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THE LEAFHOPPERS OF THE RÉSERVE NATURELLE DE LA MASSANE - A CASE STUDY ON DIVERSITY, GRAZING MANAGEMENT AND THREATS IN A MEDITERRANEAN MOUNTAIN ECOSYSTEM

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ABSTRACT.- Semi-natural grasslands are threatened throughout Europe and conservation measures as well as monitoring are urgently needed. Leafhoppers (Auchenorrhyncha), a functionally important taxon with a close host plant connection and rapid reaction to changes in management, have increasingly received attention as bioindicators. We here present a case study in a Mediterranean mountain ecosystem, the Réserve Naturelle Nationale de la Forêt de la Massane, aiming to compile an inventory of its leafhopper species and to study the effects of cattle grazing on Mediterranean leafhopper communities. Leafhoppers were sampled in 2022 on 21 transects covering all of the habitats present in the reserve. A direct comparison was made between intensively grazed pastures and rocky outcrops inaccessible to cattle (12 and 4 transects respectively).The inventory increased the number of leafhopper species known in the reserve from 72 to 129. Species richness and abundance were significantly higher in the ungrazed areas. Grazed and ungrazed transects differed in their species composition with rare and in part endemic species only occurring on the ungrazed rocky outcrops. We conclude that a reduction of the grazing intensity in combination with shrub removal measures to keep the pastures open would have a positive effect of the leafhoppers and other invertebrates in the reserve and the surrounding Massif des Albères, where grazing pressure is similarly high.

INTRODUCTION

Semi-natural, extensively used meadows and pastures have been developed through human land use over millennia (Hejcman *et al.* 2013). They belong to the most diverse open habitats in Europe, both floristically (Ellenberg & Leuschner 2010) and in terms of their arthropod diversity (Poschlod & WallisDeVries 2002, Malenovský *et al.* 2011). Their diversity is threatened by both agricultural intensification and abandonment of traditional land use practices like extensive grazing and mowing (Strijker 2005, Janssen *et al.* 2016), often also leading to changes in species composition (Wesche *et al.* 2012, Schuch *et al.* 2012). For the successful conservation of grassland habitats across Europe, their appropriate management and restoration are crucial and in order to evaluate whether the chosen strategies are successful, monitoring in both the short and long term is necessary (Goldsmith 2012).

Historically, only a few groups of organisms have been routinely used as bioindicators. Assessments are thus often based on plants and birds (Kamp *et al.* 2021) while insects and other invertebrates have largely been neglected (van Swaay *et al.* 2002). An exception are butterflies and grasshoppers, which are both highly mobile groups and often only present in small numbers of species and individuals (e.g. Fartmann *et al.* 2012, Krämer *et al.* 2012).

More recently, other taxa have received more attention, notably leafhoppers (Auchenorrhyncha), a diverse and abundant group of insects - a suborder of the Hemiptera - found in all terrestrial environments (Bartlett *et al.* 2018). Many species predominantly occur in grassland habitats (Biedermann *et al.* 2005) but also on trees and shrubs (Nickel 2003), and densities can exceed 1000 individuals per m^2 (Nickel & Hildebrandt 2003). Leafhoppers have a high functional importance, feeding on plant sap with an often very close host plant dependency (Nickel 2003). They are an important prey group for birds, spiders and other predators and host a diverse community of parasitoids (Waloff 198, Biedermann *et al.* 2005).

Many species, particularly those with short wings (brachypterous species), have limited mobility, often spending their entire lives on the same host plant, i.e. they have very small-scale site fidelity (Nickel 2003, Biedermann *et al.* 2005). This makes them very good indicators of their preferred habitat type and its management (Hamilton 2005, Nickel & Achtziger 2005, Wallner *et al.* 2012), such as the grazing or mowing regime (Kruess & Tscharntke 2002, Kőrösi *et al.* 2012). Many species depend on extensive management and low nutrient levels and are thus threatened by agricultural intensification. This is why 35.6 % of species in Germany, for example, are presently found on the Red List (Nickel *et al.* 2016).

In addition, leafhopper sampling can easily be standardised so that communities can be compared between different sites and habitats (Biedermann *et al.* 2005) and years (Hollier *et al.* 2005). Good identification guides exist, especially for Central Europe (Holzinger *et al.* 2003, Biedermann & Niedringhaus 2004, Kunz *et al.* 2011, Stöckmann *et al.* 2013) but also for France (Ribaut 1936, 1952, Della Giustina 1989, 2019).

While in Central Europe leafhoppers are well studied and increasingly used as indicator organisms for biodiversity monitoring, in Mediterranean environments, they have received little attention and their diversity, ecology and distribution are still largely unexplored (but see e.g. Primi *et al.* 2016). This case study thus aims to increase the knowledge about leafhopper diversity and ecology in Mediterranean ecosystems, specifically the Réserve Naturelle Nationale de la Forêt de la Massane (hereafter called "Réserve de la Massane"), a nature reserve in the heart of the Massif des Albères in the French département Pyrénées-Orientales. While the largest part of the reserve is covered by ancient beech and oak forests, open grassland areas that have been used for grazing livestock since the Neolithic are found on the mountain ridges. Grazing with cattle has become increasingly unregulated over the last decades, leading to a high grazing pressure which is exacerbated by shrub encroachment that is progressively reducing the open, once extensive pasture areas (Bentou 2009). Climate change further reduces forage availability and thus increases grazing pressure through altered precipitation patterns and heatwaves.

The study has two main objectives: (1) to establish a comprehensive inventory of the leafhopper species that occur in the reserve and (2) to study the effects of cattle grazing on its leafhopper communities.

We thus compare intensively grazed pastures with ungrazed rocky outcrops in terms of their leafhopper species richness, abundance and community composition. Specifically, we hypothesise that species richness and abundance are higher in ungrazed areas and that the community composition of the different habitats is shaped by the effects of grazing that blur the influence of other environmental variables like altitude.

MATERIALS AND METHODS

Study area

The study was conducted in the Réserve Naturelle Nationale de la Forêt de la Massane in the département Pyrénées-Orientales in the South of France at the border to Catalonia in Spain (Fig. 1). It is located at the foot of the Pyrenees in the Massif des Albères (42°28′41″N, 3°01′26″E). The reserve has an area of 336 ha, surrounding the upper reaches of the river Massane and stretching in a triangle between the Col de la Place d'Armes (667 m a.s.l.) just below the Tour de la Massane (793 m a.s.l.), the Pic de Sallfort (981 m a.s.l.) and the Pic des Quatre Termes (1158 m a.s.l.).

Study design

Leafhoppers (Hemiptera: Auchenorrhyncha) were sampled on 21 transects of approx. 50 m length distributed over the entire reserve in order to cover as many of the habitat types present in the reserve as possible (Fig. 1, Table I). The majority of transects (12) were located on grazed grasslands in different parts of the reserve, four were placed on rocky outcrops that were inaccessible to cattle (Fig. 2). The vegetation of the transects on grazed grasslands was intensively grazed throughout the growing season (May-October) and thus low and sparse (approx. 5 cm, Fig. 2A), while on the rocky outcrops it was higher and denser (up to approx. 30 cm) with tussocks of grasses (Fig. 2B+C). The remaining five transects were placed in heathland areas, the understorey of the beech forest, in a small wetland and in the riparian forest of the river Massane. Non-standardised sampling in other parts of the reserve in the summers 2022 and 2023 was aimed at capturing additional leafhopper species to complete the inventory.

Code	Habitat type	Name of place	Altitude (m a.s.l.)	lat	lon
T17	Rocky outcrops	Col de la Massane	1060	42.469536	3.004157
T19	Rocky outcrops	Tour de la Massane	793	42.498344	3.027132
T20	Rocky outcrops	Pic Sallfort	960	42.473702	3.038968
T21	Rocky outcrops	Col de la Massane	1080	42.471059	3.002773
T3	Heathland	Station météo	670	42.490155	3.029615
T9	Degraded heathland	Serrat del Pi	860	42.478320	3.027738
T1	Beech forest	Réserve intégrale	660	42.492753	3.032450
T10	Pasture	Col del Pal	900	42.475576	3.030183
T12	Pasture	Col del Pal	920	42.474300	3.033605
T13	Pasture	Pic Sallfort	960	42.473968	3.039882
T14	Pasture	Refuge Tomy	900	42.478811	3.039549
T15	Pasture	Pic des Quatre Termes	1158	42.473698	2.997639
T16	Pasture	Source de la Massane	1000	42.472638	3.002996
T18	Pasture	Tour de la Massane	793	42.498480	3.026396
T4	Pasture	Col del Fondo	740	42.487583	3.026394
T5	Pasture	Col del Fondo	780	42.484056	3.025580
T6	Pasture	Barraques de les Colomates	800	42.480931	3.027221
T7	Pasture	Barraques de les Colomates	800	42.480833	3.026280
T8	Pasture	Termanera	880	42.478399	3.017080
T2	Riparian forest, pasture	Refuge de la Réserve	660	42.490231	3.028999
T11	Wetland	Col del Pal	900	42.475711	3.030832

Table I.- Overview over the sampled transects: Habitat type, name of place, altitude (m a.s.l.) and location (lat/lon).

Sampling

Each transect was sampled once a month in May, June, July and September 2022. Two main sampling methods were used: suction sampling with a modified leaf blower (Stihl SH 56, Waiblingen, Germany) and with a sweep net. In order to standardise sampling, the suction sampler was placed on the vegetation 50 times for 2 s on each transect, at a distance of approx. 1 m. The tube of the suction sampler had a diameter of 11.5 cm, i.e. in total a surface of 0.5 m^2 per transect was sampled. The sweep net captures were carried out in a non-standardised manner in order to record as many of the leafhopper species present in the reserve as possible. To complete the list, trees, shrubs and other vegetation structures were sampled with the sweep net, a Japanese umbrella or a mouth aspirator. Several nocturnal light-capture sessions helped to record arboreal species that are otherwise difficult to catch. Sorting of the catches was done directly in the field in order to immediately release all the species that were not leafhoppers. The captured specimens were preserved in ethanol (96 % vol.) in individual tubes for each transect and passage.

Species identification

The specimens we caught were identified to species level with the help of Ribaut (1936, 1952), Della Giustina (1983, 1989, 2019), Della Giustina & Remane (2001), Holzinger *et al.* (2003), Biedermann & Niedringhaus (2004), Kunz *et al.* (2011) and Gnezdilov *et al.* (2014). If possible, nymphs were determined as well (Stöckmann *et al.* 2013). However, most nymphs of the subfamilies Deltocephalinae (1036 individuals) and Delphacinae (402 ind.) could not be identified. For doubtful or difficult cases specialists were consulted. Some specimens of the genus *Psammotettix* (7 ind.), which requires fundamental revision, could not be determined to species level. The same applies to species in which only females were captured, but for which identification to species level requires males. However, they also represent only a small percentage of the individuals caught.

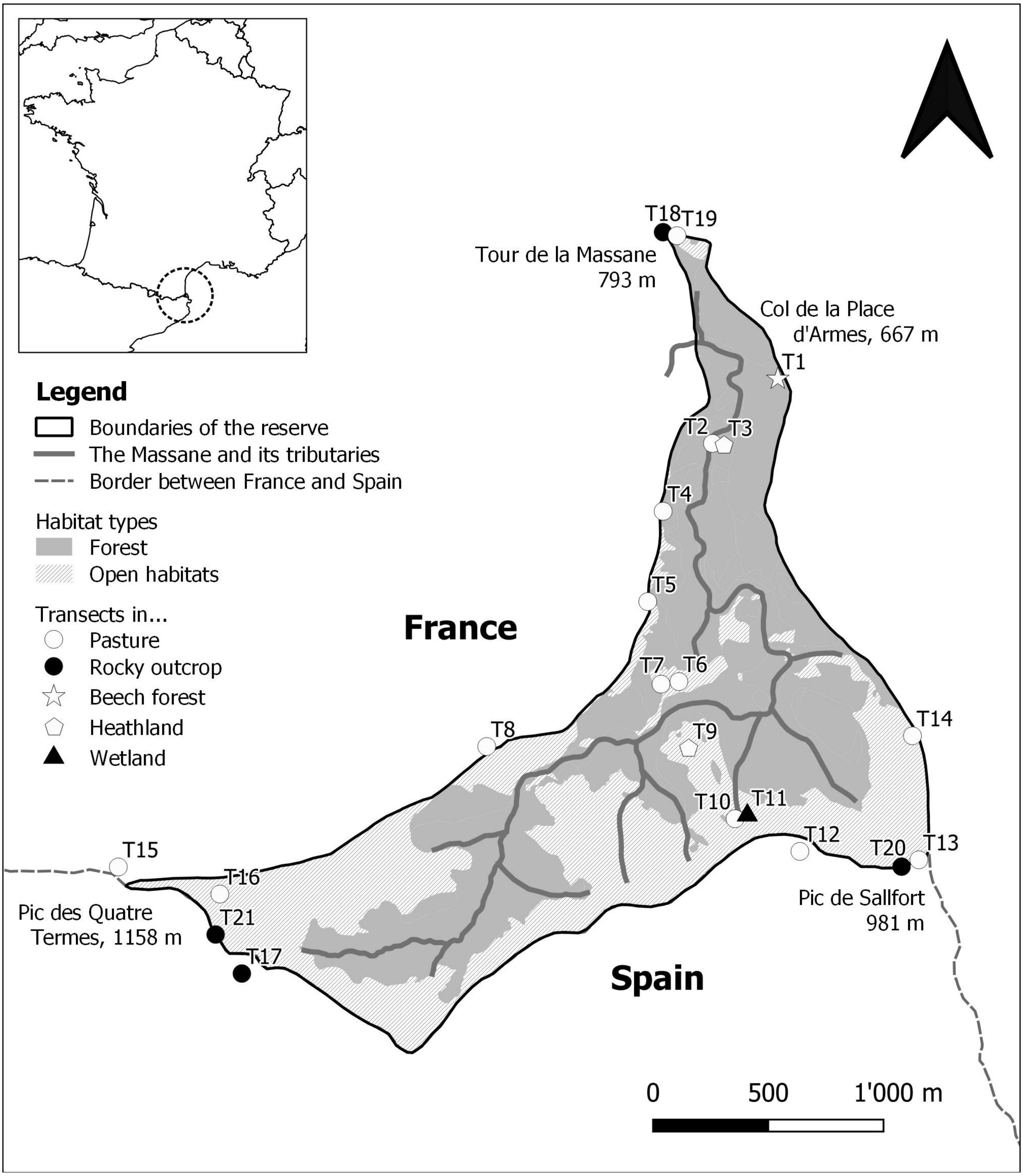

Fig. 1.- Localisation of the 21 transects in the Réserve Naturelle Nationale de la Forêt de la Massane.

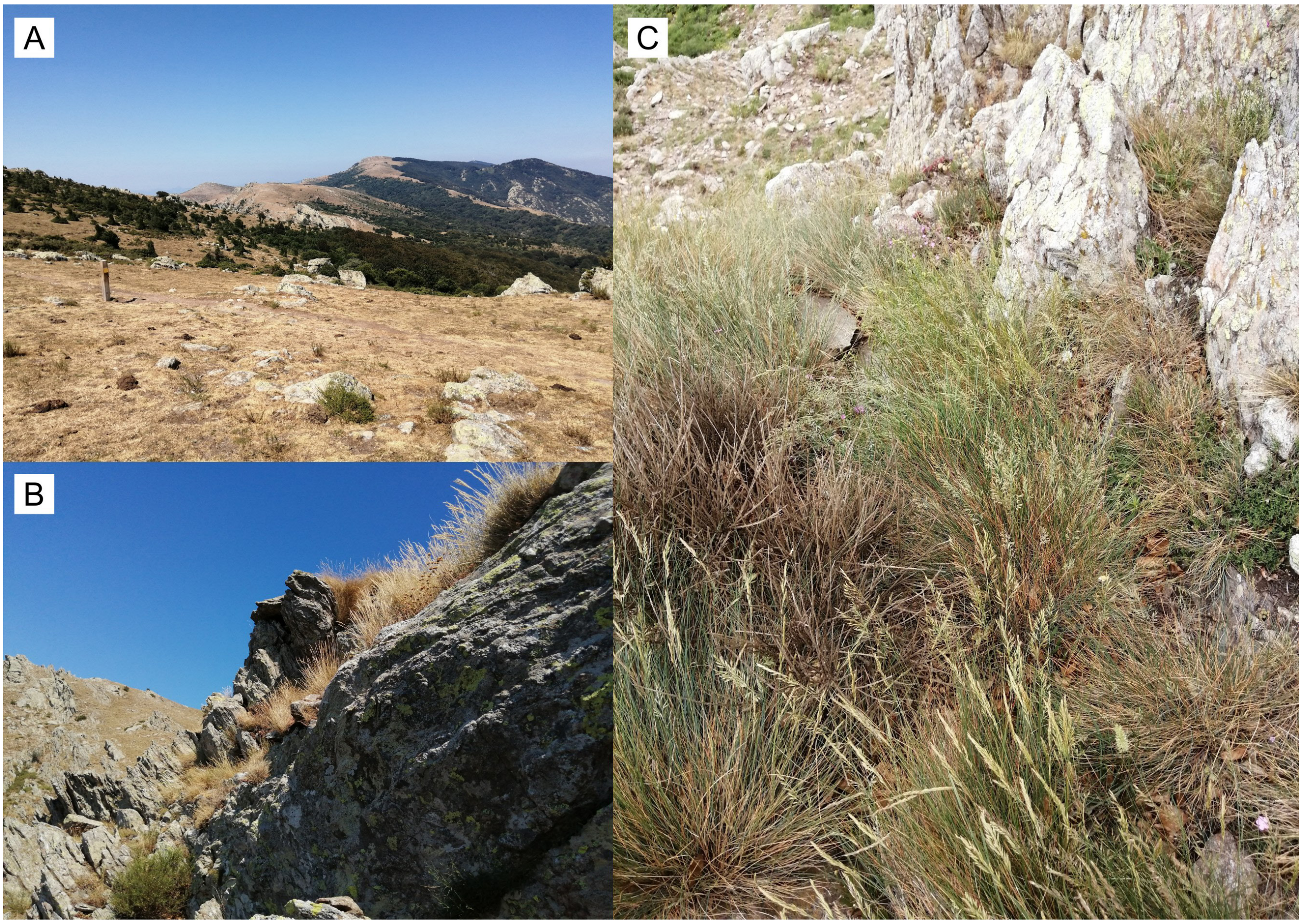

Fig. 2.- A, View over the intensively grazed mountain ridges of the Réserve de la Massane from the Pic de Sallfort towards the Pic des Quatre Termes (July 2022). B, Rocky outcrop at the Pic de Sallfort with tussocks of *Festuca ovina* agg. (July 2022), C, Close-up of tussocks of *Festuca ovina* agg. (June 2022).

Data from 2009-2014

There is list of leafhoppers in the reserve which is mainly based on captures from Malaise traps and pan traps between 2009 and 2014, with no mention of the number of specimens per species. It contains 86 species, some of which are doubtful or misidentified. It also contains a number of duplicates due to nomenclatural synonyms and species identified only up to genus level. All of the doubtful species were removed from the list.

Statistical analyses

Only the standardised suction samples pooled over the four sampling dates were included in the statistical analyses. We analysed the differences in number of species and individuals as well as differences in community composition between transects on grazed grassland (n = 12) and rocky outcrops inaccessible to cattle (n = 4). In order to analyse the influence of habitat type (grazed grasslands vs. rocky outcrops) on species richness and the number of individuals per transect, we fitted generalised linear models (R package MASS, Venables & Ripley 2002) with habitat type as explanatory variable. For the analysis of species richness, a model with Poisson errors was used, for the analysis of the number of individuals we used a model with negative binomial errors.

To analyse differences in the composition of leafhopper communities between grazed grassland and rocky outcrops, Nonmetric Multidimensional Scaling, a nonmetric ordination method, was used to position each transect according to its similarity score (of racemes) with the other transects (function 'metaMDS', package 'vegan', Oksanen *et al.* (2013)). The similarity measure is based on the Bray-Curtis dissimilarity index calculated from presence/absence matrices for each species found on the transects. The relative position of each species and the direction of any significant environmental forcing (in this case habitat type and altitude) are added to the ordination diagram using the function 'envfit', package 'vegan', Oksanen *et al.* (2013) which determines the magnitude and direction of the correlations between the similarity of the communities and the environmental variables added to the model. All statistical analyses were carried out using R version 4.3.1 (R Core Team 2023).

RESULTS

Species diversity

During the survey in 2022/23 we recorded more than 4074 specimens (including approx. 2152 nymphs) comprising 105 species (Table I, Table II). Combined with the list from 2009-2014 which, after removing doubtful, misidentified or synonymous species, contains 72 species, the number of species recorded in the reserve amounts to 129. This number represents 15.2 % of the approximately 850 species currently known from France (Della Giustina & Remane 2001).

Most of the species recorded (76) in the reserve live in the herbaceous vegetation of the grazed grasslands, the rocky outcrops, the small wetland area, heathlands and in the undergrowth of forested areas (Table II). Eleven species are vertical migrants, i.e. they live in the herbaceous vegetation as nymphs while the adults move to the canopy of shrubs and trees. The arboreal community comprises 42 species.

We found significantly more species and individuals on the ungrazed rocky outcrops compared to the grazed grassland areas. On average, taking into account only the standardised suction samples, 11.8 ± 2.0 species per transect were found on the rocky outcrops, compared to 6.2 ± 0.9 species in the grazed areas (Fig. 3A, Table III). This difference is even more marked if the number of individuals is considered: 370.5 ± 137.1 adult and juvenile individuals were present in the ungrazed rocky outcrops compared with 49.5 ± 8.3 individuals in the grazed areas (Fig. 3B, Table III).

Community composition

The grazed grasslands differed markedly from the ungrazed rocky outcrops in terms of species composition (‘nMDS’ GOF = 0.16, R2 = 0.36, P < 0.001, Fig. 4). In addition, altitude was identified as an environmental variable with a significant effect on species composition (‘envfit’, R2 = 0.53, P = 0.011). It was thus represented as a vector in the ordination diagram.

Taxon	2009	2022/23	Total	Vegetation layer	Host plants	Habitat types
AUCHENORRHYNCHA						
FULGOROMORPHA						
Cixiidae						
Cixius cunicularius (Linnaeus, 1767)	x		x	Tree layer	deciduous trees	BF
Cixius simplex (Herrich-Schäffer, 1835)	x		x	Tree layer	deciduous trees	RF
Hyalesthes obsoletus (Signoret, 1865)	x	1	x	Herb layer	polyphagous	GG
Hyalesthes scotti (Ferrari, 1882)	x		x	Tree layer	?	MF
*Nanocixius discrepan*s (Fieber, 1876)		2	x	Tree layer	*Erica arborea*	HL
Tachycixius distinctus (Signoret, 1865)		1	x	Tree layer	?	GG
Delphacidae						
Delphacinae						
Conomelus anceps (Germar, 1821)		172	x	Herb layer	*Juncus* spp.	WL
Ditropis pteridis (Spinola, 1839)		31	x	Herb layer	*Pteridium aquilinum*	GG
Eurysa lineata (Perris, 1857)		4	x	Herb layer	Poaceae	GG
Eurysanaea pyrenaea (Fieber, 1866)		98	x	Herb layer	*Festuca ovina* agg. (?), V. Rösch, unpubl. data	RO, BF, HL
Florodelphax leptosoma (Flor, 1861)		30	x	Herb layer	*Juncus* spp.	WL
Javesella dubia (Kirschbaum, 1868)		7	x	Herb layer	Poaceae (also Cyperaceae and Juncaceae)	WL
Laodelphax striatellus (Fallen, 1826)		9	x	Herb layer	Poaceae	GG
Muellerianella cf. fairmairei (Perris, 1857)		5	x	Herb layer	*Holcus lanatus*, *H. mollis*	RF
Toya propinqua (Fieber, 1866)		1	x	Herb layer	*Cynodon dactylon*	GG
Caliscelidae						
Peltonotellus sp. sp. n.		18	x	Herb layer	*Festuca ovina* agg. (?), V. Rösch, unpubl. data	RO
Issidae						
Hysteropterum vasconicum (Gnezdilov 2003)		8	x	Herb layer	?	RO
Issus coleoptratus (Fabricius, 1781)	x	4	x	Vertical migrant	polyphagous, nymphs: in the herb layer, adults: tree layer	RF, MF
Mulsantereum maculifrons (Mulsant & Rey, 1855)		1		Tree layer	trees and shrubs	
Tettigometridae						
Tettigometra impressifrons (Mulsant & Rey, 1855)		1	x	Herb layer	Asteraceae	GG
Tettigometra sulphurea (Mulsant & Rey, 1855)		5	x	Herb layer	Asteraceae	GG
Tettigometra virescens (Panzer, 1799)		3	x	Herb layer	Asteraceae	GG
CICADOMORPHA						
Cercopidae						
Cercopis sanguinolenta (Scopoli, 1763)	x	11	x	Herb layer	polyphagous	GG, RO
Cercopis vulnerata (Rossi, 1807)	x		x	Herb layer	polyphagous	GG

Taxon	2009	2022/23	Total	Vegetation layer	Host plants	Habitat types
Haematoloma dorsatum (Ahrens, 1812)	x		x	Vertical migrant	nymphs: roots of grasses, adults: *Pinus* spp.	MF
Aphrophoridae						
Aphrophora alni (Fallen, 1805)	x	4	x	Vertical migrant	deciduous trees	RF
Neophilaenus minor (Kirschbaum, 1868)	x	48	x	Herb layer	*Corynephorus canescens, Festuca ovina* agg., *Koeleria glauca* and other fine-leaved grasses	GG, RO
Philaenus spumarius (Linnaeus, 1758)	x	9	x	Herb and tree layer	extremely polyphagous	GG, WL, SH
Membracidae						
Centrotus cornutus (Linnaeus, 1758)	x	1	x	Vertical migrant	nymphs: in the herb layer, adults: tree layer	SH
Cicadellidae						
Aphrodinae						
Anoscopus albifrons (Linnaeus, 1758)		7	x	Herb layer	Poaceae	GG
Anoscopus histrionicus (Fabricius, 1794)		20	x	Herb layer	Poaceae	GG
Aphrodes makarovi (Zachvatkin, 1948)	x	5	x	Herb layer	polyphagous	GG
Planaphrodes trifasciata (Fourcroy, 1785)		2	x	Herb layer	*Calluna* and *Thymus*?	RO
Cicadellinae						
Cicadella viridis (Linnaeus, 1758)	x	1	x	Herb layer	*Juncus* spp. and other herbs	RF, WL
Evacanthus acuminatus (Fabricius, 1794)		3	x	Herb layer	polyphagous (dicotyledons)	RF
Deltocephalinae						
Allygus communis (Ferrari, 1882)	x		x	Vertical migrant	nymphs: in the herb layer, adults: on *Quercus* and *Betula*	MF
Allygus maculatus Ribaut, 1952		4	x	Vertical migrant	nymphs: in the herb layer, adults: on *Quercus*	OF
Allygus mixtus (Fabricius, 1794)		12	x	Vertical migrant	nymphs: in the herb layer, adults: in the tree layer	RF, MF
Allygus modestus (Scott, 1876)		1	x	Vertical migrant	nymphs: in the herb layer, adults: in the tree layer	MF
Araldus propinquus (Fieber, 1869)	x		x	Herb layer	*Brachypodium retusum,* V. Rösch, unpubl. data	GG
Arocephalus longiceps (Kirschbaum 1868)	x		x	Herb layer	Poaceae	GG
Balclutha frontalis (Ferrari, 1882)		2	x	Herb layer	Poaceae	WL
Balclutha punctata (Fabricius, 1775)	x	38	x	Herb layer	Poaceae	GG, WL
Balclutha saltuella (Kirschbaum, 1868)		5	x	Herb layer	Poaceae	RF, WL
Chiasmus conspurcatus (Perris, 1857)		1	x	Herb layer	?	WL
Circulifer haematoceps (Mulsant & Rey, 1855)	x	7	x	Herb layer	*Sedum* spp., *Cistus monspeliensis*	GG, SH
Eohardya fraudulenta (Horváth, 1903)		8	x	Herb layer	Poaceae	GG
Eupelix cuspidata (Fabricius, 1775)	x	26	x	Herb layer	Poaceae	GG, RO
Euscelidius schenkii (Kirschbaum, 1868)	x		x	Herb layer	polyphagous	GG, MF
Euscelis lineolatus (Brullé, 1832)	x	34	x	Herb layer	Poaceae, Fabaceae	GG
Goniagnathus brevis (Herrich-Schäffer, 1835)		5	x	Herb layer	*Thymus* spp.	RO, HL
Macrosteles sexnotatus (Fallen, 1806)		23	x	Herb layer	Poaceae, *Carex* spp., probably other dicotyledonous herbs	WL, RF
Mocydiopsis attenuata (Germar, 1821)	x		x	Herb layer	*Festuca* spp.	RF

Taxon	2009	2022/23	Total	Vegetation layer	Host plants	Habitat types
Nanosius sp. sp. n.		109	x	Herb layer	*Festuca ovina* agg. (?), V. Rösch, unpubl. data	RO
Nesoclutha erythrocephala (Ferrari, 1882)	x		x	Herb layer	Poaceae	GG
Paradorydium paradoxum (Herrich-Schäffer, 1837)		2	x	Herb layer	Poaceae	RO
Phlepsius ornatus (Perris, 1857)	x		x	Herb layer	?	GG
Placotettix taeniatifrons (Kirschbaum, 1868)	x	1	x	Herb layer	*Quercus* spp.	OF
Platymetopius sp. groupe *undatus*		1	x	Vertical migrant?	swept from *Pyrus amygdaliformis*	SH
Proceps acicularis (Mulsant & Rey, 1855)	x	1	x	Herb layer	Poaceae	RO
Psammotettix alienus (Dahlbom, 1850)	x	8	x	Herb layer	Poaceae	GG, RF
Psammotettix confinis (Dahlbom, 1850)	x	71	x	Herb layer	Poaceae	GG
Psammotettix nodosus (Ribaut, 1925)	x	574	x	Herb layer	Poaceae	GG, RO, WL
Rhopalopyx elongata (Wagner, 1952)		66	x	Herb layer	Poaceae	GG
Rhytistylus proceps (Kirschbaum, 1868)		125	x	Herb layer	*Festuca ovina* agg.	RO
Sardius argus (Marshall, 1866)	x	35	x	Herb layer	*Agrostis capillaris* and other grasses?	GG
Selenocephalus obsoletus (Germar, 1817)	x		x	Herb and tree layer	polyphagous: high herbs, woody Fabaceae, *Cistus* spp., *Myrtus communis*	GG
Stegelytra putoni (Mulsant & Rey, 1875)	x	5	x	Tree layer	*Quercus ilex*, *Quercus suber*	OF
Synophropsis lauri (Horvath, 1897)	x	5	x	Vertical migrant	sclerophyllous trees and shrubs (e.g. *Hedera helix, Laurus nobilis, Arbutus unedo*)	MF, SH
Thamnotettix dilutior (Kirschbaum, 1868)	x	83	x	Vertical migrant	nymphs: in the herb layer, adults: on *Quercus*	OF
Iassinae						
Iassus lanio (Linnaeus, 1761)	x	4	x	Tree layer	*Quercus* spp.	OF
Idiocerinae						
Acericerus heydenii (Kirschbaum, 1868)	x	4	x	Tree layer	*Acer* spp.	MF
Acericerus ribauti (Nickel & Remane 2002)	x		x	Tree layer	*Acer* spp.	MF
Acericerus vittifrons (Kirschbaum, 1868)	x	1	x	Tree layer	*Acer* spp.	MF
Balcanocerus larvatus (Mulsant & Rey, 1855)		11	x	Tree layer	*Prunus spinosa*	SH
Balcanocerus pruni (Ribaut, 1952)	x		x	Tree layer	*Prunus spinosa*	SH
Idiocerus sp.		2	x	Tree layer	*Salix* spp. (found on *Salix atrocinerea*)	RF
Metidiocerus impressifrons (Kirschbaum, 1868)	x		x	Tree layer	narrow-leaved willows, preferably on *Salix viminalis*	RF
Stenidiocerus poecilus (Herrich-Schäffer, 1836)	x		x	Tree layer	*Populus nigra*	RF
Tremulicerus tremulae (Estlund, 1796)	x		x	Tree layer	*Populus tremula*	RF
Viridicerus ustulatus (Mulsant & Rey, 1855)	x		x	Tree layer	*Populus albus*	RF
Ledrinae						
Ledra aurita (Linnaeus, 1758)	x	2	x	Tree layer	*Quercus* spp. and other deciduous trees	MF
Macropsinae						
Macropsis fuscula (Zetterstedt, 1828)	x	2	x	Tree layer	*Rubus fruticosus* agg., *R. caesius, Rubus idaeus*	SH
Macropsis scotti (Edwards, 1920)		6	x	Tree layer	*Rubus fruticosus* agg.	SH

Taxon	2009	2022/23	Total	Vegetation layer	Host plants	Habitat types
Macropsis sp.	x	4	x	Tree layer	*Salix* spp. (found on *Salix atrocinerea*)	RF
Oncopsis alni (Schrank, 1801)		5	x	Tree layer	*Alnus glutinosa, Alnus incana*	RF
Pediopsis tiliae (Germar, 1831)		1	x	Tree layer	*Tilia cordata, Tilia platyphyllos*	RF
Megophthalminae						
Agallia consobrina (Curtis, 1833)	x	233	x	Herb layer	Lamiaceae	RO
Anaceratagallia glabra (*Dmitriev, 2020*)	x	15	x	Herb layer	?	GG
Anaceratagallia uncigera (Ribaut, 1935)	x	36	x	Herb layer	?	RO
Austroagallia sinuata (Mulsant & Rey, 1855)	x	3	x	Herb layer	polyphagous	GG
Megophthalmus scabripennis (Edwards, 1915)		14	x	Herb layer	?	RO
Typhlocybinae						
Alebra cf. coryli (Le Quesne, 1977)		2	x	Tree layer	*Corylus avellana*	RF
Alebra sp.	x	4	x	Tree layer	deciduous trees	MF
Arboridia spathulata (Ribaut, 1931)	x		x	Tree layer	*Quercus* spp.	OF
Dikraneura variata (Hardy, 1850)	x	11	x	Herb layer	*Deschampsia flexuosa, Festuca* spp.	BF, MF
Edwardsiana crataegi (Spinola, 1839)		3	x	Tree layer	woody Rosaceae	RF
Edwardsiana flavescens (Fabricius, 1794)		5	x	Tree layer	polyphagous on trees	RF
Eupterycyba jucunda (Herrich-Schäffer, 1837)		3	x	Tree layer	*Alnus glutinosa*	RF
Eupteryx curtisii (Flor, 1861)	x	15	x	Herb layer	*Teucrium scorodonia* (and other Lamiaceae?)	BF
Eupteryx cyclops (Matsummura, 1906)	x		x	Herb layer	*Urtica dioica*	RF
Eupteryx decemnotata (Rey, 1891)	x	7	x	Herb layer	Lamiaceae	BF, GG, WL
Eupteryx filicum (Newman, 1853)	x	30	x	Herb layer	ferns	GG
Eupteryx urticae (Newman, 1853)	x	4	x	Herb layer	*Urtica dioica*	RF
Eupteryx zelleri (Kirschbaum, 1868)		2	x	Herb layer	Lamiaceae	RO
Eurhadina concinna (Germar, 1831)	x		x	Tree layer	*Quercus robur, Quercus petraea* and other deciduous trees	OF
Fagocyba carri (Edwards, 1914)	x		x	Tree layer	*Quercus robur, Quercus petraea*	OF
Fagocyba cruenta (Herrich-Schäffer, 1838)	x	65	x	Tree layer	*Fagus sylvatica* and other deciduous trees	BF
Forcipata citrinella (Zetterstedt, 1828)		1	x	Herb layer	low-growing species of *Carex* like *C. flacca*	GG
Frutioidia bisignata (Mulsant & Rey, 1855)	x	21	x	Tree layer	woody Rosaceae, prticularly *Crataegus* spp.	SH
Hauptidia distinguenda (Kirschbaum, 1868)	x		x	Herb layer	*Geranium* spp.	BF
Hauptidia lapidicola (Vidano 1964)		12	x	Herb layer	Lamiaceae	BF, RF
Hauptidia maroccana (Melichar, 1907)	x	51	x	Herb layer	polyphagous	BF, RF
Hebata decipiens (Paoli, 1930)		1	x	Tree and herb layer	polyphagous	WL
Hebata solani (Curtis, 1846)		1	x	Herb layer	polyphagous	GG
Lindbergina aurovittata (Douglas, 1875)	x	5	x	Tree layer	*Quercus* spp.	OF
Linnavuoriana sexmaculata (Fallen, 1806)		1	x	Tree layer	*Salix* spp. (grey-leaved speecies)	RF

Taxon	2009	2022/23	Total	Vegetation layer	Host plants	Habitat types
Ribautiana debilis (Douglas, 1876)		2	x	Tree layer	*Rubus fruticosus* agg., *Rubus caesius*, other woody Rosaceae, deciduous trees	SH
Ribautiana scalaris (Ribaut, 1931)		1	x	Tree layer	*Quercus* spp. (preferably *Quercus petraea*)	OF
Ribautiana tenerrima (Herrich-Schäffer, 1834)	x	29	x	Tree layer	*Rubus fruticosus* agg., *Rubus caesius*, *Rubus idaeus*, sometimes other deciduous trees	SH
Wagneriala palustris (Ribaut, 1936)		1	x	Herb layer	*Carex distachya* and other species of *Carex,* V. Rösch, unpubl. data	RF
Zygina luteipennis (Rey, 1894)		21	x	Tree layer	*Erica arborea, Calluna vulgaris?*	HL
Zygina rubrovittata (Lethierry, 1869)		10	x	Herb layer	*Calluna vulgaris*	HL, RO
Zygina schneideri Günthart, 1974		17	x	Tree layer	woody Rosaceae	SH
Zygina tiliae (Fallen, 1806)	x		x	Tree layer	*Alnus glutinosa*, also *Alnus incana*, *Tilia cordata* and other deciduous trees	MF
Zyginella pulchra (Low, 1885)	x	6	x	Tree layer	*Acer* spp.	MF
Zyginidia scutellaris (Herrich-Schäffer, 1838)	x	49	x	Herb layer	Poaceae	GG
Ulopinae						
Ulopa reticulata (Fabricius, 1794)		5	x	Herb layer	*Calluna vulgaris*	HL
Utecha trivia (Germar, 1821)	x	48	x	Herb layer	polyphagous, e.g. on *Hippocrepis comosa, Echium vulgare* and *Plantago lanceolata*	GG
Sum of species	72	105	129			
Sum of adult specimens	-	1922				
Sum of nymphs	-	2152				

Table II.-Taxonomic list of the leafhoppers occurring in the Réserve de la Massane. The taxonomy follows Mühlethaler et al. (2018) except for the inclusion of the subfamily Agalliinae in the subfamily Megophthalminae (Dietrich 2005). The host plant records are mainly derived from Nickel (2003) but also from Ribaut (1936, 1952) and Della Giustina (1989, 2019). Personal observations of host plants are marked with V. Rösch, unpubl. data. Habitat types in the reserve in which the species were found: GG - Grazed grasslands; RO - Rocky outcrops, Forest types: BF - Beech, OF - Oak, RF - Riparian, MF - Mixed forest; SH - Shrubs; WL - Wetland; HL - Heathland.

In total, 46 species living in the herb layer were found on the 12 transects on grazed grasslands (data from suction and sweep net samples taken together). By far the most common species was *Psammotettix nodosus* (29.8 % of adult individuals, Table II). It was abundant on all the grazed grasslands, but also in most of the other habitat types. *Rhopalopyx elongatus, Psammotettix confinis, Thamnotettix dilutior, Utecha trivia, Sardius argus, Eupelix cuspidata, Anoscopus histrionicus* and *A. albifrons* were also regularly encountered, albeit in much lower numbers. In addition, some individuals the genus *Tettigometra* (*T. virescens, T. sulphurea* and *T. impressifrons*) were found.

On the ungrazed rocky outcrops (n = 4), 30 species were found including two previously undescribed species. One is a species from the genus *Nanosius* (Cicadellidae, subfamily Deltocephalinae). The other species belongs to the genus *Peltonotellus* (Caliscaelidae). Both genera were not previously known in the Pyrenees. Other species associated with the rocky outcrops were *Erysanaea pyrenaea, Rhytistylus proceps, Anaceratagallia uncigera, Goniagnathus brevis, Agallia consobrina, Megophthalmus scabripennis, Paradorydium paradoxum* and *Hysteropterum vasconicum*, an endemic species of the southern Pyrenees.

DISCUSSION

This study has markedly increased the knowledge of the Auchenorrhyncha of the Réserve de la Massane and the Massif des Albères. In addition, two undescribed species were found. The comparison between the intensively grazed pastures and the ungrazed rocky outcrops on the mountain ridges that are inaccessible to cattle revealed that more species and individuals occurred on the ungrazed rocky outcrops and that their community composition differed markedly. The grazed grasslands mainly hosted species that can tolerate intense grazing pressure, many of which are common and widespread throughout Europe (Nickel 2003). Some species, like *Tettigometra* sp. and *Neoaliturus fenestratus*, are associated with Asteraceae with rosettes of leaves (e.g. *Cirsium*, *Carlina*, *Leontodon*) which are avoided by livestock (Nickel 2003, Bunzel-Drüke *et al.* 2019).

On the other hand, the occurrence of rarer species like *Peltonotellus* sp. sp. n., *Nanosius* sp. sp. n. *Erysanaea pyerenaea* and *Hysteropterum vasconicum* (Holzinger *et al.* 2003, Nickel 2003, Della Giustina 2019) was largely restricted to the rocky outcrops. Although altitude also had an effect on species composition, likely due to changes in pasture productivity and plant species composition with elevation, the effects of grazing seemed to prevail (Primi *et al.* 2016).

Unfortunately, knowledge of the composition and ecology of leafhopper communities in the Mediterranean is still limited. Due to differences in climate and vegetation, the results from Central Europe, where the ecology of leafhoppers and the impact of grazing on their diversity have already been studied in more detail (e.g. Nickel 2003, Bucher *et al.* 2016, Helbing *et al.* 2017, Rösch 2020), can only be used for comparison to a limited extent. Above all, it is difficult to transpose the grazing intensity considered 'extensive' in Central Europe to Mediterranean biomes, as in general the habitats of southern Europe are much less productive due to the summer drought. Nevertheless, numerous studies have shown that the species richness and composition of leafhopper communities depend on vegetation height and density as well as on plant species diversity and composition (Morris 2000, Nickel 2003, Biedermann *et al.* 2005, Everwand *et al.* 2014). All these factors are influenced by grazing intensity (Kőrösi *et al.* 2012, van Klink *et al.* 2016) as well as the type of livestock (e.g. cattle, goats, sheep, horses) used (Bunzel-Drüke *et al.* 2019). In general, ungrazed or lightly grazed sites have higher diversity and greater numbers of specimens than sites with intensive grazing (Waloff 1980; Kruess & Tscharntke 2002, Kőrösi *et al.* 2012, Kormann *et al.* 2015).

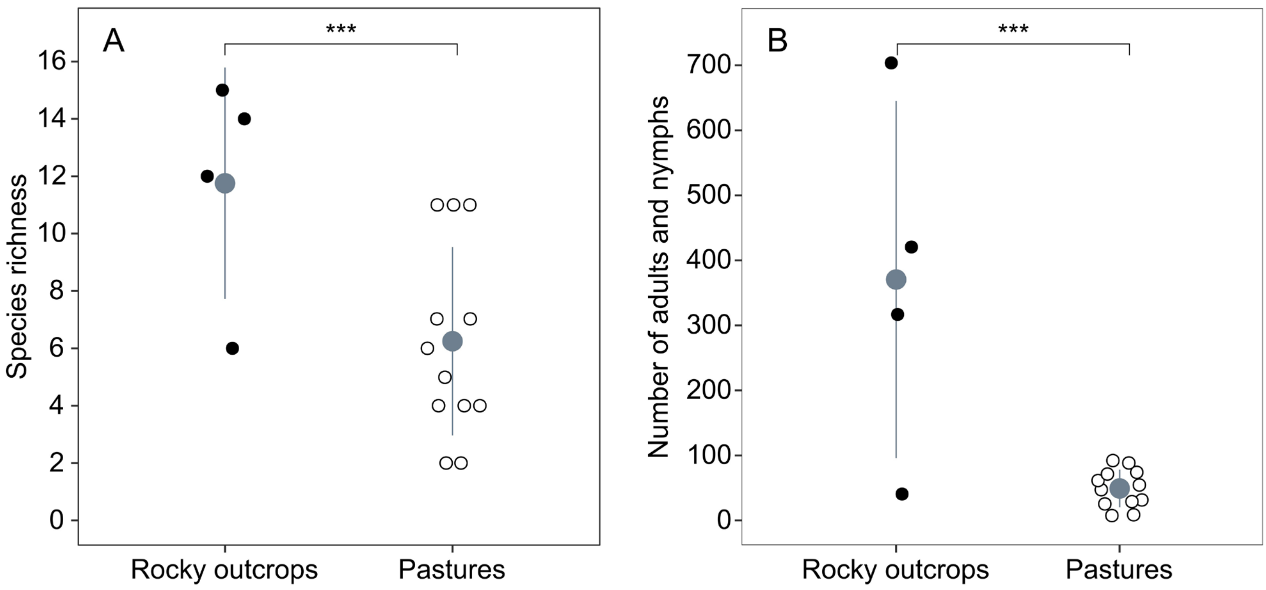

Fig. 3.- Differences in the number of species (A) and the number of individuals (adults and nymphs, B) captured in the herbaceous vegetation on rocky outcrops and pastures. Mean ± SE and raw data points are shown. Significance levels: *P < 0.05, **P < 0.01, ***P < 0.001.

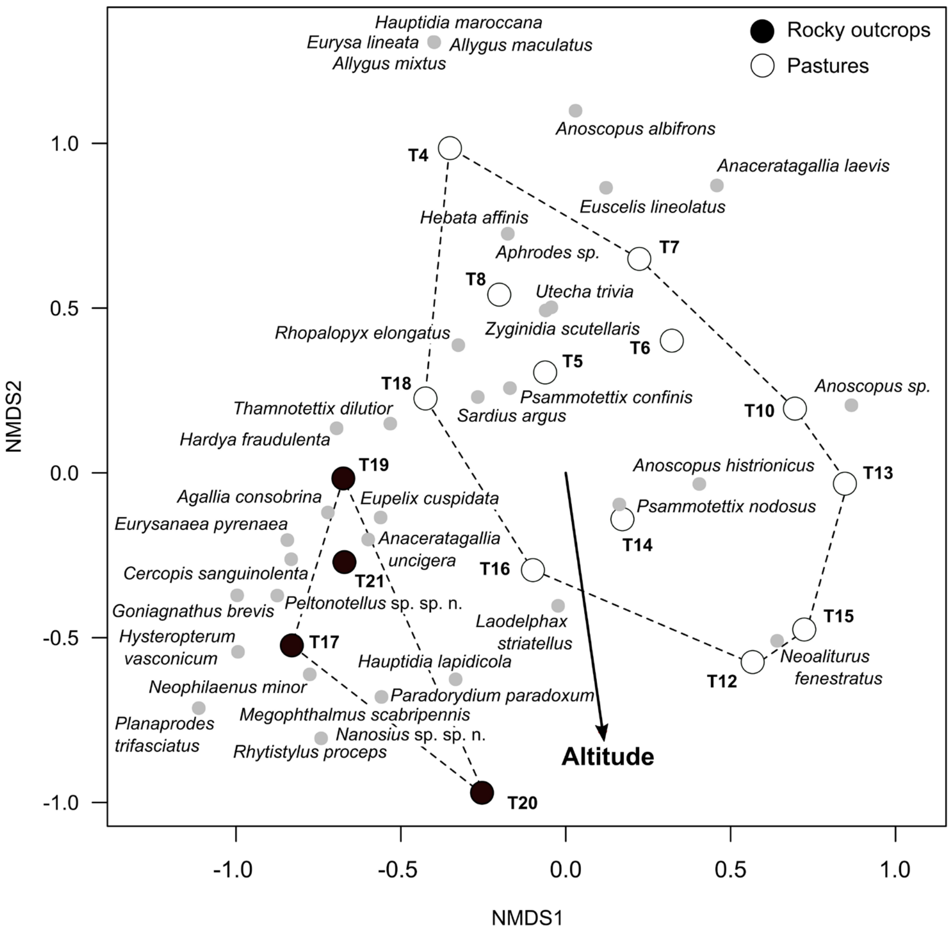

Fig. 4.- NMDS plot showing the differences in the species composition of ungrazed rocky outcrops and grazed grasslands as a function of altitude.

		Estimate	SE	*z*	*P*
Species richness	Intercept	2.46	0.15	16.89	**<0.001**
	Habitat type	-0.64	0.19	-3.46	**<0.001**
Number of individuals	Intercept	5.91	0.35	16.86	**<0.001**
	Habitat type	-2.01	0.41	-4.95	**<0.001**

Table III.- Results of linear models on the effect of habitat type (pasture vs rocky outcrop) on leafhopper species richness and number of individuals. SE = standard error, P-values < 0.05 are shown in bold.

Fig.5.- Pasture at 1000 m a.s.l. in Py (September 2022). The vegetation structure with herbs and tussocks of grasses and is comparable to the one found on the rocky outcrops in the Réserve de la Massane.

This also applies to the Réserve de la Massane, where the intensively grazed pastures were less rich in species and individuals than the ungrazed rocky outcrops with their taller and denser vegetation. However, the use of the rocky outcrops as reference areas needs to be seen as a compromise, as their topography and, to a certain extent, also their plant species composition differs from the grazed grasslands (pers. obs.). Nevertheless, it can be assumed that these areas are naturally open and treeless, which is not the case for the grazed areas on the mountain ridges which have been kept open by livestock since Neolithic times (Bentou 2009). Exclosures that limit or exclude the impact of grazing on the pastures could give a more comparable impression of the development of the leafhopper communities after a reduction of the grazing intensity (van Klink *et al.* 2016).

Another indication of the potential diversity of leafhoppers in extensively grazed pastures in the Albères may be given by a sampling carried out in September 2022 and June 2024 near the village of Py in the Conflent (42.499466, 2.352579, 1000 m a.s.l.). The pastures around Py have a highly diverse plant species community that is comparable to the one found in the Réserve de la Massane, but grazing pressure can be assumed to be significantly lower since the vegetation is visibly taller and denser (Fig. 5). Across the two sampling dates, around 40 species were recorded. The leafhopper community comprised a combination of species which in the Réserve de la Massane were either mainly found in grazed areas (e.g. *Psammotettix nodosus, Neophilaenus minor, Sardius argus* and *Utecha trivia*) or on the rocky outcrops (e.g. *Rhytistylus proceps, Hysteropterum vasconicum, Paradorydium paradoxum* and *Peltonotellus* sp. sp. n.). In addition, numerous species which might be expected to occur in the reserve, e.g. *Arocephalus languidus, A. sagittarius, Mocydia crocea, Doratura exilis, Jassargus curvatus* and *Hardya tenuis*, were observed.

In summary, a reduction of the grazing intensity in combination with shrub removal measures to keep the pastures open can be expected to have a positive effect of the leafhoppers and other invertebrates in the Réserve de la Massane and the surrounding Massif des Albères, where grazing pressure is similarly high. A possible scenario for the future is the progressive encroachment of the open mountain ridges by woody vegetation due to a lack of its management by manual removal or due to the general cessation of cattle pastoralism in the region. However, the rocky outcrops where the most interesting species were found, are likely to remain naturally open.

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