sciences sociales. Des auteurs influents incarnent cette tendance (figure 4), combinant des méthodes interdisciplinaires pour répondre aux défis socio-écologiques complexes. Cependant, les partenariats transatlantiques (par exemple Espagne-États-Unis) privilégient souvent des modèles globaux au détriment de solutions localisées, négligeant des stress régionaux comme l'aridification accélérée au Maghreb des pelouses de pâturage.

À l'inverse, l'Afrique du Nord, dépourvue de structures fédératrices comparables à la Fédération européenne des prairies (*European Grassland Federation*, EGF), peine à promouvoir une voix collective. Comme le souligne l'étude bibliométrique du Partenariat pour la recherche et l'innovation dans la région méditerranéenne (*Partnership for Research and Innovation in the Mediterranean Area*, PRIMA), les co-publications des pays du Maghreb avec les institutions européennes représentent moins de 1 % des publications scientifiques, mettant en évidence un déficit structurel dans les collaborations internationales (Fournier *et al*. 2018). De plus, les institutions majeures du sud de la Méditerranée, comme l'Institut national de la recherche agronomique (INRA) du Maroc, restent marginales dans les grands réseaux de recherche. Des initiatives comme le Système d'information sur la conservation méditerranéenne des écosystèmes (SICMED), bien que prometteuses pour la recherche méditerranéenne (Hill *et al*. 2008), voient leur impact limité par des asymétries de financement et de participation, illustrant les difficultés des institutions nord-africaines à s'intégrer pleinement dans les dynamiques scientifiques régionales.

Limites et perspectives

Cette recherche constitue la première synthèse spatiale et thématique des travaux scientifiques relatifs aux pelouses pâturées méditerranéennes. Toutefois, l'exclusion des sources non indexées et en langues locales peut sous-estimer les résultats de cette analyse. Limiter l'étude à la période 2004-2024 restreint aussi l'observation des tendances à long terme de dégradation et de régénération des pelouses de pâturage méditerranéennes. En dépit de ces limites, cette cartographie des connaissances offre une première base scientifique pour élaborer des politiques adaptées aux défis méditerranéens, tels que l'aridification et la dégradation des sols dans les rives sud de la Méditerranée. Elle souligne aussi les asymétries, notamment la faible représentation des institutions nord-africaines dans les co-publications scientifiques. Pour les recherches futures, il serait donc essentiel d'inclure les savoirs locaux et les archives régionales pour enrichir la compréhension des dynamiques socio-écologiques de ces habitats ; de favoriser l'articulation entre la science et les pratiques pastorales pour améliorer la gestion des pelouses et des paysages méditerranéens ; et d'encourager un rééquilibrage des collaborations scientifiques et de valoriser les acteurs locaux pour une résilience socio-écologique durable.

Conclusion

Cette analyse bibliométrique des pelouses pâturées méditerranéennes a mis en lumière des dynamiques de recherche contrastées. Des avancées significatives ont été réalisées dans les thématiques liées à la biodiversité fonctionnelle et aux services écosystémiques. Cependant, la recherche reste marquée par des disparités géographiques et institutionnelles, avec une concentration des publications en Europe et une sous-représentation des contributions issues de l'Afrique du Nord.

Cette marginalisation reflète des inégalités historiques qui freinent l'élaboration de stratégies de conservation adaptées de ces pelouses aux contextes locaux. Le faible engagement des institutions nord-africaines dans les collaborations scientifiques internationales souligne la nécessité d'un renforcement des partenariats et d'une meilleure valorisation des savoirs locaux.

Pour les recherches futures, il serait essentiel :
– d'approfondir les études sur les interactions entre les pratiques pastorales locales et la dynamique des écosystèmes pâturés ;
– de développer des modèles de gestion participatifs impliquant activement les communautés locales afin d'assurer la durabilité et la pertinence des stratégies de conservation des pelouses pâturées ;
– d'encourager les collaborations scientifiques internationales entre les deux rives de la Méditerranée.

Remerciements

Je tiens à exprimer ma profonde gratitude à mon professeur encadrant pour ses précieux conseils éclairés et son soutien tout au long de cette étude. Son expertise et sa disponibilité ont été d'une grande aide dans la réalisation de ce travail. Je remercie également toutes les personnes qui m'ont aidé de près ou de loin dans cette étude, par leurs encouragements, leurs contributions ou leur soutien moral. Enfin, une pensée toute particulière pour ma famille, dont le soutien inconditionnel, la patience et les encouragements m'ont été d'un grand réconfort tout au long de ce parcours.

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The impact of the olive orchards on rainfall repartitioning in a semi-arid region of eastern Algeria

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Abstract

The olive trees, which cover significant areas in Algeria, redistribute incident rainfall (Pi) into throughfall (TF), stemflow (SF) and interception (I) and play an important role in the water balance of olive orchards. This study aims to evaluate the role of olive trees in rainfall partitioning into TF, SF and I, in a semi-arid climate in Khenchela province (Eastern Algeria). Several measurements were carried out between November 2023 and April 2024 to evaluate the aforementioned parameters (Pi, TF, SF and I). The results showed that the rate of throughfall, stemflow and interception were 82.49, 7.93 and 9.57% respectively. The models generated by this study made it possible to deduce the amount of rainfall necessary for the start of throughfall and stemflow, which were 0.78 and 6mm, respectively.

Introduction

Rainfall is the basis for proper functioning agriculture, particularly in arid and semi-arid environments, which represent a third of the world's land area (Mirzabaev *et al*. 2022). Its intensity and distribution determine soil humidity and partially the availability of nutrients (Castro *et al*. 2006; Zabret *et al*. 2023; Zhang *et al*. 2023). These latter affect plant growth, development and yield crop quality (Blume *et al*. 2021; Lima *et al*. 2022; Nanko *et al*. 2022; Yang *et al*. 2023). Unfortunately, these areas are facing severe challenges of droughts and the increasing overexploitation of water resources (Li *et al*. 2019; Mirzabaev *et al*. 2022).

Besides, the rain that falls on orchards does not fully reach the soil. By the action of plant cover, some fraction of incident rainfall (Pi) is retained by trees for a period of time and then evaporates as interception (I), some drips off the branches and leaves and then reaches the soil as throughfall (TF); and some flows down along the stems and branches to the base of plants as stemflow (SF) (Nazari *et al*. 2020; Lima *et al*. 2022; Zhang *et al*. 2023; Anys & Weiler 2024).

The role of crop canopies in the global water cycle is a topic of increasing international interest (Zhao *et al*. 2023; Zabret *et al*. 2023). Li *et al*. (2023) claimed that the complex

Keywords: olive, throughfall, stemflow, interception, southern Mediterranean region.

feedback mechanisms between vegetation, climate, water and humans need further comprehensive exploration in the future. Moreover, knowledge of water balance is necessary to choose variety and promote management practices that may ensure both production and water sustainability (Gomez *et al*. 2001; Nóbrega *et al*. 2015; Valente *et al*. 2020; Zabret *et al*. 2023). Interception studies have been carried out for a variety of vegetation types (Zabret *et al*. 2023; Van Stan *et al*. 2024). However, Gomez et *al*. (2001) confirmed that there were relatively few studies related to interception in olive orchards, particularly in Algeria. Estimating the interception of rainfall is very important for understanding the effects of large-scale afforestation practices on the water cycle processes and effective climate response planning in arid and semi-arid ecosystems (David *et al*. 2010; Benhizia *et al*. 2023; Li *et al*. 2023). The Interception models have been considered also as efficient tools for predicting the effects of climate and land-cover type changes on water resources (Llorens & Domingo 2007). Climate change is mainly caused by an increase in temperature and a decrease in rainfall (Blume *et al*. 2021; IPCC 2021). The aforementioned elements can affect significantly rainfall interception (Benhizia *et al*. 2023). Lian *et al*. (2022) pointed out that rainfall events have become less frequent and more intense since 2000. Together with the change in rainfall regime and according to several researchers (Zabret *et al*. 2023; Zhang *et al*. 2023), the water balance will also deteriorate significantly by the rising average temperature. Thus, any alterations in rainfall or temperature will directly affect the dynamics of the rainfall interception (Benhizia *et al*. 2023).

For or several thousand years, the olive (*Olea europaea* L.) has been grown in the region surrounding the Mediterranean, as a rain-fed crop (Gomez *et al*. 2001; Carr 2013). The area cultivated with olive trees has been continuously expanding in the Mediterranean zone (FAO 2024). During the season 2022/2023, Algeria is ranked among the most productive countries according to the International Olive Council, either in table olive with 256,500 tons (IOC 2024a) or olive oil with 75,500 tons (IOC 2024b). The olive tree is cultivated throughout the national territory, ranging from humid areas to arid and Saharan areas (Touati *et al*. 2022). The continuous evolution of areas reserved for olive growing in conjunction with the increase in densities in the new orchards (1000-2250 trees ha^{-1}) can reduce the quantities of water that will reach the soil of the orchards by TF and SF. Therefore, it can significantly increase rainfall interception and change hydrological regimes at the regional scale (Gomez *et al*. 2002; Carr 2013; Nazari *et al*. 2020).

Olive orchards are not immune to climate change and water scarcity problems. Several authors (Carr 2013; Abed *et al*. 2019) asserted that fruit trees are exposed to adverse climatic impacts, particularly in the Mediterranean Basin. Indeed, the rainfall TF and SF are closely linked to climate change, olive orchard productivity and sustainability of water (Gomez *et al*. 2002; Bruley *et al*. 2022). That is why improving current approaches is very important to quantify the rainfall interception in olive orchards for water management purposes and to enhance the precision of water applications especially after rainfall.

Two essential reasons encouraged us to perform this investigation. The first relates to the insufficiency of studies, which have focused on the interception of incident rainfall by the action of fruit trees including olive trees throughout the world (Antoneli *et al*. 2020; Mali *et al*. 2020). To the best of our knowledge, only Gomez *et al*. (2001; 2002) have worked on olive trees with isolated trees. Besides, there is a total absence of studies focusing on the influence of the olive tree on the rain interception in North Africa (Antoneli *et al*. 2020). The second reason concerns the influence of climate change on rainfall interception, because the evaluation of the interception in the study of Gomez *et al*. (2001) was carried out in 1996. After almost 30 years of evaluation, it is possible to have some changes in the rainfall regime or in the dynamic of interception. Furthermore, data on TF, SF and rainfall interception by the action of plant cover are much needed by hydrologists throughout the world, including the Mediterranean region (Antoneli *et al*. 2020; Benhizia *et al*. 2023).

Thus, this study aims to investigate the role of olive trees in the redistribution of rainfall into TF, SF and I in a semi-arid bio-climate of Eastern Algeria.

Material and methods

Study site

Our study concerns an olive orchard in the Aurès region (Eastern Algeria, Figure 1). It is located at 29km in the south the town of Khenchela (35°10'09" N Latitude; 7°06'05" E Longitude; 1170m Altitude). The orchard is constituted mainly by olive trees (Algerian Chemlal variety). The choice of this orchard is justified by the fact that Chemlal is the most important cultivar with 40% of the Algerian olive area (Hamlat *et al*. 2022; Touati *et al*. 2022). The trees of the study site are aged 70 years, and they have a height that varies between four and six meters and a diameter between 28 and 35cm. The basal area of the olive orchard and its density are 35.36m^2 and 520 trees per hectare, respectively.

According to the data provided by Khenchela meteorological station, the average temperature of the same region over a period of 20 years (1999-2019) was 15.96 °C. On the other hand, the annual rainfall average for the same period was 495.1mm. In addition, the ombrothermic diagram shows that dry period in the studied region extend from May to August (Figure 2).

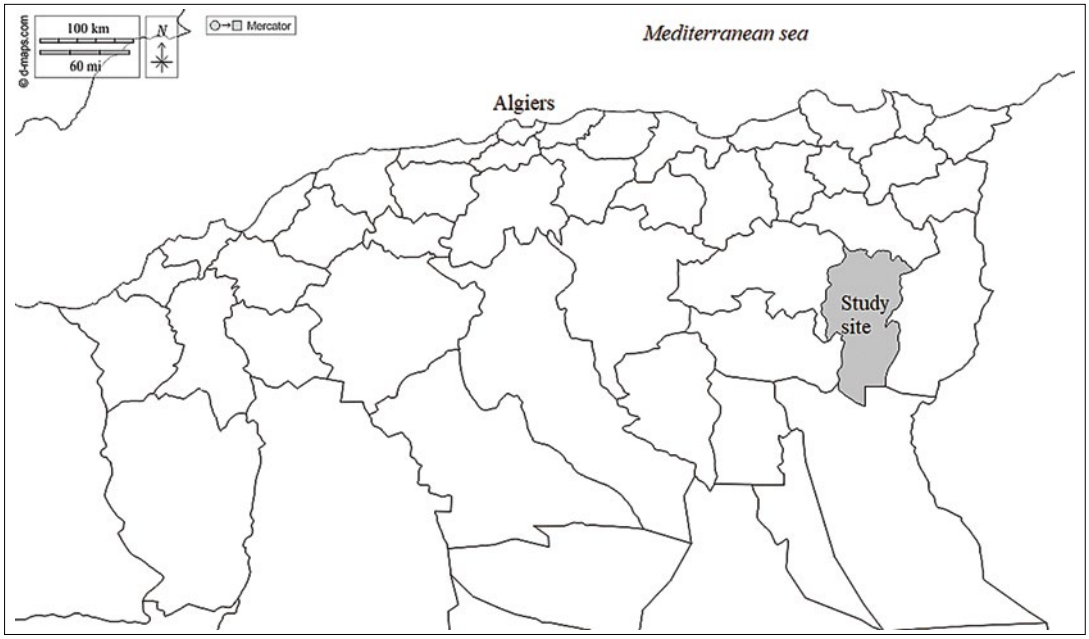

Figure 1 – The location of the study region in Algeria (D-maps 2025).

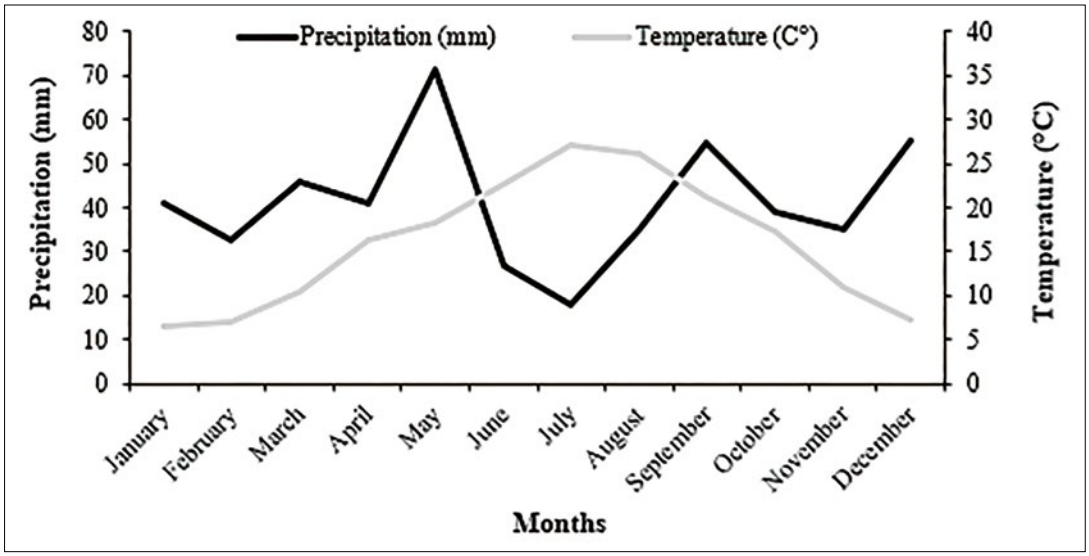

Figure 2 – Ombrothermic diagram in the study region.

Experimental design

The tools and protocol used in this study are inspired by works which have already evaluated the action of fruit trees on the redistribution of incident rainfall (Pi) into TF, SF and I (Gomez *et al*. 2001; Gomez *et al*. 2002; Mali *et al*. 2020; Wang *et al*. 2022).

The Pi and TF in this study were collected by using plastic bottles with the upper part cut off and returned into a funnel. The neck is fitted with a piece of tulle intended to retain plant debris. The receiving surface for each bottle is of 0.0225m^2. These bottles were well embedded and fixed at soil level of our olive orchard. They were also fixed throughout the period of measurements. TF was quantified by four plastic bottles installed under each tree. They were installed randomly under the crown of 29 olive trees, for 116 bottles. The overall surface of reception of drip water in this study (2.61m^2), was considered sufficient to correctly estimate this fraction of water according to Rodrigo and Avila (2001) and Llorens and Domingo (2007). Pi volumes were evaluated by installing 20 more bottles, identical to those used to TF, and approximately 13m away from olive trees in an open space.

As for the SF, it was collected from 10 trees using the plastic collars sealed strictly around the trunks of olive trees and made waterproof using putty. These collars were connected with a container made of plastic through a 2.5cm diameter pipe. Llorens & Domingo (2007) stated that 57% of studies used collars almost identical to those used in the present study. The volumes of rainfall, TF and SF were measured continuously, from November 2023 until April 2024, using a test tube. The measurements were taken immediately after each rainfall event to avoid evaporation.

The volumes of incident rainfall collected in the orchard were converted into mm by the formula (Vialard-Goudou & Richard 1956):

$$P\,(mm) = 10 \times V/S$$

with:
S: reception surface (cm^2); V = volume of water collected (cm^3).

The SF heights in mm were calculated by dividing the volumes collected by the crown surface of olive trees (Livesley *et al*. 2014).

The intercepted rainfall amounts were estimated by the formula (Nazari *et al*. 2020; Lima *et al*. 2022; Zhang *et al*. 2023; Anys & Weiler 2024):

$$I\,(mm) = P - (TF + SF).$$

Statistical analyses

Monthly differences in Pi, TF, SF and I were tested using an analysis of variance (ANOVA) at the 5% error threshold, using the SPSS software version 10.0.5 (SPSS Inc.); while the relationships between Pi, TF, SF and I events were assessed by linear regressions using Microsoft Excel 2016© (Gomez *et al*. 2001; Llorens & Domingo 2007, Zhang *et al*. 2023).

Results

Incident rainfall (Pi)

The Pi was 406.52mm during the six months of study. The results relating to the number of rainfall events showed that daily incident rainfall fluctuates between 6.11 and 27.93mm.However, the average of all rainfall events is 14.02 ± 5.54mm. The classification of this amount in rainfall intervals is recorded in the Table 1.

During the six months of measurement, the rainiest months were noted in February (100.9mm) and December (98.32mm) and April (97.02mm) (Figure 3). Conversely, the weak rains were recorded during the months of March (11.02mm) and November (34.75mm). The ANOVA shows that the monthly variation in rainfall was very significant ($P < 0.05$) (Table 2). The number of rainfall events varies from one month to another; it fluctuates between 1 and 8 per month.

Table 1 – Rainfall events, their frequencies and accumulations according to ranges from zero to 40mm.

Rainfall event (mm)	Frequencies (rainfall events)	Cumulative rainfall mm	%
[0-5mm]	0	0	0
]5-10mm]	10	88.15	21.68
]10-20mm]	14	224.63	55.26
]20-40mm]	5	93.74	23.06
Total	**29**	**406.52**	**100**

Table 2 – ANOVA analysis of the monthly variation of Pi, TF, SF and I at the studied orchard.

Studied parameters	P
Pi	0.000*
TF	0.000*
SF	0.000*
I	0.870

* Significant difference if P < 0.05

Throughfall (TF)

The TF percentage found by this study is 82.49%, which represents an amount of 335.34mm in six months of study while the average quantity of TF, for the 29 events, is 11.56 ± 4.81mm per rainfall event. At the monthly scale variation, ANOVA showed a significant difference. TF percentages range from 75.66 to 85.84% of incident rainfall.

Stemflow (SF)

The average rate of SF found in this study is 7.93%, while its quantity per rain event was 1.12 ± 0.74mm. For the monthly variation, ANOVA showed a significant difference. In November, the SF rate was 5.36%, which increases notably in December to 8.44%. This trend continued in January (9.30%), and the SF reached a peak of 9.34 ± 0.49% in April.

Interception (I)

The calculated I rate (9.57%) corresponds to a quantity of 38.94mm. The Figure 3 shows a slight monthly variation of I, although the ANOVA did not show a significant difference (Table 2). Interception percentages ranged from 5.71 (in December) to 15.82% (in November) (Table 3).

Relationship between incident rainfall and stemflow

Figure 4 shows that SF along the trunks is linearly related to incident rainfall ($R^2 = 0.86$). This equation revealed the minimum theoretical amount of rainfall (6mm) required to trigger SF along the trunks. Therefore, SF along the trunks is a phenomenon that occurs later and only during significant rainfall events (Figure 4).

Relationship between incident rainfall events and throughfall

For the studied olive orchard, the TF as a function of Pi follows the relationship shown in Figure 5. It reveals that the amount of TF is positively correlated with Pi ($R^2 = 0.99$). The equation shown in the same figure is considered a predictive model for the TF. Thus, to have 1mm of TF, it needs 1.82mm of rainfall.

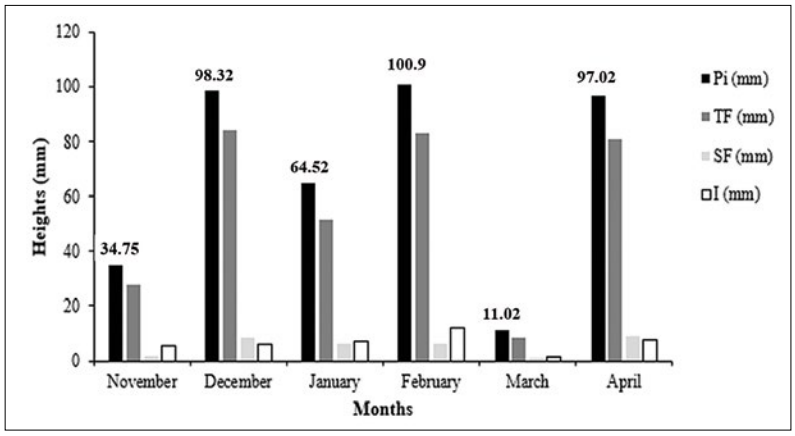

Figure 3 – Monthly variation (in mm) of Pi, TF, SF and I at the studied orchard.

Table 3 – Monthly percentages of the TF, SF and I rates.

	Nov.	Dec.	January	February	March	April	During the study period
TF	79.13	85.84	79.63	82.39	75.66	83.07	82.49
SF	5.36	8.44	9.30	6.46	9.08	9.34	7.93
I	15.82	5.71	9.29	11.56	15.34	7.45	9.57

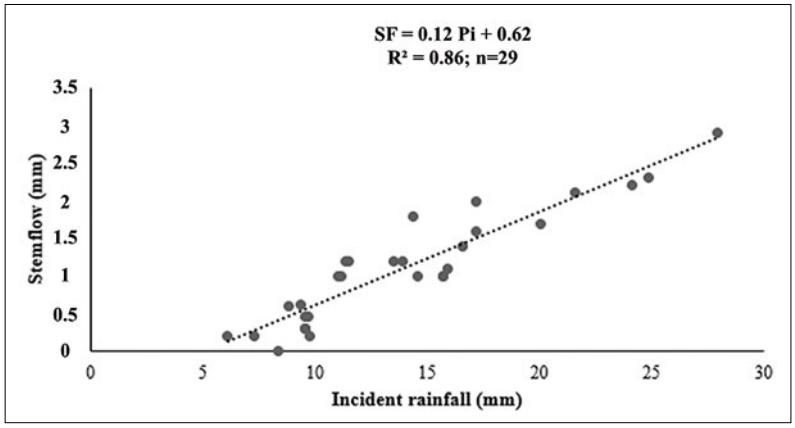

Figure 4 – Relationship between incident rainfall (mm) and stemflow (mm).

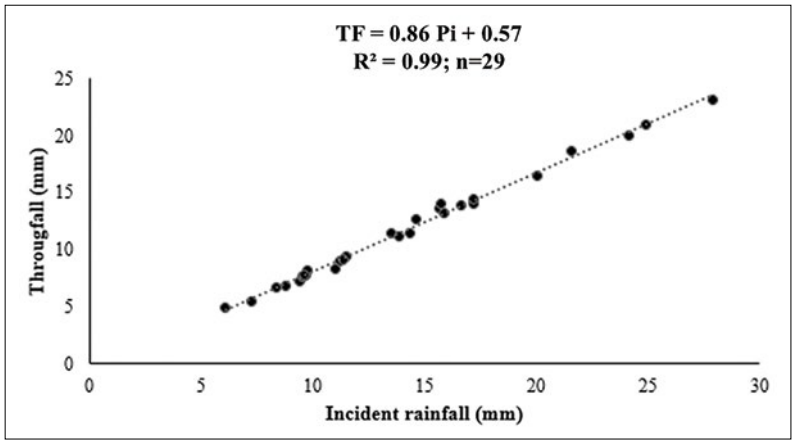

Figure 5 – Relationship between incident rainfall (mm) and throughfall (mm).

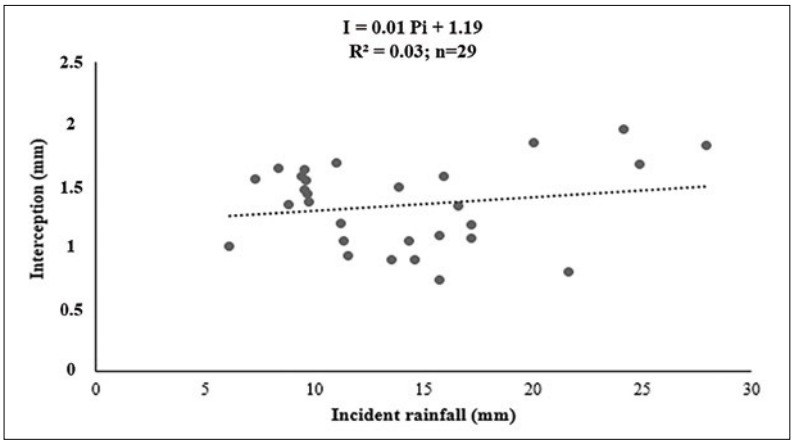

Figure 6 – Relationship between incident rainfall (mm) and interception (mm).

Relationship between incident rainfall and interception

The results presented in Figure 6 show that rainfall interception by the tree canopy was little dependent on the amount of incident rainfall.

Discussion

Incident rainfall

The cumulative incident rainfall recorded in the present investigation during six months (406.52mm) are important and it represents more than 80% of the average annual rainfall in the Khenchela region (495mm) for the period 2000-2019. Similarly, the average height of 14.02 per rainfall event is considered very useful for olive trees. At the inter-monthly level, our results indicated that February was the rainiest month. In contrast, previous studies (Benhizia *et al*. 2018; Benhizia *et al*. 2020) asserted that two peaks characterize rainfall in the semi-arid climate of Algeria: the first is observed in spring and the second in autumn.

Throughfall

The total TF found by this study is around 82.49% which represents an amount of 335.34mm in six months of study. Similarly, Valente *et al*. (2020) reported a throughfall percentage of 79.4% for a low-density olive orchard. Whereas, TF in our case is relatively high compared to the rates of TF reported in recent studies for the olive tree (Lombardo *et al*. 2018; Antoneli *et al*. 2020). The latter researchers reported rates of TF which fluctuate between 56 and 70%. Nevertheless, the studied orchard and the rainfall regime are not the same. While, Lombardo *et al*. (2018) found throughfall percentage of 68% of incident rainfall. This difference can be explained by the difference in rainfall intensity. In fact, the same authors stated that maximum hourly rainfall above 3mm/h increased throughfall percentages (from 55 to 72% of gross rainfall).

The recorded quantity of TF (335.34mm) is very significant in a semi-arid climate and it contributes to the water and mineral supply of the soils of our orchards. TF take part in water and nutrient dynamics, since they provide water, supply and alter the chemistry of the soil in olive orchards (Lombardo *et al*. 2012; Lombardo *et al*. 2018; Lima *et al*. 2022). The important TF in our case is attributed to the volume of rainfall by event. In fact, a mean of 14.02mm per rainfall event is able to affect the vibration of the olive leaves and increase the amount of TF. This also corroborates the results of Holder & Lauderbaugh (2023) who stated that the accumulation of raindrops during the important rainfall event contributes quickly to the tilting of leaves and consequently to increase the TF rate. According to Nanko *et al*. (2022), the TF rate is not really important during the first 5mm of rainfall and more rainfall is needed to increase the TF rate. Indeed, small events less than 5mm produce little or no TF in fruit orchards and some researchers (Zhang *et al*. 2021) suggested that rainfall between 5 and 7mm will not be beneficial for fruit tree trees.

Our results of the average rate of TF remain consistent with the rates found in sites composed of fruit trees (Apple, citrus, coffee, palm and grapes) which exceed 80% (Antoneli *et al*. 2020; Zhang *et al*. 2021). Moreover, TF rates are influenced by orchards stand characteristics, such as density of trees and the structure of the canopy (Antoneli *et al*. 2020; Blume *et al*. 2021), vegetative surface characteristics, especially inclination, shape, surface roughness, the presence of trichomes on leaves (Levia *et al*. 2019; Antoneli *et al*. 2020; Nanko *et al*. 2022; Anys & Weiler 2024) and the time between two successive rainfalls (Levia *et al*. 2017; Wang & Wang 2019; Zabret *et al*. 2023).

Concerning the considerable monthly variation, it turns out that the amount of rainfall in each event is the determining factor. According

to Nanko *et al*. (2022), the TF rate does not stabilize for the first 5mm. They indicated that smaller droplets were generated earlier during precipitation, while greater rainfall accumulation is needed to initiate larger drops.

Stemflow

The average SF rate found in this study was 7.93%. It is in agreement with the works of Antoneli *et al*. (2020) who have mentioned that the SF in the olive orchard varied from 1.5 to 24%. In contrast, our results are relatively high compared to the results of Gomez *et al*. (2001) indicating SF rates up to 6% for olive trees. This is most likely due to the rainfall regime during the study period. 78.32% of rainfall events are greater than 10mm in the studied orchard. The low rate of SF compared to the TF attests that SF is a phenomenon that occurs after TF (Gomez *et al*. 2002). In contrast, the SF found in our study is higher than that found in studies by Lombardo *et al*. (2018) and Valente *et al*. (2020) for olive trees. The difference can be attributed not only to different rainfall patterns and intensities (Lombardo *et al*. 2018) but also to the different ages of the two orchards (70 for our orchard and 90 for the orchard studied by Valente *et al*. 2020). Despite the differences that exist between the SF rates found by the preceding studies, they agree that the SF rate always remains low compared to the TF rate. Indeed, SF has been considered to be a minor component of water budgets compared with TF (Llorens & Domingo 2007; Tonello *et al*. 2021; Lima *et al*. 2022). Nevertheless, the SF is a fundamental component for nutrient leaching, since SF improves ion availability in the soil (Lima *et al*. 2022). During the rainfall events, there is also a redistribution of particulate matter that is deposited from the atmosphere on vegetative surfaces and transported to soil layers by TF and SF (Lima *et al*. 2022).

In terms of quantity, the average volume of SF was 1.11 ± 0.74mm per rainfall event. Despite its small fraction, SF has a particular importance in biogeochemical cycle of nutrients in the olive orchards because it is a spatially localized point input of water and nutrients at the plant stem of trees (Levia & Frost 2003; Tonello *et al*. 2021). According to Van Stan *et al*. (2024), the SF rate influences the canopy water balance, soil microbial ecology, and intrasystem nutrient cycling. The previous researchers have also pointed out that the arrival of SF to near-stem soils can provide important or negligible inputs of water, solutes, and suspended organisms belowground.

Interception

The I rate found by this study (9.57%) is in agreement compared to the result of Gomez *et al*. (2001) who found an interception which varies from 7 to 25%, in Spanish sites which received 606mm per year. Because studies on the redistribution of incident rainfall by the action of olive orchards are not exhaustive, we judge that it is very useful to compare our results with other studies, which focused on fruit trees and their action on the rate of interception.

Our results are in agreement with the results Wang *et al*. (2022) who worked on the rainfall interception by the canopy of apple trees and they found an annual percentage fluctuated between 7.1 and 10.7%. Similarly, Mali *et al*. (2020) found for mango, lychee, guava and jackfruit an interception, which fluctuates between 6.5 and 21.3%.

In addition, Benhizia *et al*. (2018) recorded an I which fluctuates between 25 and 35% under forest covers in an Algerian semi-arid region. Despite the fact that several researchers (Llorens & Domingo 2007; Zhang *et al*. 2023), affirmed that forest trees intercept more rainfall compared to fruit trees, the simple comparison of the rainfall regime of the two studies shows that the rainfall regime in semi-arid bioclimate, is often characterized by rainfall less than 5mm (Benhizia *et al*. 2018; Llorens *et al*. 2018). However, incident rainfall less than 5mm was absent in the present investigation. Therefore, it seems that the study period is relatively rainy compared to the average for the region. The rains received on the bare soil next to the orchard for six months are relatively close to the annual average (495.1mm) of Khenchela region for a period of 20 years (2000-2019). Thus, we suggest that under semi-arid Algerian bioclimate, the interception of rains is mainly influenced by the rainfall regime. This is consistent with other studies (He *et al*. 2022), which stated that the rainfall is responsible for more than 40% of variations in interception. According to the same researchers, temperature also contributed with more than 40%, particularly for arid and semi-arid regions. Besides, Herbst *et al*. (2006) have already

affirmed that the magnitude of the average loss per interception in deciduous forests depends on both climate, rainfall regime and canopy structure and varies from 9 to 36% depending on the climate.

On the other hand, the interception rate found in our study is high compared to the results of Valente *et al*. (2020) who found a low interception rate of 3.5% on olive trees, although the orchard density is not the same (83 trees for Valente *et al*. (2020) versus 520 for our study).

Relationship between Pi, TF, SF and I

The predictive models mentioned in Figures 4–6 are in agreement with those created previously for fruit trees (Farmanta & Sugand 2015; Mali *et al*. 2020). The exploitation of these models highlights that at least 0.78mm of incident rainfall is needed to trigger the TF in olive orchards. This quantity is relatively close to that found by Calheiros De Miranda & Butler (1986) who worked on the rainfall interception under the action of the apple tree, for a period of three months of summer (0.5mm). Nevertheless, this quantity is slightly weak comparatively to the range reported by Mali *et al*. (2020). These researchers reported amounts between 1.1 and 2.3mm for 4 fruit trees. The difference can be attributed to the difference in the fruit tree species and their heights.

On the other hand, the volumes needed to trigger the SF in this study (6mm), are greater than those needed to trigger the TF, which is totally consistent with several studies (Benhizia *et al*. 2018; Wang *et al*. 2022; Zhang *et al*. 2023). Similarly, they are high compared to the results of Zhang *et al*. (2023) which showed that the SF starts to decrease from 3.3mm. This is perhaps due to the dust accumulated on the leaves and branches of the olive tree.

Concerning the factors influencing the rainfall interception in orchards in addition to the rainfall regime, Mali *et al*. (2020) stated that for fruit trees and for rainfall less than 10mm, branch and trunk roughness and LAI are the most important in the dynamics of interception in orchards.

Conclusion

The results obtained may contribute to better assessment of the ecological and hydrological functions of olive orchard and their potential impact on the water balance, the nutrients cycle and soil dynamics, through the development of predictive equations and the identification of rainfall thresholds. The evaluation of rainfall interception for olive orchards is very important also for the selection of appropriate management practices to reduce unproductive water flows (I) and for the recharge of the groundwater in semiarid environments. Our findings can also contribute to more effective management and conservation strategies for olive orchards in Algeria, ultimately promoting sustainable land use practices and enhancing ecosystem resilience in the face of environmental challenges. Other variables are known to influence patterns of TF and SF and merit future investigation, including drop size distribution, temperature and wind condition.

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The consumption of Corsican pine seeds by the Eurasian treecreeper in Corsica

La consommation de graines de pin laricio par le grimpereau des bois en Corse

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Abstract

This study investigates the winter diet of the Eurasian treecreeper (Certhia familiaris corsa)*, a subspecies endemic to Corsica, focusing on its potential consumption of Corsican pine* (Pinus nigra laricio) *seeds. Treecreepers are insectivorous forest birds, but some populations are known to supplement their diet with seeds during winter. Using environmental DNA metabarcoding from fecal samples, the diet of individuals captured in mature Corsican pine forests across various sites and months is analyzed. Results revealed that* Pinus *DNA was present in 55% of the fecal samples, suggesting regular seed consumption. Although arthropods are presumed to remain the primary food source, their low detection in the samples is attributed to methodological limitations rather than true dietary absence. The study contributes to our understanding of the foraging ecology of the Corsican treecreeper and its potential interactions with the Corsican nuthatch* (Sitta whiteheadi)*, which relies heavily on pine seeds in winter. These findings also highlight the ecological significance of mature Corsican pine forests, which face conservation threats from logging and wildfires.*

Keywords: cache, *Certhia*, conifer seeds, environmental DNA, kleptoparasitism, treecreeper.

Résumé

Cette étude examine le régime alimentaire hivernal du grimpereau des bois (Certhia familiaris corsa)*, une sous-espèce endémique de la Corse, en mettant l'accent sur sa consommation potentielle de graines de pin laricio* (Pinus nigra laricio)*. Les grimpereaux sont des oiseaux forestiers insectivores, mais certaines populations complètent leur alimentation avec des graines en hiver. En utilisant la métagénomique de l'ADN environnemental extrait d'échantillons fécaux, le régime alimentaire d'individus capturés dans des forêts matures de pin laricio à travers différents sites et mois est analysé. Les résultats ont révélé que de l'ADN de pin était présent dans 55 % des échantillons, ce qui suggère une consommation régulière de graines. Bien que les arthropodes restent vraisemblablement la principale source de nourriture, leur faible détection dans les échantillons est attribuée à des limitations méthodologiques plutôt qu'à une absence réelle dans l'alimentation. Cette étude améliore notre compréhension de l'écologie alimentaire du grimpereau en Corse et de ses interactions potentielles avec la sittelle corse* (Sitta whiteheadi) *qui dépend fortement des graines de pin en hiver. Ces résultats soulignent également l'importance écologique des forêts matures de pin laricio, menacées par l'exploitation forestière et les incendies.*

Mots-clés : cache, *Certhia*, graines de conifère, ADN environnemental, klepto-parasitisme, grimpereau.

Introduction

Treecreepers form a small, homogeneous group of insectivorous birds characterized by thin, slightly decurved bills, short and slender legs, and cryptically colored plumage, typically brown with streaks or mottling. The greatest diversity of treecreepers is found in the genus *Certhia,* which inhabits the forests of Sino-Himalayan montane region, Europe and North America (Fjeldså *et al*. 2020). While treecreepers species are distinct microhabitat specialists, they are generalists in their diet within these specialized habitats: they primarily extract their prey, consisting mostly of small arthropods and their eggs, by probing into barks, crevices and epiphyte clusters on tree trunks and branches, rarely on the ground (Harrap & Quinn 1996; Poulin *et al*. 2020). A brief review of the known winter diets of certain species provides the following insights:

– *Certhia familiaris* L. (large distribution in Eurasia): primarily arthropods and their eggs (spiders are frequently mentioned), but also conifer seeds (notably pine and spruce) reported in several regions of Russia (summarized in Cramp & Perrins 1993), France (Muller 2015), Scandinavia (Kuitunen & Törmälä 1983; Kuitunen 1989; Suhonen & Kuitunen 1991), and Switzerland (Maumary *et al*. 2007);
– *Certhia americana* Bonaparte (Northern America): a variety of insects and larvae, spiders and their eggs, ants, and pseudoscorpions; also, a small quantity of seeds and other plant material (Poulin *et al*. 2020);
– *Certhia brachydactyla* CL Brehm (limited distribution in the Western Palaearctic): diet mainly consists of insect larvae and pupae, along with spiders; some seeds are also consumed (Harrap & Quinn 1996);
– *Certhia himalayana* Vigors (Central Asia): feeds on insects, spiders, and other small invertebrates; seeds are occasionally included in its diet (Harrap & Quinn 1996).

Thus, several treecreeper species inhabiting conifer forests partially feed on seeds during the winter period. The Corsican treecreeper, a well-differentiated subspecies (*Certhia familiaris corsa* Hartert), is endemic to Corsica Island (Pons *et al*. 2019) (Figure 1). By genetically analyzing Corsican treecreeper feces using DNA barcoding (Ando *et al*. 2020), our aim is to determine whether these birds consume Corsican pine [*Pinus nigra var. laricio* (Loudon)] seeds, at least during the winter period, to supplement arthropod resources that are presumably less abundant than during the rest of the year. Our goal is to enhance knowledge about the ecological characteristics of the Eurasian treecreeper on the island (Thibault *et al*. 2023) and its interactions with the Corsican nuthatch (*Sitta whiteheadi* Sharpe). Living in forest stand where the Corsican pine is the dominant tree, the nuthatch feeds primarily on seeds during winter, which it stores in the bark of trunks and branches (Löhrl 1960). These mature Corsican pine forests, which form the primary habitat of both species, face growing conservation challenges due to logging and recurrent wildfires (Torre 2014).

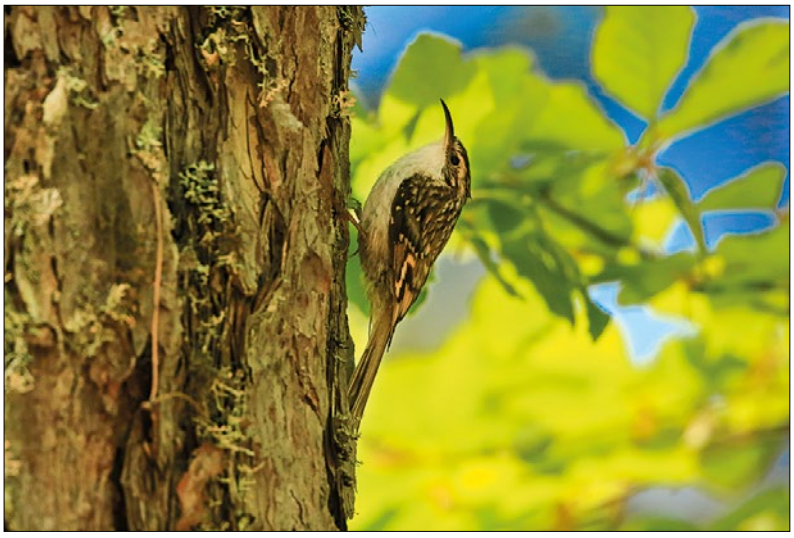

Figure 1 – Eurasian treecreeper* (Certhia familiaris corsa) *climbing along a Corsican pine trunk, Aitone forest, Corsica (24 May 2019).
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Methods

Capture of Eurasian treecreepers (hereafter treecreeper) and Sample Collection

The study was performed in mature stands of Corsican pine in Corsica Island (42°N, 9°E). We ensured the joint presence of cone-bearing trees, Corsican nuthatch, and treecreeper at the same sampling site. All five sites were located between 800 and 1350 meters in altitude. Treecreepers are birds whose social structure is based on a monogamous pair defending a territory of a few hectares throughout the year. Thus, the broadcasting of songs and calls of conspecifics helps attract them and

guides them through a narrow corridor bordered by young stands where a net is set up. We used recordings by Roché (1990) played through a Zoom H2n recorder-transmitter. The birds were captured using a six-meter-long mist net, which is relatively fine and thus invisible ("Jean Richardet", 19mm mesh, 4 pockets). The setup and dismantling of the net require only a few minutes, allowing for high mobility and quick movement from one territory to another. During the winter period, capture time was limited to just a few hours (starting from 8:30am. – once the birds had fed – until 2pm., when activity typically declines). Days with negative temperatures were excluded to minimize the risk of bird mortality, as well as windy days when the net would then become more visible and deter the birds. Vocalization playback lasted about ten minutes. Once captured, the birds were kept in bags for about twenty minutes, which is the estimated gut transit time for passerines (Snow & Snow 1988). The bags were washed after each use, and the feces were preserved in tubes containing 90% alcohol. A total of 20 samples were analyzed (Table 1).

Identification of food

Feces were analyzed using a metabarcoding technique targeting four molecular markers enabling the detection of either plant or arthropod DNA (ANTAGENE 2024). This method involves extracting DNA from the feces, then amplifying specific DNA regions using primers targeting the consumed species. The resulting amplicons are subsequently sequenced using high-throughput sequencing technologies, allowing the identification and quantification of various taxa by comparing these sequences to reference databases. Taxonomic assignment was performed using the BLAST (Basic Local Alignment Search Tool) search in the NCBI database GenBank.

Plant Analysis

For plants, two molecular markers were targeted: 1) the trnL intron, a universal plant marker targeting the initial portion of the trnL gene region (approximately 110-170 base pairs), which yielded the most consistent and reliable results; and 2) the Internal Transcribed Spacer 1 (ITS1), a non-universal plant marker located in the intergenic region of ribosomal DNA (approximately 210-300 base pairs), offering higher taxonomic resolution for certain groups. Given the broader applicability and robustness of the trnL marker, we focused our analysis on the results obtained from this region.

Arthropod Analysis

For arthropods, two other molecular markers were targeted: 1) the terminal portion of the mitochondrial cytochrome oxidase I (COI) gene (approximately 310-320 base pairs), which offers high taxonomic resolution but can be difficult to amplify from degraded DNA due to its length; and 2) the miniCOI marker, targeting the initial portion of the same gene (approximately 133 base pairs), which is more suitable for degraded samples thanks to its shorter length, though it provides lower taxonomic resolution for certain groups.

Statistical Analyses of DNA Sequences

For each sample, the relative abundance of DNA sequences associated with each taxon was calculated in relation to the total number of identified sequences of interest. The methodology used is semi-quantitative, as the number of detected DNA sequences – and thus their relative abundance – can be influenced by several factors, such as the ingested biomass, DNA degradation, and the ability to detect taxa equivalently. The three most represented taxa were searched within each sample.

Table 1 – Monthly distribution of feces samples across the different sites.

Forest sites / months ->	November	December	January	April
Ascu (42.4311 N, 8.9868 E)	n = 1 (2023)		n = 1 (2022)	
Poggio di Nazza 42.0511 N, 9.2683 E)		n = 4 (2021)		
Rospigliani (42.1744 N, 9.2702 E)		n = 1 (2023)	n = 2 (2022)	
Rospa sorba (42.1986 N, 9.2907 E)		n = 7 (2023)	n = 1 (2022)	n = 2 (2024)
Pietrapiana (42.0443 N, 9.2504 E)				n = 1 (2024)

Results

Plants

Genetic analyses revealed the presence of several dozen plant taxa in the feces of the treecreeper. Only one sample did not contain any plant DNA. In 93% of the samples, three taxa accounted for 90% to 100% of the total plant-based diet. The genus *Pinus* (trnL target) was the dominant taxon in 55% of the samples, contributing between 56% and 100% of the diet in these cases (Table 2). Additionally, *Pinus* was identified as the second- or third-most abundant taxon in four other samples. Within the long list of identified plants, some may have been consumed (*e.g.* *Prunus*), while others could have been achenes or pollen grains adhered to the plumage and accidently ingested during preening (*e.g.* *Castanea sativa* Mill., *Quercus* sp. which pericarp of acorn are too hard to be eaten; *Crepis* sp., *Parietaria* sp.). Others may represent either contaminations during various handling processes or mismatches in the reference database, in the absence of the targeted DNA (*e.g.* Musaceae). Finally, some taxa may reflect erroneous automated responses due to insufficient DNA quantity or sample degradation. Table 2 lists the most represented plants in the analyses. Table 3 indicates monthly distribution of *Pinus* in the five sites.

Arthropods

Only five out of twenty fecal samples revealed the presence of arthropods with the miniCOI target and three with the COI target, which does not allow for qualitative or quantitative assessments of their contribution to the treecreeper diet in Corsica (Table 4).

Discussion

Several analyses of stomach contents and visual observations indicate that the winter diet of treecreepers is primarily composed of arthropods, sometimes supplemented by plant material (Kuitunen & Törmälä 1983; Kuitunen 1989; Suhonen & Kuitunen 1991; Cramp & Perrins 1993; Harrap & Quinn 1996; Maumary *et al.* 2007; Muller 2015; Poulin *et al.* 2020). We assume therefore that the scarcity

Table 2 – Most represented plant taxa identified by metabarcoding of the trnL fragment in fecal samples of treecreepers. "Taxon 1", "Taxon 2", and "Taxon 3" indicate the three most abundant taxa in each sample. Cells are left blank when fewer than three plant taxa were detected in a given sample.

Sampling date	Site	Taxon 1 relative abundance	Taxon 1	Taxon 2	Taxon 3
17/12/2023	Rospa Sorba	61%	*Pinus*	*Prunus*	
17/12/2023	Rospa Sorba	73%	*Parietaria*	Brachytheciaceae	*Pinus*
16/12/2023	Rospa Sorba	64%	*Fagaceae*	*Castanea sativa* Mill.	*Pinus*
15/12/2023	Rospa Sorba	92%	*Pinus*	*Magnoliopsida*	*Quercus*
15/12/2023	Rospa Sorba	77%	*Liriodendron tulipifera* L.	*Persea* americana Mill.	
07/12/2023	Rospa Sorba	100%	*Crepis*		
06/12/2023	Rospa Sorba	64%	*Brachytheciaceae*	*Magnoliopsida*	*Ananas comosus* (L.)
11/04/2024	Pietrapiana	100%	*Pinus*		
14/04/2024	FT Rospa Sorba	43%	*Magnoliopsida*	Brachytheciaceae	Cupressaceae
14/04/2024	Rospa Sorba	99%	*Pinus*	Anacardiaceae	*Anacardium*
11/01/2022	Rospa sorba	75%	*Pinus*	Brassicaceae	*Parietaria*
30/12/2021	Poggio di Nazza	57%	*Pinus*	*Magnoliopsida*	Brassicaceae
29/12/2021	Poggio di Nazza	98%	*Pinus*	*Magnoliopsida*	Hypnales
22/12/2021	Poggio di Nazza	76%	*Pinus*	*Parietaria*	Asteraceae
21/12/2021	Poggio di Nazza	54%	Asteraceae	*Pinus*	*Raphanus*
04/12/2023	Fospigliani	56%	*Pinus*	*Solanum*	Solanaceae
13/01/2022	Rospigliani	100%	*Pinus*		
13/01/2022	Rospigliani	0%			
27/11/2023	Ascu	100%	*Musaceae*	*Pinus*	
04/01/2022	Ascu	100%	*Pinus*		

Table 3 – Occurence of* Pinus *in metabarcoding analysis of the trnL fragment in fecal samples of treecreepers (distributed by month).

	lack of *Pinus* in the feces	under the threshold	*Pinus* as taxon 1	*Pinus* as taxon 2	*Pinus* as taxon 3
November	0	0	0	1 (5%) (Ascu)	0
December	3 (15%) (Rospa Sorba)		6 (30%) (Poggio di Nazza, Rospigliani, Rospa Sorba)	1 (5%) (Poggio di Nazza)	2 (10%) (Rospa Sorba)
January	0	1 (5%) (Rospigliani)	3 (15%) (Rospigliani, Ascu, Rospa Sorba)	0	0
April	1 (5%) (Rospa Sorba)	0	2 (10%) (Pietrapiana, Rospa Sorba)	0	0

Table 4 – Most represented arthropod taxa in metabarcoding analysis of the miniCOI target in fecal samples of treecreeper. "Taxon 1", "Taxon 2", and "Taxon 3" indicate the three most abundant arthropod taxa in each sample, ranked by the number of sequencing reads. "Number of reads Taxon 1", "Number of reads Taxon 2", and "Number of reads Taxon 3" refer to the total number of reads assigned to each respective taxon. Cells are left blank when fewer than three taxa were detected in a given sample.

Sampling date	Site	Taxon 1 relative abundance	Taxon 1	Number of reads Taxon 1	Taxon 2	Number of reads Taxon 2	Taxon 3	Number of reads Taxon 3
21/12/2021	Poggio di Nazza	100%	*Cyrtaspis scutata* (Charpentier) (Orthoptera)	16679				
15/12/2023	Rospa Sorba	46%	*Tapinoma melanocephalum* (Fabricius) (Formicidae)	408	*Dermatophagoides pteronyssinus* Trouessart (Acariformes)	243	Cecidomyiidae Newman	241
29/12/2021	Poggio di Nazza	51%	*Dermatophagoides pteronyssinus* Trouessart (Acariformes)	185	*Eulachnus* Guercio sp. (Aphididae)	180		
22/12/2021	Poggio di Nazza	54%	Chironomidae Newman	187	Oribatulidae Thor	159		
27/11/2023	Ascu	100%	*Philodromus aureolus* (Clerck) (Araneae)	128				
17/12/2023	Rospa Sorba	0%						
30/12/2021	Poggio di Nazza	0%						
04/01/2022	Ascu	0%						
11/01/2022	Rospa sorba	0%						
13/01/2022	Rospigliani	0%						
13/01/2022	Rospigliani	0%						
14/04/2024	Rospa Sorba	0%						
14/04/2024	Rospa Sorba	0%						
16/12/2023	Rospa Sorba	0%						
17/12/2023	Rospa Sorba	0%						
11/04/2024	Pietrapiana	0%						
15/12/2023	Rospa Sorba	0%						
06/12/2023	Rospa Sorba	0%						
07/12/2023	Rospa Sorba	0%						
04/12/2023	Rospigliani	0%						

of arthropods in the feces in treecreepers from Corsica corresponds to methodological biases rather than a true predominance of plant material. It is indeed possible that the primers used to amplify the miniCOI target may also amplify non-target DNA, particularly that of the host species (Klure *et al*. 2022), thereby reducing the detectability of arthropod prey.

Thus, the analyses do not allow us to estimate the proportion of arthropods in the winter diet. However, Bookwalter *et al*. (2023), with same methods, found very high prey diversity and very little overlap within and among insectivorous passerines living in dwarf mountain pine (*Pinus mugo* Turra) forest. For plant analyses, the universal marker (trnL) primarily detected the consumption of pine (genus *Pinus*), which necessarily belongs to the Corsican pine species. The other pine species found in Corsica, the Maritime pine (*Pinus pinaster* Aiton), is rare or absent in the studied areas, and its seeds are not consumed by small passerines (e.g. tits, Corsican nuthatch) due to their hard shells (lignified pericarp) and large size (Thibault *et al*. 2002). The presence of Corsican pine seeds in treecreeper feces was recorded across several seasons and in forests separated by several tens of kilometers, suggesting that their consumption was not accidental. Corsican pine seeds likely represent a significant part of the winter diet of treecreepers when arthropod resources are more limited. They become abundantly accessible in mature woodlands starting in November, when the cones begin to open, until March and even later in years of high production (Debazac 1991). When temperatures exceed 6°C and the weather is dry, the cones open to release their seeds, which are dispersed by the wind, carried by their wings (Thibault *et al*. 2006). However, no observations have been reported in Corsica of treecreepers extracting seeds from cones as they open or picking up seeds that have fallen to the ground (Thibault & Prodon 2006, pers. obs.). By contrast, Corsican nuthatches, whose winter diet consists primarily of Corsican pine seeds, extract them by pulling on the seed wing with their beak, using their feet for leverage on the cone. On nearby trees, they cache the seeds under bark along the trunks as well as on and beneath branches, sometimes covering them with a small piece of bark. This leads to the hypothesis that some of these seeds may be recovered by treecreepers, which are specialists in foraging for food in the bark of branches and trunks. Ornithological literature is silent on kleptoparasitism that treecreepers might practice (Brockmann & Barnard 1979), with only a single mention: "*will take food from food-caches of tits* Parus" (Zonov 1978 cited by Cramp & Perrins 1993). In North America, for tits and nuthatches, caches are primarily intended to protect seeds from theft by conspecifics or other species rather than from bad weather; consequently, caching locations may vary from one population to another in response to kleptoparasitism (Petit *et al*. 1989). Concerning mixed flocks of European tit species, Suhonen & Alatalo (1991) suggest that the risk of interspecific kleptoparasitism influences the selection of hoarding sites. In Corsica, treecreepers and Corsican nuthatches have relatively similar densities (Arrizabalaga *et al*. 2002), habitats (groves with large trees: Villard *et al*. 2014; Thibault *et al*. 2023) and their territories tend to overlap, with both species searching for standing dead trees (treecreepers favoring those with bark still present, although detached from the trunk). Considering the significant amount of time nuthatches spend daily caching seeds when cones are open, we assume that the volume of cached seeds is substantial. Predation of these caches by treecreepers is likely negligible, given that the two species have coexisted for at least tens of thousands of years (Pons *et al*. 2019) without nuthatches developing strategies to better hide their seeds.

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A glimpse into the terrestrial invertebrate communities of Sazani island, Albania (arthropods, molluscs)

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Abstract

An exploration of the island of Sazani (Albania) was carried out from September, 3rd to 7th September 2012 within the framework of the programme "PIM Initiative for the Small Islands of the Mediterranean". Most arthropod groups and molluscs were sampled or observed: myriapods, arachnids (pseudoscorpions), crustaceans (Isopoda or woodlice), insects (Coleoptera, Heteroptera, Lepidoptera, Orthoptera and related groups, Odonata and Hymenoptera). Eleven species are new to Albania. A comparison with the Karaburun peninsula highlights the originality of the invertebrate communities on the island of Sazani. The most urgent management measures involve protecting the island beaches by limiting visitor numbers, eliminating plastic waste and conserving sea driftwood.

Përmbledhje

Një ekspeditë në ishullin e Sazanit (Shqipëri) u zhvillua nga data 3 deri më 7 shtator 2012 në kuadër të programit 'Iniciativa PIM për Ishujt e Vogël të Mesdheut'. Grupet artropodëve dhe molusqeve u grumbulluan ose u vëzhguan, ishin: myriapodët, araknidët (pseudoakrepat), krustacet (gafore), insekte (Coleoptera, Heteroptera, Lepidoptera, Orthoptera, Odonata dhe Hymenoptera). Njëmbëdhjetë lloje referohen të reja për Shqipërinë. Krahasimi me faunën e gadishullit të Karaburunit, jep të dhëna për individualitetin e faunës jovertebrore të ishullit të Sazanit. Për menaxhimin e ruatjes së kësaj faune duhen të meren masa të shpejta si p.sh: mbrojtja e plazheve të ishullit duke kufizuar numrin e vizitorëve, eliminuar hedhjet e mbetjeve plastike, dhe duke ruajtur depozitimet e detit.

Keywords: arthropods, mollusks, Sazani, Karaburun, insularity, conservation management.

Fjalë kyçe: artropodët, molusqet, Sazani, Karaburun, izolimi, menaxhimi i ruajtjes.

Introduction

Since 2006, the *Conservatoire du Littoral* coordinates an international programme to promote and assist the management of Mediterranean island micro-spaces. This programme, the "PIM Initiative for Small Islands of the Mediterranean", is co-financed by the *Fonds français pour l'environnement mondial* (FFEM) and the *Agence de l'eau Rhône Méditerranée-Corse* (PIM 2025). The PIM Initiative is developing a system for exchanging and sharing the knowledge needed to develop best management practices in these exceptional areas. During field missions and training courses, rangers, technicians, scientists, naturalists, managers, administrations and associations come together to promote the protection of small Mediterranean islands and implement concrete management actions that have a positive impact on ecosystems, biodiversity, natural resources and uses. The Sazani mission is part of a partnership between the University of Tirana, APAWA (Association for Protection of Aquatic Wildlife of Albania) and the *Conservatoire du littoral* as part of the PIM Initiative for Small Mediterranean Islands, with the support of the French Embassy in Tirana, the UNDP Programme in charge of Albanian Marine Protected Areas and the University of Vlorë. The main objective of this mission was to carry out a terrestrial and marine diagnosis of the island of Sazani, with the aim of improving our knowledge of the island natural environment and defining recommendations for integrated land-sea management.

Part of the Karaburun-Sazani Marine Protected Area (MPA), Sazani is Albania's largest island (570ha, 4.8km long and 2km wide), with a maximum altitude of 337 metres (Figures 1 and 2). Part of the municipality of Vlorë, the island is around 12km from the town's fishing port and 4.8km from the mainland at the nearest point. The Karaburun peninsula forms the western part of the bay of Vlorë. Together with the island of Sazani, the area has been identified as a priority zone by numerous national and international studies. However, the island of Sazani is not included within the perimeter of the Logara-Karaburun National Park. The creation of the Karaburun-Sazani MPA in 2010 (Albania's first MPA) is a first step towards the sustainable exploitation of marine resources in the area, while ensuring the preservation of its biodiversity and landscapes.

Due to its position between the Adriatic and Ionian Seas, the island has always been a strategic point for military defence. The history of the occupation of the island of Sazani is particularly complex, especially in the period between the Second World War and the present day. The construction of numerous military buildings and bunkers, and the presence of an extensive network of galleries, bear witness to a major military occupation. Possessed by Turkey in the 15th century, then by Italy in the 18th century, the island was ceded to Greece in 1864, who abandoned it in 1914. The installation of an Italian military base was ratified in 1915 in the Treaty of London. The Italian authorities then built a lighthouse and naval fortifications, before fishermen's families settled there. From 1943 to 1944, the island was under German occupation, before control was taken over by Albania. Today, access to the island is controlled and regulated by the Albanian Army. An Italo-Albanian military base was set up in 1997 to control illegal trafficking at sea. In the 1970s, the island was occupied by more than 300 families. In parallel with the development of the military bases, infrastructure and buildings were built to accommodate families on a long-term basis: housing, schools, a hospital, a library, a village hall, a cinema, a football pitch, etc. Extensive sheep farming and subsistence agriculture were also practised. In the mid-1980s, these families were removed from Sazani, leaving the island uninhabited to this day. The remains of many of the buildings are still visible. Until recently, the inaccessibility of the island has allowed vegetation to reclaim these areas, which are heavily marked by the imprint of past activities. Since 2014, the island has been open to visitors, and tourism has increased significantly. Now, the island has been open to tourists for several years. During summer, visitors reach the island via boats organized by travel agencies for beach trips. Several boats, each carrying around 30 people, arrive daily throughout the summer. It is now a key tourist destination for many agencies and tour operators in Albania, particularly in the Vlorë area. Several management plans, action plans, and strategies have since been developed and implemented for Sazani Island, the Karaburun-Sazani MPA, and the broader Vlorë region.

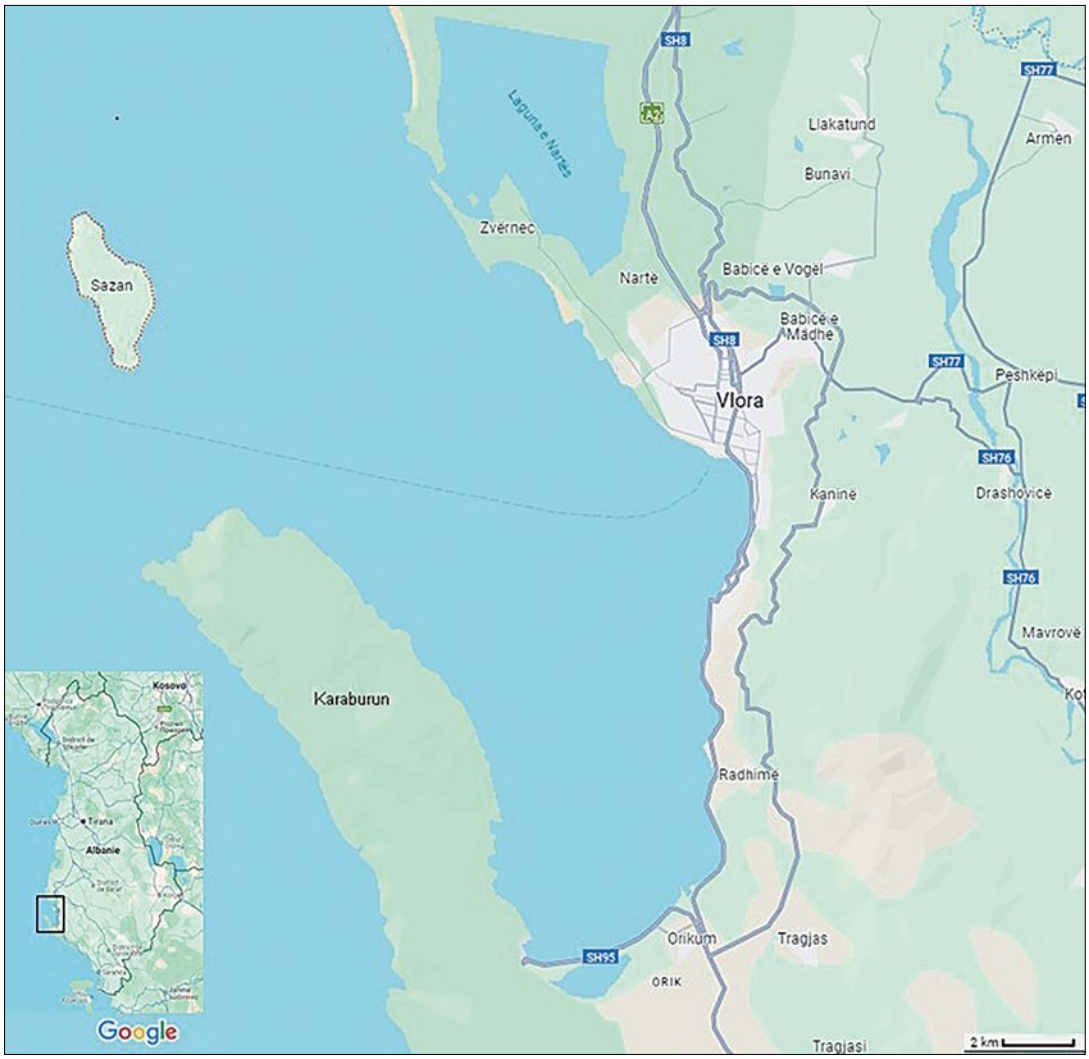

Figure 1 – Location of Sazani island.

Figure 2 – Sazani Island, September 2012.
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Materials and methods

Arthropods were collected using conventional methods of investigation: sight-hunting under stones, on flowers, under bark, prospecting with a beating tray for frondicolous fauna and with a sweep net for fauna associated with the herbaceous stratum. We also carried out a night-time survey using a headlamp around the old school. Given the limited time available (4 days, 1 night on the island + 1 day on the peninsula), we were only able to visit the entrances to the bunkers and galleries. The presence of intact ammunition did not encourage us to penetrate deeper into the network of galleries in search of troglobitic and troglophilic fauna. Most arthropod groups were sampled or observed: myriapods, arachnids, crustaceans (woodlice), insects (Coleoptera, Lepidoptera, Orthoptera and related groups, Odonata and Hymenoptera). The nomenclature used for arthropods is taken from the Fauna Europaea website (2011). Molluscs were not systematically surveyed during the mission, although a few shells were collected on sight.

Study sites

– 3-IX-2012 - Sazani, near the port and coastal path to the north, stands of *Euphorbia dendroides*.
– 4-IX-2012 - Sazani, southern track and tour of the southern tip of the island.
– 5-IX-2012 - Sazani, central mountain (elevation 331m), summit and south-facing slope.
– 6-IX-2012 - Sazani, south-east coast (*Lotus* zone, *Typha* zone), and survey of the *Pinus brutia* valley (N 40.49549° E 19.28230° alt. 72m) with numerous dead and dying trees.
– 7-IX-2012 - Karaburun Peninsula. The peninsula was briefly explored in order to compare the Sazani island arthropod populations with those of the nearby mainland. We were dropped off at two points on the peninsula and followed the coastal track along the north-east coast.

Results

Pseudoscorpiones

Only one species was collected under *Pinus* barks: *Rhacochelifer maculatus*, a common species around the Mediterranean, but not yet reported from Albania.

Coleoptera

As a whole, 40 taxa of coleoptera were identified (Appendix 1). This figure is clearly an underestimation of the real beetle community, but the early September survey season was not appropriate for most Coleoptera, especially the phytophagous species, which live on herbaceous vegetation and disappear when the vegetation dries up in late summer.

The port area and the surroundings of dwellings with ruderal vegetation showed the greatest diversity in Coleoptera, but also in other arthropods (Heteroptera, Orthoptera *sensu lato*), perhaps because of the diversity of ruderal plants, the diversity of habitats and the slightly greater humidity, but, paradoxically, this sector is the most disturbed and the most artificial on the island. Numerous coprophages linked to faeces (probably dog faeces) were identified in this area, in particular *Onthophagus furcatus* and *Sisyphus schaefferi*. Many beetles were found on the ground, under stones, at the base of plants growing among the rubble: *Pseudoophonus rufipes, Drasterius bimaculatus, Hirticomus quadriguttatus, Paederus littoralis*. *Ecballium elaterium* is the host plant for the ladybird *Henosepilachna elaterii*, which was found wherever its host plant was found (Figure 3). The flea beetles *Longitarsus albineus* was found on its host plant *Heliotropium*, *Longitarsus tabidus* on *Verbascum* and *Ochrosis ventralis* on Borraginaceae. The presence of many *Parietaria* (Urticaceae) allowed the associated fauna to thrive, including in particular the small, widely distributed weevils *Kalcapion semivittatum* and *Taeniapion rufulum*.

Otiorhynchus aurifer (Figure 4) and *Otiorhynchus armatus* (Figure 5) are two weevil species originating from the Mediterranean basin and expanding progressively throughout Europe (Germann 2006; Heijerman & Drost 2000). Both were found under stones in the vicinity of the port area.

Figure 3 **– Henosepilachna elaterii *feeding and mating in a flower of* Ecballium elaterium.**
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Figure 4 **– Otiorhynchus aurifer.**
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Figure 5 **– Otiorhynchus armatus.**
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The tree associated beetle fauna included the tiny Scolytidae *Hypoborus ficus*, very abundant on fig-trees wearing dead branches and twigs. On elm-trees (*Ulmus*) it was possible to observe the xylophagous Cerambycidae *Exocentrus punctipennis*, along with the corticolous Salpingidae *Salpingus planirostris*. A few unidentified *Tamarix* formed a thicket at about 1km to the North-West of the harbour (N 40.50679° E 19.27581° alt. 1m). Beating these trees provided a female *Cryptocephalus* belonging to the sub-genus *Burlinius*, impossible to identify on isolated female specimen, and plenty of specimens of an Anthicidae species, *Cyclodinus constrictus*, with a wide distribution in the Mediterranean basin.

An abundant population of the Tenebrionidae *Allophylax picipes* (Figure 6) was also discovered in the port, a remarkable find as this beetle is new to Albania. This species was reported from Southern France, Corsica, the Tyrrhenian coast of Italy, Puglia (Is. Tremiti included), Sicilia (minor islands included), Dalmatia; old records from Tunisia and Algeria (Aliquò *et al*. 2006). The presence of this species in the port area where various materials have been deposited and stored for many years suggests that it may have been unintentionally introduced by humans along with materials or vehicles. It would be interesting to see whether this species is present elsewhere on the island. *Stenosis intermedia dalmatina* (Figure 7) is restricted to Albania, Croatia and Greece (Löbl *et al*. 2008). Another darkling beetle, *Pedinus helopioides*, was discovered in this area, this is a common species reported from the Balkan Peninsula, Bulgaria, Southern Italy (Aliquò *et al*. 2006).

A small population of the tiger beetle *Calomera littoralis* was isolated on the beach near the port. This population is limited to a few individuals whose chances of survival

***Figure 6* – Allophylax picipes.**
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***Figure 7* – Stenosis intermedia dalmatina.**
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in the event of sampling or environmental disturbance are questionable. The scarcity of beaches on the island is not favourable to the survival of this species.

Matorral with *Pistacia lentiscus*, *Olea europaea* and *Quercus coccifera* were surveyed since this plant formation covers most of the island (Figure 8). However the early September survey season was completely unsuitable to this type of warm and dry Mediterranean environment, a region where rainfalls are totally missing in summer. As a result, a very small number of coleoptera were recorded. Debris of *Parmena* were discovered under a stone; this is probably the species *Parmena bicincta*, which has a very limited distribution (Albania, Bosnia-Herzegovina, Croatia, Montenegro). Confirmation of this identification on fresh material of better quality would be highly desirable.

The ladybird *Chilocorus bipustulatus*, a very common frondicolous species, was present everywhere on the foliage of *Pinus brutia* (Figures 9 and 10) and *Cupressus sempervirens*. Beating the dry, scorched foliage of recently felled pine trees yielded one species of *Ernobius*, and *Opilo domesticus*. The only *Ernobius* specimen collected is a female, which does not allow a definite specific identification, however the external morphological characters correspond exactly to the French specimens of *Ernobius parens*. It is very likely that this is this species, that has never been recorded from Albania. In Provence, this *Ernobius* develops at the expense of pine branches, especially the Aleppo pine *Pinus halepensis*. The Anthribidae *Noxius curtirostris* was also found on the yellowed foliage of pine branches that had fallen to the ground, as well as on *Euphorbia dendroides*. On long-dead pine trees, the saproxylophagous weevil *Brachytemnus porcatus* is common under dehiscent barks. *Cis chinensis*, a chinese species now cosmopolite (Rose 2012), was common inside old bracket fungi growing on dead pines. Finally, remains of dead *Buprestis cupressi* were found on the ground, this is a xylophagous jewel beetle that thrives in the dead wood of *Cupressus* trees (Figure 11).

Figure 8 – Matorral with* Pistacia lentiscus *dominant.
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Figure 9* – Pinus brutia *forest on the eastern coast of Sazani.
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Figure 10* – *Mature stand of* Pinus brutia *with abundant dead trees.
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***Figure 11* – Buprestis cupressi.**
(https://www.galerie-insecte.org/galerie/ref-222606.htm, licence CC BY NC)

The stands of old *Euphorbia dendroides* with many dead stem and branches seemed favourable to the presence of a community of saproxylophagous Coleoptera. We were able to collect two specimens of the Anthribidae *Noxius curtirostris* and one unidentified species of *Laemophloeus*. *Noxius curtirostris* is not specifically associated with *Euphorbia*, but is a polyphagous saproxylophagous beetle able to develop on a wide variety of plants (broadleaved and coniferous). We did not come across *Dichromacalles rolletii* (Germar 1824), although it has been reported from Greece, not so far away. Further surveys in spring would be useful to potentially find this remarkable weevil on the island of Sazani.

Exploration of the island bare summits yielded a restricted but interesting beetle fauna. The island main "peaks" are just over 300m above sea level (Figure 12), so we did not expect to find mountain fauna there. However, the slightly more humid conditions than at lower altitudes meant that we were able to find a few beetles that had not been seen elsewhere, such as *Asida fasciculatis lineatocollis* and *Opatrum verrucosum*, which were seen right at the top of the central mountain (elevation 331m), and nowhere else on the island. However, it is possible that surveys to be carried out during the wetter season will reveal the presence of these two species in other parts of the island. The subspecies *lineatocollis* of *Asida fascicularis* (Figure 13) is restricted to Albania, Bosnia-Herzegovina, Croatia, Greece (Soldati 2008). *Opatrum verrucosum* (Figure 14) is an east Mediterranean species reported from Anatolia, Greece, Ionian islands, Adriatic coasts of the Balkan Peninsula, Southern Italy, Sicilia (Aliquò *et al*. 2006).

Figure 12 – Hills on Sazani, the Karaburun peninsula is visible in the background.
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Figure 13 **– Asida fascicularis *ssp.* lineatocollis.**
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Figure 14 **– Opatrum verrucosum.**
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Heteroptera

A total of 20 species of Heteroptera were identified to the species level. Few species were collected, however three common species are listed as new to Albania: *Lygus italicus*, *Nysius helveticus* and *Ortholomus punctipennis*. Numerous juvenile individuals of *Coranus*, *Dicranocephalus* and Lygaeidae were observed but not identified. A small Miridae belonging to the genus *Tuponia* had also developed in the *Tamarix* thicket near the port, but specific identification was impossible as it was teneral (i.e. state of the imago just after molting during which it is soft and immature in colouring).

Most of the species observed are polyphagous and widely distributed in the Western Palaearctic region, but mainly in warm, dry environments. However, several species are oligophagous, such as *Cydnus aterrimus* and *Dicranocephalus medius*, which depend on various *Euphorbia* species, *Eysarcoris ventralis*, which lives on *Juncus* and *Cyperus*, and *Hyalochilus dolosus*, which lives on *Parietaria* (*Parietaria officinalis* and *P. erecta*) (Péricart 1998b). *Orsillus maculatus* is associated with conifers, such as *Cupressus sempervirens*, *Pinus halepensis* and *Juniperus phoenicea* (Péricart 1998a). *Graphosoma semipunctatum* is associated with the Apiaceae. Some species are uncommon and their biology is poorly understood: *Proderus bellevoyei*, an East Mediterranean and Pontic species known from the Balkans, Crimea, Caucasus, Transcaucasia, Anatolia, Asia Minor and the Near East (Péricart 1998c), *Aoploscelis bivirgata*, a rare ponto-mediterranean species, which appears to be widespread from the Iberian Peninsula and Morocco in the west to the Near East and Transcaucasia in the east (Péricart 1998b), and *Hyalochilus dolosus*, a Pannonian species known from the Balkans, Cyprus, Anatolia, Transcaucasia and Turkmenia (Péricart 1998b).

Orthoptera

Fifteen species were identified during the survey (Appendix 1). Most of them are very common and widespread in the Mediterranean Basin. A small cricket was also observed under the seagrass on the beach near the harbour, but careful examination revealed that it was *Arachnocephalus vestitus*, a common species throughout Sazani, and not *Pseudomogoplistes squamiger*, a much rarer species that has been observed on a beach on the Karaburun peninsula.

Concerning other Orthoptera, two male *Calliptamus* were caught and identified by examination of the genitalia. It turns out that these specimens belong to the species *Calliptamus italicus* and not *Calliptamus barbarus*. In Provence, *C. italicus* tends to be associated with slightly damp, open environments with herbaceous vegetation and is able to live in mountains, whereas *C. barbarus* seeks out the most xeric biotopes at lower altitudes. The same situation is observed in Greece. For the moment, there is no verified data for *C. barbarus* in Albania. At Sazani, *Calliptamus* were only caught around the port in areas with cooler ruderal vegetation, but no specimens from the driest open areas with *Pistacia lentiscus, Euphorbia dendroides,* etc. were monitored. It cannot therefore be ruled out that the two species may coexist on the island, and further surveys would be necessary to clarify this point. One specimen of *Eupholidoptera* was observed but not collected and hence not identified, but *Eupholidoptera schmidti* is the only *Eupholidoptera* present in the Vlorë region.

Mantodea

The two species observed on Sazani, *Ameles decolor* and *Mantis religiosa*, are common and widespread in the Mediterranean Basin.

Dermaptera

Along with the tiger beetle *Calomera littoralis*, an isolated population of the maritime earwig *Anisolabis maritima* represented by very few individuals was observed very close to the port, on a pebble beach with scattered sea driftwood and other marine plant debris. Again, the scarcity of beaches on the island is not favourable to the survival of this species. Beating *Euphorbia dendroides* provided the widely distributed Mediterranean forficula *Forficula decipiens*. This is the only insect found in abundance on this bush species.

Phasmida

A population of *Bacillus rossius* (Phasmida) (Figure 15) was found on the island. The island of Sazani falls within the geographical range occupied by *Bacillus rossius redtenbacheri* Nascetti & Bullini 1983 (southern Italy, Sardinia, Dalmatia, Albania, Greece). However, the taxonomy of this group is

Figure 15 **– Bacillus rossius *cf.* redtenbacheri.**
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delicate and the identification must be considered provisional (Lelong 1993; Berni 1997). Further research would be desirable to study this island population.

Hymenoptera

Two families only were collected, Formicidae and Vespidae (Appendix 1). Among the ants, two species are new for Albania, *Messor wasmanni* and *Tetramorium semilaeve*. The identified species of Vespidae are the very common *Vespa orientalis* and *Vespula germanica*. As for Heteroptera, the limited number of species observed at Sazani is certainly a consequence of this short survey.

Lepidoptera

The Lepidoptera community is represented by 16 species, 13 butterflies and 3 moths (Appendix 1). Unfortunately it was not possible to install a light trap, which explains the rarity of moths. As a whole, the Lepidoptera are represented by common and widespread species, most are polyphagous but *Aglais io*, *Polygonia egea* (Figure 16) and *Vanessa atalanta* feed on diverse *Urtica* and *Parietaria* species during the larval stages. Other host plants includes *Rumex* (*Lycaena phlaeas*), *Lonicera* (*Limenitis reducta*), *Prunus* (*Iphiclides podalirius*), *Iberis* (*Pieris mannii*), various Fabaceae (*Polyommatus icarus*) and various Poaceae (*Maniola jurtina*). An interesting butterfly flew in *Hyparrhenia hirta* grasslands (Figure 17), probably *Gegenes nostrodamus* but unfortunately the identification cannot be confirmed since no specimens were caught and a confusion with *Gegenes pumilio* is possible. The caterpillars of both *Gegenes nostrodamus* and *G. pumilio* eat this Poaceae species.

Odonata

Streams and marshes are scarce or absent on Sazani, hence dragonflies and damselflies are represented by very few species (Appendix 1). *Sympecma fusca, Sympetrum fonscolombii, Sympetrum meridionale,*

***Figure 16* – Polygonia egea.**
© M. Pascal

***Figure 17* – Biotope of Gegenes *sp. with population of* Hyparrhenia hirta.**
© P. Ponel/IMBE

Figure 18 – Brackish water pond near the port, possible habitat for several species of Odonata.
© P. Ponel/IMBE

Sympetrum striolatum are all able to develop in brackish water, so their occurrence at Sazani may be explained by the presence of small water bodies close to the sea (Figure 18). One specimen of *Aeshna* was observed in flight but not caught and not identified, it is possible that this good flyer was a vagrant specimen originating from the Narta lagoon close to Vlorë, and located to the East 9km away from Sazani.

Isopoda

The Oniscoids *Trachelipus* cf. *camerani*, *Porcellio obsoletus* and *Armadillidium pallasii* thrive under dead tree barks in *Pinus brutia* woods and artificial stands of *Cupressus sempervirens*.

Gastropoda

The shells of six species of Gastropoda only were collected on Sazani, but the mollusc community is certainly much more diversified since Sazani is a limestone island, favourable to this group of animals. *Cochlostoma tesselatum* is in the broadest sense an endemic Balkan species found only in western Greece (including the Ionian Islands) and the southern half of Albania. Within this species, numerous 'forms', often treated as subspecies, are sometimes recognised and it could therefore be *C. tesselatum excisum* (Mousson 1859). According to Fehér *et al*. (2001), this taxon is not of significant taxonomic value. *Pomatias elegans* is a Western European species that is abundant almost everywhere. It is much rarer and localised in North Africa. Following the advice of F. Welter-Schultes and H. Nordsieck, *Siciliaria* cf. *stigmatica* is the name given to the clausilids collected on the island of Sazani. However, they stand out because of their small size and deserve further study. Some of the other shells collected seem to correspond to *Cernuella virgata*, a widely distributed species, which undoubtedly originated in the Mediterranean but is now widely distributed throughout Europe following introductions, some of which are very old. Further collections will enable us to make a definitive decision on the exact identity of the taxon observed on the island. *Cochlicella acuta* is a Mediterranean-Atlantic species, common mainly on the coasts within its wide range covering Western Europe and the Mediterranean Basin. For certain identification of *Monacha*

species, and in particular to distinguish it from *Monacha cartusiana* (Müller 1774), it is normally necessary to study internal anatomy. However, *M. cartusiana* appears to be found only in northern Albania (see distribution map in Welter-Schultes 2012). We therefore attribute these empty shells collected from Sazani to *M. claustralis*, a species distributed from southern Albania to western Turkey.

Comparison with Karaburun peninsula

It was possible to spend a few hours exploring the tip of the Karaburun peninsula, in the part closest to the island of Sazani (Figure 19). A comparison with the list of species recorded on the peninsula is interesting because it shows significant differences with the fauna of Sazani. Despite the very limited number of insects seen in Karaburun, 11 species were not recorded on the island, although the survey effort was much greater on the latter. The populations of the two regions (continent and island) therefore appear to be very different, even at the same altitude. The effect of insularity on biodiversity seems therefore obvious, however an over-exploitation of the island in the past, leading to the local extinction of certain species, cannot be ruled out. The advantages of combining a continental and an insular part in the same protected area are highlighted by this comparative study (which deserves to be developed further). The same observations seem to apply also to the flora since, for example, the Mount Thabor oak (*Quercus ithaburensis* subsp. *macrolepis*) is absent from Sazani but well represented on the north-east coast of Karaburun peninsula, only a few kilometers away (Tomàs-Vives 2014).

Arthropods marked with an asterisk were seen on the peninsula but not on the island of Sazani:

– *Ameles decolor* (Charpentier 1825)
– **Empusa fasciata* Brulle 1832
– *Calliptamus italicus* (Linnaeus 1758)
– **Acrida ungarica* (Herbst 1786)
– **Chorthippus* cf. *mollis* (Charpentier 1825)
– **Pseudomogoplistes squamiger* (Fischer 1853), several specimens on a pebble beach (Figure 20)

Figure 19 – View of Sazani island from the northern tip of Karaburun peninsula.
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***Figure 20 – Beaches at the northern tip of Karaburun peninsula, habitat of* Pseudomogoplistes squamiger.**
© P. Ponel/IMBE

– **Capnodis cariosa* (Pallas 1776), many specimens flying around *Pistacia lentiscus*
– **Cetonia aurata* (Linnaeus 1761)
– **Chrysolina vernalis* (Brulle 1832)
– **Otiorhynchus lugens* (Germar 1817)
– *Pedinus helopioides* Ahrens 1814
– *Stenosis intermedia dalmatina* Reitter 1916
– **Ophonus subquadratus* (Dejean 1829)
– *Vespa orientalis* Linnaeus 1771
– **Graphosoma semipunctatum* (Fabricius 1775)
– **Cataglyphis nodus* (Brulle 1832)
– *Limenitis reducta* Staudinger 1901
– **Papilio machaon* Linnaeus 1758
– **Argynnis paphia* (Linnaeus 1758)

Species new for Albania

Despite the unfavourable survey season, a significant number of arthropod species new to Albania were found.

On Sazani island:
– *Rhacochelifer maculatus* (L. Koch, 1873)
– *Ernobius parens* (Mulsant & Rey 1863)
– *Carphoborus pini* Eichhoff 1881
– *Allophylax picipes* (Olivier 1811)
– *Lygus italicus* Wagner 1950
– *Nysius helveticus* (Herrich-Schäffer 1850)
– *Ortholomus punctipennis* (Herrich-Schäffer 1838)
– *Messor wasmanni* Krausse 1910
– *Tetramorium semilaeve* André 1883

On Karaburun peninsula:
– *Otiorhynchus lugens* (Germar 1817)
– *Pseudomogoplistes squamiger* (Fischer 1853)

Conclusions, prospects for future investigations

Despite the unfavourable summer weather and the relatively limited survey time, the results of this first survey of arthropods and molluscs on the island of Sazani show that, despite the long history of human activity on the island (several millennia) and the major development work carried out in the more

recent past, the fauna appears to be relatively rich.

In the event that more field-trips are planned to complete the survey, the ideal period would be April-May for most arthropod groups.

The abandoned galleries and other subterraneous habitats were not visited in detail, despite their potential interest, due to the inadequacy of the lighting available and the presence of old munitions here and there. However, spiders were observed at the entrances to some of the galleries. An important project would be to study the subterranean fauna in this particular habitat. As the island is limestone, the possibility that the network of diaclases is home to cave dwellers (beetles, arachnids, myriapods, etc.) should be considered.

If new surveys were scheduled during the hottest periods of summer (late June to late August), it would be very interesting to carry out surveys using UV light, as many species of saproxylophagous Coleoptera are crepuscular and are attracted by this type of light. This is the most effective inventory method for this group, as these insects are very difficult to detect using the usual sight-hunting methods, particularly species that live in inaccessible parts of dying trees (pines, for example).

Assuming that staff would be present on the island between April and September, it would also be interesting to install aerial insect traps, either with "polytrap" traps (see for example Brustel 2012), or with less expensive simplified traps (see for example Allemand & Aberlenc 1991). These traps should be checked at least every 15 days. This type of traps, also known as a glass trap or interceptor trap, can operate without bait, but can also be fitted with a bait consisting of beer contained in the receptacle jar. This technique increases the attractiveness of the trap. Its effectiveness is based on the attractiveness of fermented liquids to many species of Coleoptera. As the beetles fly around the trap, they hit the Plexiglas plates and are collected in the receiver jar, which contains the bait with added salt and sugar. To increase trap yields, a tube with a pierced stopper containing sawdust soaked in a 50% mixture of rubbing alcohol and turpentine oil could be added to each trap. The purpose of this additional bait is to attract beetles associated with coniferous species.

Surveys carried out from autumn to spring would make it possible to sample the "leaf litter" fauna. The "leaf litter" is the mixture of dead leaves, twigs and various plant debris that accumulates at the foot of trees and shrubs. Many micro-organisms and invertebrates are found in this habitat and are involved in the fragmentation, degradation and natural transformation of this plant debris into humus. To sample these decomposer invertebrates (including many Coleoptera) living in this very particular environment, it is necessary to use a special entomological sieve, the Winkler sieve. This tool is used to treat accumulations of plant debris by separating the coarse fragments from the fine particles. The latter fall into the receiving bag along with the small insects. Back in the laboratory, this mass of debris is placed on a Berlese apparatus, which automatically extracts the microfauna by desiccation. The small animals pass through the grid and fall into the receiving bottle placed under the funnel.

Finally, it would be highly desirable to develop research on the Karaburun peninsula, where the entomological population quickly surveyed in 2012 appears to be quite different from that of Sazani. A comparison of these two close environments, one insular and the other continental, would certainly be instructive.

Management recommendations

There are currently few conservation problems on the island, at least as far as invertebrates are concerned. The most sensitive point concerns the small beaches of the port. There are at least two remarkable species in this area, the marine earwig *Anisolabis maritima*, and a beetle associated with coastal sands, the tiger beetle *Calomera littoralis*, both represented by reduced populations. Increased visitor numbers would be detrimental to the survival of these species, as would be the cleaning of the seagrass beds, which absolutely must not be eliminated (with the obvious exception of imputrescible waste of human origin: plastics, bottles, polystyrene, etc.) (Boudouresque *et al*. 2017). Not all the beaches were visited, but these comments apply to the entire coastline of the island of Sazani and the Karaburun peninsula. It should also be pointed out that a significant proportion of the arthropod diversity is supported by the ruderal vegetation that has developed around the inhabited areas of the port. This is the case, for example, with

nettles, which feed many Coleoptera, butterfly caterpillars and Heteroptera. Even if many of these species are insects with a fairly wide distribution, we should certainly take them into account and avoid destroying these plant formations. It should also be noted that a fairly rich fauna has been identified under the bark of dead and dying pine trees. A common sense measure would obviously be to leave the felled or standing trees in place (which do not necessarily harbour the same species) (Zuo *et al*. 2021). Finally, as mentioned above, the arthropod fauna associated with cavities and artificial galleries really deserves to be studied (Gueorguiev 1977). In this case, it would be necessary to clean these structures, which still contain a variety of munitions that present a danger of explosion.

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Appendix

Appendix 1 – Check-list of animals observed on Sazani island. See Appendix 2 for identification and reference documents.

CHILOPODA	**Scutigeromorpha**	Scutigeridae	*Scutigera coleoptrata* (Linnaeus 1758)
ARACHNIDA	**Pseudoscorpiones**	Cheliferidae	**Rhacochelifer maculatus* (L. Koch, 1873)
INSECTA	**Coleoptera**	Aderidae	*Aderus populneus* (Creutzer in Panzer 1796)
		Anobiidae	**Ernobius parens* (Mulsant & Rey 1863)
		Anthicidae	*Cyclodinus constrictus* (Curtis 1838)
		Anthicidae	*Hirticomus quadriguttatus* (Rossi 1792)
		Anthribidae	*Noxius curtirostris* (Mulsant & Rey 186)
		Anobiidae	*Ernobius parens* (Mulsant & Rey 1863)
		Buprestidae	*Buprestis cupressi* Germar 1817
		Carabidae	*Calomera littoralis* (Fabricius 1787)
		Carabidae	*Microlestes fissuralis* (Reitter 1901)
		Carabidae	*Pseudoophonus rufipes* (De Geer 1774)
		Carabidae	*Syntomus impressus* (Dejean 1825)
		Cerambycidae	*Exocentrus punctipennis* Mulsant & Guillebeau 1856
		Cerambycidae	*Parmena bicincta* Kuster 1849
		Chrysomelidae	*Cryptocephalus* (*Burlinius*) sp. (♀)
		Chrysomelidae	*Longitarsus albineus* (Foudras 1860)
		Chrysomelidae	*Longitarsus tabidus* (Fabricius 1775)
		Chrysomelidae	*Ochrosis ventralis* (Illiger 1807)
		Ciidae	*Cis chinensis* Lawrence 1991
		Cleridae	*Opilo domesticus* (Sturm 1837)
		Coccinellidae	*Chilocorus bipustulatus* (Linnaeus 1758)
		Coccinellidae	*Coccinella septempunctata* Linnaeus 1758
		Coccinellidae	*Henosepilachna elaterii* (Rossi 1794)
		Curculionidae	*Otiorhynchus armatus* Boheman 1843
		Curculionidae	*Otiorhynchus aurifer* Boheman 1843
		Curculionidae	*Brachytemnus porcatus* (Germar 1824)
		Curculionidae	*Kalcapion semivittatum* (Gyllenhal 1833)
		Curculionidae	*Taeniapion rufulum* (Wencker 1864)
		Dermestidae	*Dermestes undulatus* Brahm 1790
		Elateridae	*Drasterius bimaculatus* (Rossi 1790)
		Salpingidae	*Salpingus planirostris* (Fabricius 1787)
		Scarabaeidae	*Onthophagus furcatus* (Fabricius 1781)
		Scarabaeidae	*Sisyphus schaefferi* (Linnaeus 1758)
		Scolytidae	**Carphoborus pini* Eichhoff 1881
		Scolytidae	*Hypoborus ficus* Erichson 1836
		Staphylinidae	*Paederus littoralis* Gravenhorst 1802
		Tenebrionidae	**Allophylax picipes* (Olivier 1811)
		Tenebrionidae	*Asida fascicularis lineatocollis* Küster 1849
		Tenebrionidae	*Opatrum verrucosum* Germar 1817
		Tenebrionidae	*Pedinus helopioides* Ahrens 1814
		Tenebrionidae	*Stenosis intermedia dalmatina* Reitter 1916
	Heteroptera	Pentatomidae	*Graphosoma semipunctatum* (Fabricius 1775)
		Pentatomidae	*Dolycoris baccarum* (Linnaeus 1758)
		Pentatomidae	*Eysarcoris ventralis* (Westwood 1837)
		Pentatomidae	*Holcostethus sphacelatus* (Fabricius 1794)
		Pentatomidae	*Carpocoris purpureipennis* (De Geer 1773)
		Cydnidae	*Cydnus aterrimus* (Forster 1771)
		Cydnidae	*Geotomus sp.* (♀)
		Miridae	**Lygus italicus* Wagner 1950

	Miridae	*Tuponia (Chlorotuponia)* sp.
	Lygaeidae	*Proderus bellevoyei* Puton 1874
	Lygaeidae	*Spilostethus pandurus* (Scopoli 1763)
	Lygaeidae	**Nysius helveticus* (Herrich-Schäffer 1850)
	Lygaeidae	*Nysius graminicola* (Kolenati 1845)
	Lygaeidae	**Ortholomus punctipennis* (Herrich-Schäffer 1838)
	Lygaeidae	*Aoploscelis bivirgata* (A. Costa 1853)
	Lygaeidae	*Xanthochilus minusculus* (Reuter 1885)
	Lygaeidae	*Hyalochilus dolosus* Horvath 1897
	Lygaeidae	*Orsillus maculatus* (Fieber 1861)
	Nabidae	*Himacerus mirmicoides* (O. Costa 1834)
	Anthocoridae	*Anthocoris nemoralis* (Fabricius 1794)
	Stenocephalidae	*Dicranocephalus medius* (Mulsant & Rey 1870)
	Pyrrhocoridae	*Pyrrhocoris apterus* (Linnaeus 1758)
Orthoptera	Acrididae	*Acrida ungarica* (Herbst 1786)
	Acrididae	*Acrotylus patruelis* (Herrich-Schäffer 1838)
	Acrididae	*Aiolopus strepens* (Latreille 1804)
	Acrididae	*Anacridium aegyptium* (Linnaeus 1764)
	Acrididae	*Calliptamus italicus* (Linnaeus 1758)
	Acrididae	*Locusta migratoria* (Linnaeus 1758)
	Acrididae	*Oedipoda caerulescens* (Linnaeus 1758)
	Acrididae	*Pezotettix giornae* (Rossi 1794)
	Gryllidae	*Oecanthus pellucens* (Scopoli 1763)
	Mogoplistidae	*Arachnocephalus vestitus* Costa 1855
	Tettigoniidae	*Phaneroptera nana* Fieber 1853
	Tettigoniidae	*Tylopsis lilifolia* (Fabricius 1793)
	Tettigoniidae	*Yersinella raymondii* (Yersin 1860)
	Tettigoniidae	*Decticus albifrons* (Fabricius 1775)
	Tettigoniidae	*Eupholidoptera* sp.
Mantodea	Amelidae	*Ameles decolor* (Charpentier 1825)
	Mantidae	*Mantis religiosa* (Linnaeus 1758)
Dermaptera	Anisolabididae	*Anisolabis maritima* (Bonelli 1832)
	Forficulidae	*Forficula decipiens* Gené 1832
Phasmida	Bacillidae	*Bacillus rossius* (Rossius 1790)
Hymenoptera	Formicidae	*Camponotus aethiops* (Latreille 1798)
	Formicidae	*Camponotus lateralis* (Olivier 1791)
	Formicidae	*Crematogaster schmidti* (Mayr 1853)
	Formicidae	**Messor wasmanni* Krausse 1910
	Formicidae	*Pheidole pallidula* (Nylander 1849)
	Formicidae	**Tetramorium semilaeve* André 1883
	Formicidae	*Tetramorium* sp.
	Vespidae	*Polistes* sp.
	Vespidae	*Vespa orientalis* Linnaeus 1771
	Vespidae	*Vespula germanica* (Fabricius 1793)
Lepidoptera	Geometridae	*Orthostixis cribraria* (Hübner 1799)
	Hesperiidae	*Gegenes ?nostrodamus* (Fabricius 1793)
	Lycaenidae	*Celastrina argiolus* (Linnaeus 1758)
	Lycaenidae	*Leptotes pirithous* (Linnaeus 1767)
	Lycaenidae	*Lycaena phlaeas* (Linnaeus 1761)
	Lycaenidae	*Polyommatus icarus* (Rottemburg 1775)
	Noctuidae	*Heliothis peltigera* (Denis & Schiffermüller 1775)
	Nymphalidae	*Aglais io* (Linnaeus 1758)
	Nymphalidae	*Limenitis reducta* Staudinger 1901

		Nymphalidae	*Maniola jurtina* (Linnaeus 1758)
		Nymphalidae	*Polygonia egea* (Cramer, 1775)
		Nymphalidae	*Vanessa atalanta* (Linnaeus 1758)
		Nymphalidae	*Vanessa cardui* (Linnaeus 1758)
		Papilionidae	*Iphiclides podalirius* (Linnaeus 1758)
		Pieridae	*Pieris mannii* (Mayer 1851)
		Sphingidae	*Macroglossum stellatarum* (Linnaeus 1758)
	Odonata	Aeshnidae	*Aeshna* sp.
		Lestidae	*Sympecma fusca* (Van der Linden 1820)
		Libellulidae	*Sympetrum fonscolombii* (Selys 1840)
		Libellulidae	*Sympetrum meridionale* (Selys 1841)
		Libellulidae	*Sympetrum striolatum* (Charpentier 1840)
Malacostraca	**Isopoda**	Armadillidiidae	*Armadillidium pallasii* Brandt 1833
		Porcellionidae	*Porcellio obsoletus* Budde-Lund 1885
		Trachelipodidae	*Trachelipus* cf. *camerani* (Tua 1900)
Gastropoda	**Littorinimorpha**	Clausilidae	*Siciliaria* cf. *stigmatica* (Rossmässler, 1836)
		Diplommatinidae	*Cochlostoma tesselatum* (Rossmässler 1837)
		Hygromiidae	?*Cernuella virgata* (Da Costa, 1778)
		Hygromiidae	*Cochlicella acuta* (Müller, 1774)
		Hygromiidae	*Monacha claustralis* (Rossmässler, 1834)
		Pomatiidae	*Pomatias elegans* (Müller, 1774)

* Species new for Albania.

Appendix 2 – Identification and reference documents

There are few taxonomic works devoted specifically to the fauna of Albania, so it was necessary to consult more general works in order to identify the animals observed.

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Résumés de thèses

Karolina ARGOTE **2025**

Réponses des microarthropodes à la fragmentation de l'habitat : expériences en laboratoire dans des paysages artificiels

Microarthropod Responses to Habitat Fragmentation: Laboratory Experiments in Artificial Landscapes

Thèse de doctorat, Aix-Marseille Université, soutenue le 18 mars 2025.

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Mots-clés : configuration de l'habitat, résistance de la matrice, accessibilité de l'habitat, *Folsomia candida*, fragmentation, connectivité.

Keywords: habitat configuration, matrix resistance, habitat reachability, *Folsomia candida*, fragmentation, connectivity.

Cette thèse de doctorat étudie comment la fragmentation de l'habitat influence la persistance des populations du collembole *Folsomia candida* à travers une approche expérimentale utilisant des mini-paysages artificiels suivis en laboratoire.

Dans un premier temps, nous analysons comment la qualité des ressources et la distance entre les patches d'habitat influencent le comportement de recherche de nourriture et la démographie de *F. candida*, posant les bases de la compréhension des dynamiques de population à l'échelle du paysage. Ensuite, nous examinons comment différentes configurations d'habitat et qualités de la matrice affectent la survie et les déplacements des collemboles. Les résultats montrent que la quantité d'habitat accessible, comprenant la distance entre les habitats et la résistance de la matrice, est un bon prédicteur de la taille de la population et du risque d'extinction. La survie lors des déplacements à travers la matrice s'est révélée être un mécanisme clé, influençant les taux de colonisation et la stabilité démographique tout en limitant l'accès aux patches distants.

Nous évaluons ensuite l'efficacité des éléments de connectivité, tels que les corridors et les pas japonais (« *stepping stones* »), pour promouvoir la dispersion et la persistance des populations dans des matrices à forte résistance. Nous avons constaté que les matrices hostiles amplifient les risques liés à la dispersion, créant un compromis entre colonisation et taille de population. Bien que la connectivité facilite globalement la colonisation et augmente la reproduction dans les nouveaux patches, son efficacité dépend de la distance entre ces patches. En particulier, l'augmentation de la dispersion entraîne également une mortalité plus élevée, conduisant à des populations globalement plus petites dans les paysages connectés que dans les paysages non connectés.

Dans l'ensemble, cette thèse met en évidence la nécessité d'intégrer explicitement la résistance de la matrice paysagère dans les stratégies de conservation et les effets des éléments paysagers sur les dynamiques des populations. En quantifiant expérimentalement les effets combinés de la résistance de la matrice et de la configuration de l'habitat, ce travail insiste sur l'importance d'intégrer ces facteurs dans les modèles de connectivité et la planification de la conservation, offrant des solutions pratiques pour gérer et aménager les paysages fragmentés et restaurer les connectivités écologiques.

This PhD thesis investigates how habitat fragmentation shapes the persistence of *Folsomia candida* populations through an experimental approach using controlled artificial mini-landscapes in the laboratory.

First, we explore how resource quality and distance influence the foraging behavior and demographics of *F. candida*, setting the stage for understanding landscape-scale processes. Next, we examine how different habitat configurations and matrix qualities affect survival and movement. The results show that the amount of reachable habitat, encompassing both the quantity of habitat and matrix resistance, is a good predictor of population size and extinction risk. Survival within matrices emerged as a pivotal mechanism, driving colonization rates and demographic stability while limiting access to remote patches.

We then assess the effectiveness of connectivity elements, such as corridors and stepping stones, in promoting dispersal success and population persistence in high-resistance matrices. We found that hostile matrices amplified dispersal risks, creating a trade-off between colonization success and total population size. While connectivity facilitated colonization and increased reproduction in new patches, its effectiveness is distance-dependent. Nevertheless, increased dispersal also led to higher mortality, resulting in smaller overall populations in connected landscapes.

Overall, this research highlights the need to explicitly account for matrix resistance in conservation strategies. By experimentally quantifying the combined effects of matrix resistance and habitat configuration, it underscores the importance of incorporating these factors into connectivity models and conservation planning, providing actionable insights for managing fragmented landscapes in a changing world.

Emile MELLOUL **2025**

Effets de l'irrigation sur la biodiversité dans les écosystèmes viticoles méditerranéens

Effects of irrigation on biodiversity in Mediterranean vineyards

Thèse de doctorat, Avignon Université, soutenue le 7 avril 2025.

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Mots-clés : irrigation, vigne, végétation, arthropodes, mésofaune, micro-organismes, région méditerranéenne.

Keywords: irrigation, vineyard, vegetation, arthropods, mesofauna, microorganisms, Mediterranean region.

L'irrigation est une pratique courante en agriculture, permettant notamment d'améliorer les rendements agricoles. C'est également l'une des principales réponses des agriculteurs aux changements climatiques, qui devraient entraîner une modification des régimes de précipitations et une augmentation des températures. Ces changements seront particulièrement prononcés dans la région méditerranéenne, où des températures plus élevées, ainsi que des sécheresses plus fréquentes et plus intenses, sont attendues.

Dans les vignobles, l'irrigation est en plein essor. Elle est utilisée pour stabiliser la production et réguler le taux de sucre dans le vin. Son utilisation se fait principalement par goutte-à-goutte durant les périodes de sécheresse, afin de simuler les effets des orages d'été. Bien que bénéfique pour la production dans un contexte de stress hydrique, l'augmentation de l'humidité pourrait affecter la biodiversité de l'agroécosystème en modifiant sa composition, sa structure et ses réseaux d'interactions. Cela pourrait affecter des fonctions écologiques clés et se répercuter sur les cultures. Il est donc primordial de mieux comprendre les effets et les processus liés à l'irrigation, qui devient de plus en plus fréquente et intense.

C'est dans ce contexte que s'inscrivent mes travaux de thèse, qui visent à mieux comprendre les effets de l'irrigation sur la biodiversité dans les agroécosystèmes viticoles méditerranéens. Cette réflexion a conduit à trois grandes questions de recherche : (1) Quels effets l'irrigation a-t-elle sur la végétation et les arthropodes épigés dans les inter-rangs de vigne ? (2) Quels effets l'irrigation a-t-elle sur la végétation et les organismes du sol à court et moyen termes sous le rang de vigne ? (3) Comment les effets de l'irrigation évoluent-ils à court terme pendant la période estivale ?

Dans le premier axe (1), nous avons montré une réduction du recouvrement floral dans les vignobles irrigués, sans toutefois observer de différence en matière de richesse spécifique. L'abondance de plusieurs arthropodes bénéfiques a été directement affectée par l'irrigation. Ces effets directs étaient amplifiés par l'impact négatif de l'irrigation sur le recouvrement floral. Les taux de prédation étaient également plus faibles dans les vignobles irrigués, mais seulement pendant la journée. Dans le second axe (2), aucun effet clair de l'irrigation n'a été observé sur la végétation sous le rang de vigne. En revanche, une augmentation de la faune du sol a été notée pendant la période estivale, au moment de l'irrigation, avec une hausse des populations d'acariens prédateurs et une modification de la structure des communautés d'acariens et de collemboles. L'irrigation semble atténuer les effets de la sécheresse, qui affectent négativement les collemboles et acariens. Les collemboles, plus sensibles à la sécheresse, étaient absents des relevés effectués en août. Dans le troisième axe (3), l'apport d'eau dans les vignes pendant la période de sécheresse a montré un effet de « *priming* » sur les bactéries, sans toutefois modifier la composition de la communauté microbienne. De plus, nous avons observé une augmentation des abondances de collemboles et d'acariens, ainsi qu'une hausse de l'activité biologique du sol. Les organismes plus résistants à la sécheresse n'ont pas été affectés par l'irrigation. Les effets de l'irrigation ont disparu après seulement quelques jours. Toutefois, à long terme, un appauvrissement potentiel en matière organique du sol, dû à des pics d'activité lors des cycles de réhumidification, pourrait s'observer.

L'ensemble de ces résultats souligne l'importance d'étudier les effets de l'irrigation et leur temporalité, dans un contexte où son utilisation tend à devenir la norme. Cette thèse ouvre de nouvelles perspectives sur les effets potentiels de l'irrigation, notamment au niveau des traits fonctionnels des organismes et de la composition spécifique des communautés.

Irrigation is a common practice in agriculture, helping to improve crop yields. It is also one of the main ways in which farmers are responding to climate change, which is expected to lead to changes in rainfall patterns and higher temperatures. These changes will be particularly pronounced in the Mediterranean region, where higher temperatures and more frequent and intense droughts are expected.

Irrigation is growing rapidly in the vineyards. It is used to stabilize production and regulate sugar levels in the wine. It is mainly used as a drip irrigation system during periods of drought, to simulate the effects of summer thunderstorms. Although beneficial for production in a context of water stress, increased humidity could affect the biodiversity of the agroecosystem by modifying its composition, structure and interaction networks. This could affect key ecological functions, with repercussions for crops. It is therefore vital to gain a better understanding of the effects and processes associated with irrigation, which is becoming increasingly frequent and intense.

My work aims to gain a better understanding of the effects of irrigation on biodiversity in Mediterranean wine-growing agroecosystems. This has led to three main research questions: (1) What are the effects of irrigation on vegetation and epigeous arthropods in vine inter-rows? (2) What are the effects of irrigation on vegetation and soil organisms in the short and medium term under the vine row? (3) How do the effects of irrigation evolve in the short term during the summer period?

In the first axis (1), we showed a reduction in floral cover in the irrigated vineyards, without however observing any difference in terms of species richness. The abundance of several beneficial arthropods was directly affected by irrigation. These direct effects were amplified by the negative impact of irrigation on floral cover. Predation rates were also lower in irrigated vineyards, but only during the day. In the second axis (2), no clear effect of irrigation was observed on the vegetation under the vine row. However, an increase in soil fauna was noted during the summer period, at the time of irrigation, with an increase in predatory mite populations and a change in the structure of mite and springtail communities. Irrigation appears to mitigate the effects of drought, which have a negative impact on springtails and mites. Springtails, which are more sensitive to drought, were absent from the surveys carried out in August. In the third axis (3), the addition of water to the vines during the drought period had a priming effect on the bacteria, but did not alter the composition of the microbial community. In addition, we observed an increase in the abundance of springtails and mites, as well as an increase in biological activity in the soil. The more drought-resistant organisms were not affected by the irrigation. The effects of irrigation disappeared after just a few days. However, in the long term, a potential depletion in soil organic matter, due to peaks in activity during rewetting cycles, could be observed.

All these results highlight the importance of studying the effects of irrigation and their temporality, in a context where its use is tending to become the norm. This thesis opens up new perspectives on the potential effects of irrigation, particularly in terms of the functional traits of organisms and the specific composition of communities.

Pauline LONGEARD **2025**

Influence des brûlages dirigés sur la qualité et la décomposition de la litière et la structure des communautés d'organismes en forêt de Pinus laricio

Influence of prescribed burning on litter quality, decomposition and community structure in *Pinus laricio* forests

Thèse de doctorat, Université de Corse Pascal Paoli, soutenue le 28 mars 2025.

Jury – Catherine Fernandez (professeur, Aix-Marseille Université), rapporteure ; Alain Roques (directeur de recherche émérite, INRAE, Orléans), rapporteur ; Apolline Auclerc (maître de conférences, Université de Lorraine, ENSAIA, Vandœuvre-lès-Nancy), examinatrice ; Virginie Tihay (maître de conférences HDR, Université de Corse), examinatrice ; Lila Ferrat (maître de conférences HDR, Université de Corse), directrice de thèse ; Marie-Cécile Andrei-Ruiz (docteure, Office de l'environnement Corse), co-directrice de thèse, membre invitée ; Christophe Panaïotis (docteur, Office de l'environnement Corse), membre invité.

Mots-clés : *Pinus laricio*, brûlage dirigé, rémanents, arthropodes, décomposition, botanique.

Keywords: *Pinus laricio*, prescribed burning, residues, arthropods, decomposition, botany.

L'objectif de ce travail de thèse, à travers une étude multidisciplinaire, était de déterminer les effets des techniques de prévention incendie comme les brûlages dirigés de sous-bois et les traitements de coupe (élagage/éclaircie) sur la litière ainsi que sur la structure des communautés d'organismes en forêt de *Pinus laricio*. Une expérimentation au col

de Bavella, en Corse, a été menée sur quatre parcelles soumises à différents traitements : témoin, brûlage seul, coupe seule et combinaison des deux, qui ont été suivies pendant deux ans et quatre mois. Les coupes ont réduit la densité de la canopée de 20 % et élevé le houppier à 2 m, interrompant la continuité verticale, mais ont accumulé des rémanents en sous-bois, qui posent question pour le risque incendie. Le brûlage dirigé a éliminé jusqu'à 54 % des combustibles fins, réduisant la biomasse au sol. Dans l'horizon A, aucune augmentation de température n'a été mesurée, malgré des températures de 911 °C en surface. Les rémanents n'ont pas entraîné d'intensification du brûlage, mais des temps de résidence plus longs ont été observés. Une légère diminution des teneurs en minéraux est observée après coupe, sans effet notable sur la qualité chimique du sol après brûlage. La diversité végétale s'est affaiblie sur les parcelles traitées, avec un effet plus marqué pour la combinaison des deux traitements, entraînant l'expansion de *Brachypodium pinnatum* au détriment d'espèces comme *Cyclamen repandum*. 42 565 arthropodes ont été échantillonnés entre février 2020 et juin 2021 dans les pièges pitfall. La coupe n'a pas entraîné de modification immédiate de l'abondance des arthropodes, mais des variations ponctuelles (– 88 % d'acariens, – 42 % de collemboles). Le brûlage de faible intensité a entraîné la création d'une mosaïque de zones brûlées et non brûlées, et a limité les transferts de chaleur vers le sol. Associé à l'activité réduite des arthropodes à l'automne, cela à permis de limiter les effets du brûlage sur ces communautés. La combinaison du brûlage et de la coupe a favorisé l'abondance de certains groupes, comme les acariens, au début de l'été suivant le brûlage. Ces résultats suggèrent des interactions complexes entre les paramètres biotiques et abiotiques du sol en forêt de pin laricio.

Influence of prescribed burning on litter quality, decomposition and community structure in *Pinus laricio* forests. The aim of this PhD work, through a multidisciplinary study, was to determine the effects of fire prevention techniques such as prescribed burning of undergrowth and cutting treatments (pruning/thinning) on litter as well as on the structure of communities of organisms in *Pinus laricio* forests. An experiment at Col de Bavella, Corsica, was carried out on four plots subjected to different treatments: control, burning only, cutting only and a combination of the two, which were monitored for two years and four months. Cutting reduced canopy density by 20% and raised the crown to 2m, interrupting vertical continuity, but accumulated residues in the undergrowth, which raises questions in terms of fire risk. Prescribed burning eliminated up to 54% of fine fuels, reducing the biomass on the ground. In the A horizon, no increase in temperature was measured, despite temperatures of 911°C at the surface. Residues did not lead to increased burning, but longer residence times were observed. A slight reduction in mineral content was observed after cutting, with no significant effect on the chemical quality of the soil after burning. Plant diversity was reduced on the treated plots, with a more marked effect for the combination of the two treatments, leading to the expansion of *Brachypodium pinnatum* to the detriment of species such as *Cyclamen repandum*. 42 565 arthropods were sampled between February 2020 and June 2021 in pitfall traps. Residues did not result in any immediate change in arthropod abundance, but there were occasional variations (–88% mites, –42% springtails). The low-intensity burning created a mosaic of burnt and unburnt areas, and limited heat transfer to the soil. Combined with the reduced activity of arthropods in the autumn, this limited the effects of burning on these communities. The combination of burning and cutting favoured the abundance of certain groups, such as mites, at the beginning of the summer following the burning. These results suggest complex interactions between biotic and abiotic soil parameters in *Pinus laricio* forests.

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