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Analysis grasshopper diversity and associated factors involved in grasshopper diversity in arid Aurès mountains (Batna, Algeria)

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Abstract
The present study was conducted to investigate the diversity of grasshoppers in three sites of Aures mountains between 800 and 1200 m A.S.L through monthly samplings from March 2012 to February 2014. The present study recorded 21 species of grasshopper belonging to Pamphagidae, Pyrgomorphidae and Acrididae, and 60 plant species which were interpreted using the phytosociological system. At a local scale, flora variation explains the highest grasshopper diversity in Djerma, but not the differences observed between Hamla and Lazrou. At a regional scale, climatic constraints expressed by the shortage of growing season at higher altitudes explains the lowest grasshopper diversity at Hamla, through a counter-selection of taxa showing non-adapted life cycles. The mid-domain effect explains more than 50% of the variations in grasshopper diversities, through direct and indirect actions on grasshoppers. The local and regional scales contribute in an intricate manner, as well as mid-domain effect, to the diversity of grasshoppers.

Keywords: Grasshopper, Batna, Diversity index, mid-domain effect, local and regional scales

1. Introduction
Locusts are considered as the main pests of agricultural production. They have been the subject of much work in the economic field: particularly the ravages caused by species which are able of spectacular migrations and phase transformation [1]. Of the 250 species recorded in Africa, more than 20 species are considered to be potentially harmful to crops [2]. The grasshopper fauna of Algeria remains poorly known, except for the well-studied gregariapt species of economic interest such as: *Dociostaurus maroccanus* (Thunberg, 1815) [3, 4], *Schistocerca gregaria* (Forskal, 1775) [5, 6], and *Locusta migratoria* (Linné, 1798) [7].
The Aurès is an emblematic region of east Algeria, characterized by its history, settlement, mountains and topography. Owing to its biodiversity of 651 animals and 650 plant species, and particularly old forests of *Cedrus atlantica*, the Belezma National Park at the east of Aurès mountains, has been created in 1984 [8]. It covers an area of 26 250 ha at altitudes between 1020 and 2138 m A.S.L. First surveys allowed the description in the National Park of a new grasshopper species endemic to Algeria and the diets of the species belonging to the Pamphagidae family [9, 10]. These results were a motivation to conduct an in-depth study of all the families of grasshoppers in three sites differing by their altitude and vegetation.
The rationale of the study is to compare grasshopper diversity and community composition at three elevations between 800 m and 1200 m A.S.L. and to analyze the factors involved in community composition at different scales. At a local scale, it is expected a link between grasshopper and herbaceous flora composition [11, 12, 13], and specifically between disturbances and loss of rare insect species [14]. At a regional scale, there are two sorts of climate constraints that may influence the life cycle of insects, in terms of phenology and number of generations: summer draught linked to a Mediterranean climate [12, 15, 16] and decrease of growing season with increasing altitudes [17, 18]. The present study further considered the contribution of mid-domain effect [19, 20, 21] i.e. peak of richness at mid elevation [22] in spite of the small number of sampling sites. Given that the summit of Belezma mountain reaches about 2140 m, this model predicts that diversity would peak at around 1070 m, and that species showing a maximum abundance near the center of the gradient would have the largest mean ranges, given the truncated distribution of species situated closer to the boundaries. In summary, the aim of this work is to evaluate the weight of the different factors that possibly influence grasshopper biodiversity in this part of Aurès mountains.

2. Materials and Methods

2.1 Study sites

In order to carry out the inventory of the grasshoppers and associated flora in the region of Batna (Fig. 1), the present study considered two sites included in the National Belezma Park (Hamla at 1260 m A.S.L. and Djerma at 1021 m A.S.L.) and one outside (Lazrou site) at a lower altitude around 800 m A.S.L. (Fig. 1).

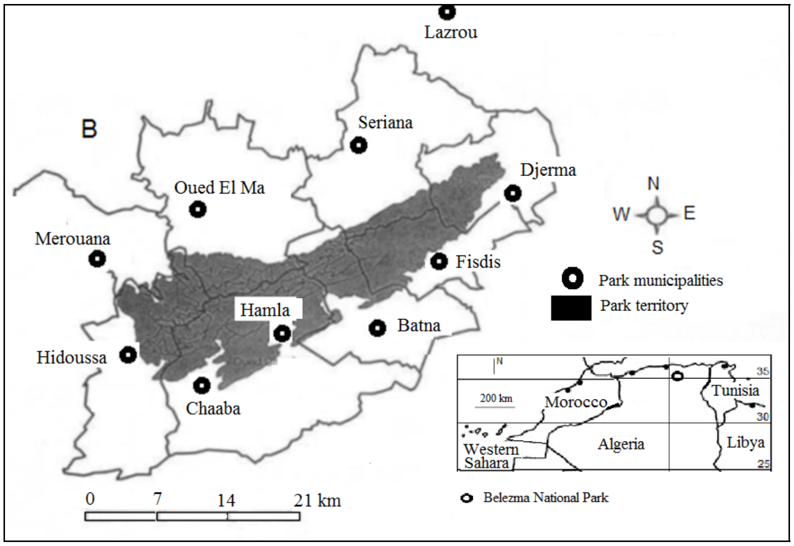

Fig 1: Location of Batna region

Lazrou site is an apple orchard of 1 ha but the agriculture of the area is devoted to livestock, forage and vegetable crop, and is situated 50 km north of Batna wilaya. Djerma site (El-Madher municipality, 20 km north east of Batna) has a vegetation less influenced by human, composed of Alpha steppe (*Stipa tenacissima*), dotted with *Pinus halepensis* and *Juniperus oxycedrus*. Hamla (about 10 km west of Batna city) is a degraded holm oak scrub (*Quercus ilex*) of around one hectare but is comprised in vast area of hundreds ha with the same vegetation (Table 1).

Table 1: Characteristic parameters of the three sites (climatic data in the 1982-2012 period)

Stations	Lazrou	Djerma	Hamla
Coordinates	35°47'13.16" N 6°13'03.22" E	35°40'31.87" N 6°16'32.94" E	35°34'48.09" N 6°04'37.00" E
Physiognomy of vegetation	Apple tree orchard	Alfa steppe	Degraded Holm Oak scrub
Soil pH	Alcaline 7.20	Alcaline 7.77	Alcaline 7.5
Altitude	810 m A.S.L.	1021 m A.S.L.	1260 m A.S.L.
Annual rainfall	320 mm	329 mm	339 mm
Minima mean of coldest month	1.6 °C	0.3 °C	0 °C

Given the annual rainfalls around 330 mm, the three stations are in the upper arid bioclimatic stage [23], near the semi-arid one, especially when winter temperatures are cold. As aridity increases with a shortage of rainfall and mildness of winter [24], there is a low-amplitude gradient from upper arid toward semi-arid stage from Lazrou to Hamla.

2.2 Sampling

For the sampling of plants, we used the transect method using 250 m^2 (50 m x 5 m) surfaces. This method allowed us to realize 6, 6 and 7 transects in Lazrou (prospective area = 1500 m^2), Djerma (prospective area = 1500 m^2) and Hamla (prospective area = 1750 m^2) respectively.

The surveys of plant species have been conducted in the month of May for 2012 and 2013 and we retained the highest values according to the year. We recorded the number of individuals and the percentage of coverage of each plant species. The number of each plant species is counted at sight within an area of 50 meters in length and the percentages of plants in each study site are calculated.

Plants were collected, dried and stored in a reference herbarium, mentioning the indication of date and location. Determinations were conducted using the keys established by [25, 26] and updated with Tela-Botanica, available at http://www.tela-botanica.org. For each plant species, its phytosociological significance was assigned in the systems of [27, 28] to determine the plant communities as in our previous works [12, 13, 15, 29]. To address the intensity of disturbance due to cultivation, it is necessary to calculate the percentage of vegetation classes of weeds.

The sampling of grasshoppers has been carried out from March 2102 to February 2014, two to three times a month for each site from 9:30 am until 5 pm, on the same transects as for plants. The capture of fast moving winged individuals was done using a sweep net, and others by hand. Elevated temperatures were avoided to ensure almost exhaustive samplings. The captured insects were placed plastic boxes mentioning the date and the situation.

To kill the grasshoppers, they were placed in the freezer at -15 °C. The largest individuals were then emptied of their internal contents and filled with cotton, while preserving their genital parts, useful in the case of Pamphagidae specimens. A voucher collection was established and the identifications were conducted using keys from several authors [30, 31, 32]. Nomenclature was updated using the website (http://orthoptera.speciesfile.org) and MNHN Paris website (http://acrinwafrica.mnhn.fr).

2.3 Statistical analyses
To assess the ecology of plants and insects, several parameters were considered: richness (total number of species), cover percentage of plant species, mean abundance S' (ratio of the total number of individuals for each species to the total number of surveys), Simpson and Shannon indexes.
To compare the composition between assemblages, the similarity index of Sorensen, varying from 0 to 1, was calculated $Cs = \frac{2J}{A+B}$, with A = the number of species present in the site a; B= the number of species present in site b; J= number of species common to sites a and b.
To quantify the differentiation between stations along the altitude gradient, beta diversities [33] were calculated using the formulas $\beta = \gamma/\underline{\alpha}$ (ratio expression) and $\beta = \gamma - \underline{\alpha}$ (difference expression) where γ is the global Shannon index for adjacent sites, and $\underline{\alpha}$ the mean of local Shannon indexes.
To compare interspecific phenology of adults, i.e. the monthly profile of abundance, cross-correlations (temporal statistics) were conducted to obtain the lag and the associated p-value between each species. For each taxon, the monthly mean abundance over the two years of the study was calculated. A lag of -1 indicates that the first species is in advance of one month relatively to the second one [34, 35].
To assess the relationship between the amplitude and barycenter (centroid) of each species along the elevational gradient, we used the formula:
Barycenter $B = \Sigma\ (ERi^* Abi)/\Sigma\ Abi$, with ERi = elevation rank of station i, varying from 1 (Lazrou) to 3 (Hamla), and Abi = mean abundance of species in station i.
The elevation amplitude (ecologic plasticity) of each species was obtained by taking the exponential of Shannon index, from the mean abundances in each site [33].
All the statistics were conducted using Past 2.17 [36].

3. Results
3.1 Flora composition
The census of plants revealed 60 species that were distributed in the three study sites with a richness of 13, 40, and 21 in Lazrou, Djerma, and Hamla respectively. There was a weak similarity between Lazrou and Djerma (8%), and higher between Djerma and Hamla (26%) and between Hamla and Lazrou (35%). The bare ground occupied an increasing surface with altitude, from 20% in Lazrou to 58% in Hamla. In the three sites, the Asteracea family was the best represented.
As regard the lowest altitude site at Lazrou, the cover values of the floristic inventory are in Table 6. *Malus communis* occurs in the dominant species, followed by *Hordeum murinum* and *Avena fatua* with percentages lower than 8%.
The floristic surveys of the Djerma site (Table 7) indicate that the flora composition was dominated by *Stipa tenacissima*. Besides Asteraceae, the main families were Lamiaceae with four species, and Fabaceae, Resedaceae and Papaveraceae with three species. The census of the flora of the Hamla site (Table 8) revealed the dominating presence of *Avena fatua* and *Asphodelus ramosus*. Besides the Asteraceae, the best represented families were the Fabaceae with three species, and the Poaceae, Cupressaceae and Lamiaceae with two species each.

3.2 Vegetation analysis
Except a few number of species endemic to North Africa, most species could be associated to a division of the phytosociological system. The results are presented in Table 2 and expressed as the percentages of plant cover.

Table 2: Cover percentages of the different phytosociological classes

Classes	Vegetation	Lazrou	Djerma	Hamla
Lygeo-stipetea Rivas-Martinez 1978 em. Kaabeche 1990	Steppic land in arid climate	3.52%	15.69%	3.53%
Rosmarinetea officinalis (Braun-Blanquet 1947) Gaultier 1990	West Mediterranean guarrigue	0%	7.33%	0%
Stellarietea mediae (Braun-Blanquet 1921) Tüxen, Lohmeyer & Preising in Tüxen 1950 em. Schubert in Schubert, Hilbig & Klotz 1995	Basophile annual weeds	0%	10.32%	1.30%
Pistacio lentisci - Rhamnetea alaterni subsp. alaterni Julve 1993	Mediterranean mattoral	0%	4.39%	6.76%
Pino halepensis - Quercetea ilicis coll. (Braun-Blanquet in Braun-Blanquet, Emberger & Molinier 1947) de Foucault & Julve 1991	Mediterranean evergreen wood	0%	0%	2.62%
Papaveretalia rhoeadis Hüppe & Hofmeister 1990	Basophile weeds	7.65%	0%	8.62%
Rhamno catharticae - Prunetea spinosae Rivas Goday & Borja Carbonell 1961	Apple tree stand	34.74%	0%	0%
Sisymbrietea officinalis Gutte & Hilbig 1975	European annual fallow land	11.90%	2.17%	5.35%
Onopordetea acanthii subsp. acanthii Braun-Blanquet 1964 em. Julve 1993	European xerophile perennial fallow land	2.52%	0.57%	0.68%
Sarcocornietea fruticosae Braun-Blanquet & Tüxen 1943 ex A. & O. de Bolòs in A. de Bolòs 1950	Halophile scrub	3.68%	0%	0%
Pegano harmalae - Salsoletea vermiculatae Braun-Blanquet & O. de Bolòs 1958	Mediterranean to sub-desert halophile scrubs	4.29%	0%	1.44%
Glechomo hederaceae - Urticetea dioicae (Passarge 1967) Julve 2003 class. nov. hoc loco	Medio-European neutrophile perennial fallow land and wood edges	2.55%	0%	0%
Dactylo glomeratae subsp. hispanicae - Brachypodietea retusi Julve 1993	Mediterranean basophile natural lawn	8.09%	6.36%	5.49%
Stipo capensis - Brachypodietea distachyi (Braun-Blanquet 1947) Brullo 1985	European annual basophile open lawn	0%	0.79%	0%

Several basophile vegetation groups were found, in relation with the alkaline soil of the three stations. The Lazrou vegetation was entirely constituted of species linked to cultivation, logically associated to the apple tree orchard: basophile weeds, annual and perennial fallow land constitute about 25% of total plant cover, while bare ground represents 20%. In contrast, the present study recorded in Djerma and Hamla stations the settlement of Mediterranean scrubs (garrigue and mattoral on alkaline and relatively acidic soils respectively) indicative of a lesser human influence. The dominant vegetation of Djerma was the Alpha steppe (*Stipa tenacissima*), with a cover reaching only 16% as a result of disturbance: basophile annual weeds occupy about 10%. In Hamla, the steppe land is replaced by a relictual holm oak forest, much degraded (cover less than 3%). This is due to the conjunction of climate as this station is near the limit between upper arid and semi-arid stages, unfavorable for holm oak development, and of human influence, as numerous trunks have been devastated for firewood. As a result, bear ground occupies more than 50% of the surface and there was a settlement of basophile weeds and European fallow lands, with a total cover about 14%. Regarding the phytosociological groups indicative of disturbance, i.e. *Stellarietea mediae*, *Papaveretalia rhoeadis* and *Sisymbrietea officinalis*, the results show cover percentages at 19.5%, 12.5% and 15.3% for Lazrou, Djerma and Hamla respectively.

3.3 Faunistic results

During the two years of study, 133 field trips were conducted to quantify grasshopper abundance. Table 9 gathers the distribution of species for the site of Lazrou, Djerma and Hamla. The numbers of samplings, the total and average richness at the three sites are shown in Table 3. During the present surveys, 9050 grasshopper individuals were collected, consisting of 7082 adults and 1968 larvae. It appears that diversity, expressed by richness and Simpson and Shannon indexes was peaking at Djerma, while the highest mean abundance was recorded at Lazrou, with more than 80 individuals by sampling date.

Table 3: Total number, richness of species and number of surveys for all sites

	Lazrou	Djerma	Hamla	Total
Total number of individuals (Qi)	3676	2453	2921	9050
Adults	2715	2010	2357	7082
Larvae	961	443	564	1968
Number of samplings (N)	42	44	47	133
Total richness (S)	12	15	10	21
Simpson_1-D	0.912	0.931	0.884	0.935
Shannon index	2.45	2.65	2.18	2.86
Number of subfamilies	8	7	5	8
Mean abundance (S')	87.52	55.75	62.15	68.04

3.4 Structure of community: It is often illustrated by rank/ ln (abundance) curves (Fig. 2). The Motomura slope is related to diversity, as a fast decreasing slope corresponds to a weak diversity [37]. It appears that the three communities have a fairly identical structure, as the slopes of the three curves are parallel. In each case, it is indicative of a stable community.

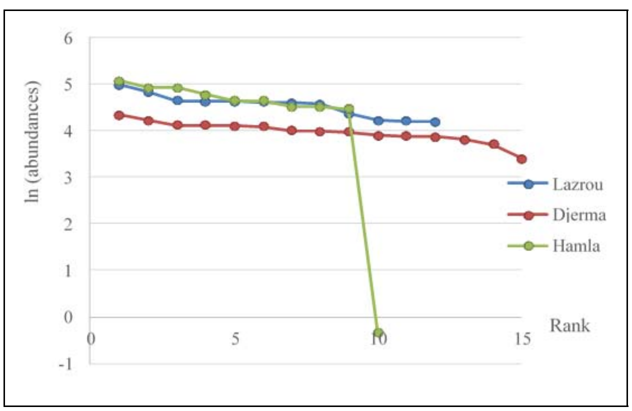

Fig 2: Community structure of grasshoppers in the three stations

However, it should be noted that the very rare *D. maroccanus* in Hamla station (ln (abundance = -0.70)) does not truly belong to the community, a view supported by an absence of larvae in this site, the species being thus only accidental. Otherwise, the higher richness in Djerma station seems to be due to three rare species, at the right end of the curve. To verify this hypothesis, we calculated the rank of the three taxa specific to Hamla: *Oedaleus decorus* 7/15, *Pamphagus djelfensis* (13/15), and *Euryparyphes sitifiensis* (15/15). This idea is thus supported for the last two species.

The differentiation between stations expressed by beta diversities are as following: in the ratio expression, beta diversities for Lazrou-Djerma and Djerma-Hamla are 1.06 and 1.145 respectively; in the difference expression, the same couples of sites gave 0.16 and 0.36 respectively, indicating with both calculations a greater differentiation between mid and higher elevation sites than between lower and mid elevation sites.

3.5 Climate and life cycle: A focus was brought on a temporal view of abundance variations in the three communities. At a first step, the phenology was assessed by considering the subfamily level, as the different species of a given subfamily show globally the same profile. The Lazrou site has the highest number of sub-families with 8, then Djerma with 7 (Cyrtacanthacridinae lacking), and Hamla with only 5 (Acridinae, Pyrgomorphinae and Thrinchinae lacking). To understand the biological significance of these lacking subfamilies, it was tested whether these subfamilies have synchronic phenologies or show a temporal lag between each other (Table 10). The results are presented in Fig. 3.

It appears that there was a succession of three groups of subfamilies in the three sites:

- the first one, represented by Pyrgomorphinae and Pamphaginae, was peaking in April and May, i.e. two to three months before the second group;
- the second one, comprising the Calliptaminae, Thrinchinae, Oedipodinae, Gomphocerinae and Acridinae, showed their maximum abundance in July;
- the third one was constituted of the Cyrtacanthracridinae, one month later than the second group, and reaches its highest density in August and September.

It can be concluded that most subfamilies peak in July, while some taxa are precocious or late. It can be hypothesized that the shortage of growing season in highest areas should counter-select the species peaking in spring. Indeed, in the highest elevation site Hamla, both species of Pyrgomorphinae (precocious subfamily) disappear. Moreover, of the 7 Pamphaginae peaking in spring, only two are recorded in that site (*Ocneridia microptera* and *O. nigropunctata*). Regarding the absence of *Tmethis cisti* (Thrinchinae) and *Truxalis nasuta* (Acridinae), adults are ordinary peaking in July, that seems to be perfectly adapted to the local climate of Hamla, leading to the conclusion that the cause of their absence is not related to a cycle/climate relationship.

Although the predictions seem to meet some support from field data, this view is simplified as several species show 2 generations a year (bivoltine).

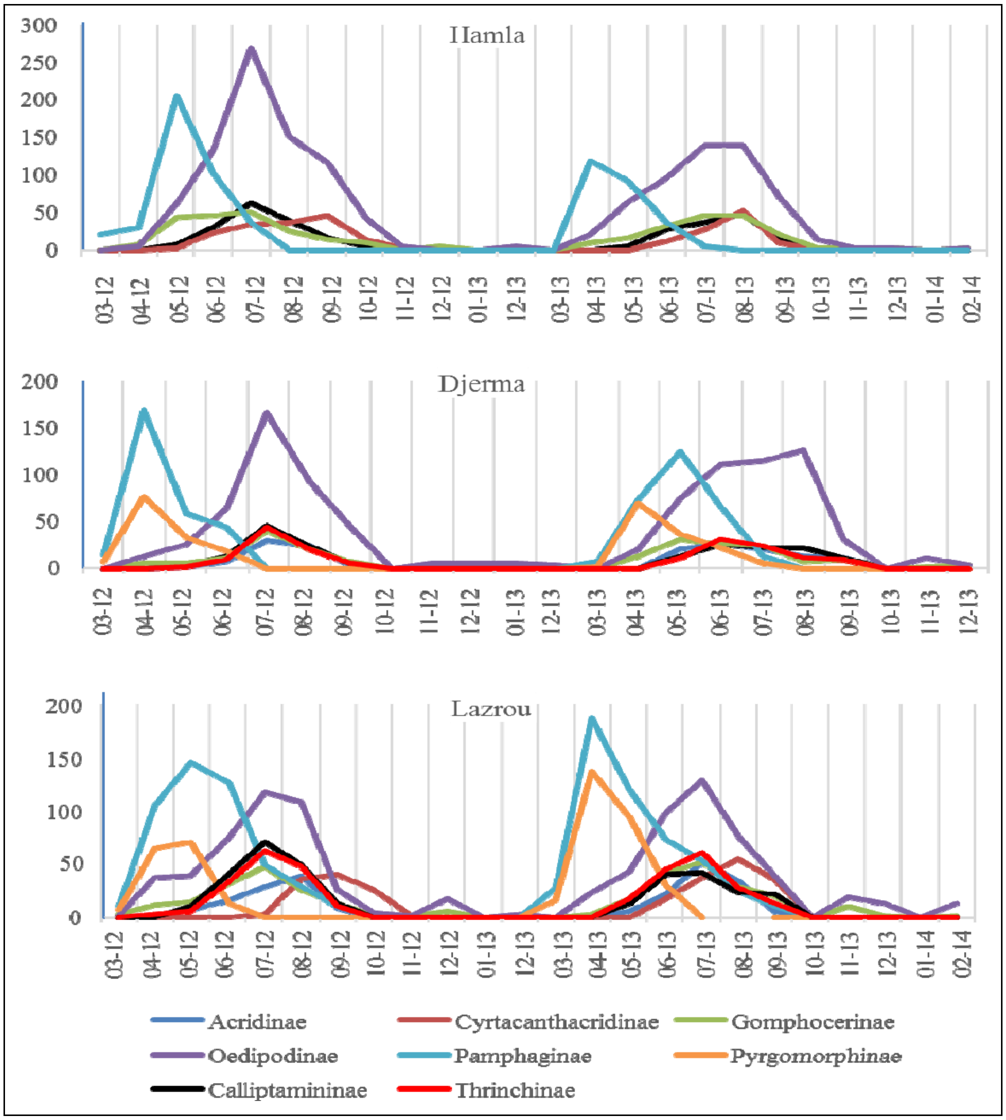

Fig 3: Temporal variations of the subfamilies. The abscissa corresponds to the months of the two years of study, and the ordinates to the mean abundance of adults per month.

The present study further compared the three communities by their cycle pattern. As developed in [12, 16], there is an adaptation of grasshopper species to summer draught through the cycle type in Mediterranean climates. An univoltine species whose adult population is peaking in July is counter-adapted whereas a shift toward spring or autumn allows avoiding this unfavorable season. Another possible solution is a bivoltine strategy, each generation having its highest density in spring and autumn. Taking advantage of larvae and adult records, we could unambiguously determine the cycle of each species at each site. No change in type cycle was observed between the three sites for each species. The results (Table 4) indicate that the proportion of adapted cycles decreases regularly from the lowest altitude site at Lazrou to the highest one at Hamla, thus from the most to the less arid climate.

Table 4: Cycle pattern of grasshoppers in the three sites

	Lazrou	Djerma	Hamla
1Gs	4	6	2
1Ga	1	0	1
2G	3	3	2
1Gj	4	6	4
Adaptated cycles %	67	60	56

With 1Gs = one generation peaking in spring; 1Ga = one generation peaking in autumn; 1Gj = one generation peaking in July; 2G = 2 generations. Adapted cycle = 1Gs+1Ga+2G/ total.

It can be concluded that the highest diversity in Djerma comes from an excess of species showing univoltine species peaking in spring and in July. As regard the lowest diversity recorded in Hamla, the explanation lays in the shorter total length of the growing season. This length can be deduced from the mean temperatures above 10 °C, which in March correspond to the emergence of larvae. This length was 3 to 4 weeks shorter in Hamla than in the two other sites, resulting in counter-selection of precocious univoltine (only two species) and bivoltine species (only three species), leading to an impoverishment of taxa number.

3.6 Mid-domain effect: As only three sites have been studied, it was inappropriate to test directly the mid-domain effect. Of course, the Djerma site around 1000 m showed a higher richness and diversity for both plants and grasshoppers than the two other sites, fitting to the model. Given the different environments recorded, this observation is not convincing by this direct evidence. However, it can be considered some consequences of this theory, given the truncated distribution of species near the boundaries of the gradient. This feature can be studied through two aspects: (i) most species should be situated near a parabola in a x-y plot dealing with amplitude-barycenter relationship [13], and (ii) the species typical of the boundaries are expected to show a decreasing abundance when they are found far from their own boundary.

Regarding the relationship between the relation between elevation amplitude and altitude barycenter (or centroid) of species, most species are situated on a parabolic curve, expressing that the taxa living in the center of the gradient have a wider habitat range than those close to the boundaries (Fig. 4). Of note, *Oedaleus decorus, P. djelfensis and Euryparyphes sitifiensis* are clearly under the curve, while *A. aegyptium* is slightly below.

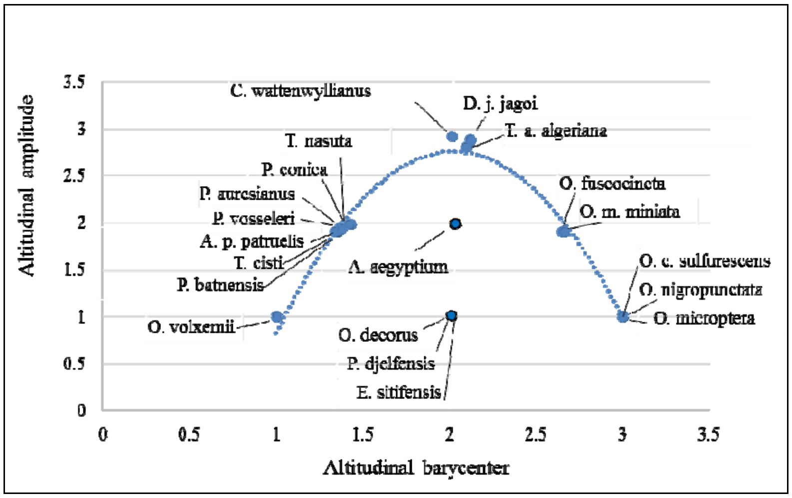

Fig 4: Relationship between altitudinal barycenter and amplitude.

The equation of the parabolic curve was calculated from the species situated on the curve.

$y = -1.850x^2 + 7.473x - 4.787$, $R^2 = 0.977$. Lazrou, Djerma and Hamla corresponds to abscissae = 1, 2 and 3 respectively.

Regarding the decreasing abundance of boundary-specific taxa from their own boundaries, Table 5 indicates that 13/20 species (65%) support this hypothesis. As a result, the peak of diversity in Djerma could largely be explained by this effect. The part coming from taxa specific to this site (3) is only marginal and represents 15%. Of note, there are four species more abundant near both boundaries than in the center of the gradient.

Table 5: Distribution of species along the altitudinal gradient.

Species	Abund. Lazrou	Abund. Djerma	Abund. Hamla
Acrotylus patruelis patruelis	146.2	76.4	0.0
Pamphagus auresianus	104.2	59.5	0.0
Tmethis cisti	100.4	53.6	0.0
Pamphagus batnensis	02.9	52.9	0.0
Truxalis nasuta	67.3	49.6	0.0
Pyrgomorpha conica	66.0	48.0	0.0
Pyromorpha vosseleri	68.2	41.0	0.0
Ocneridia volxemii	97.6	0.0	0.0
Oedipoda fuscocincta	0.0	48.6	91.2
Oedipoda miniata miniata	0.0	61.5	119.1
Oedipoda caerulescens sulfurescens	0.0	0.0	105.0
Ocneridia nigropuncata	0.0	0.0	137.8
Ocneridia microptera	0.0	0.0	90.8
Dociostaurus jagoi jagoi	102.3	68.5	137.8
Calliptamus wattenwyllianus	100.7	60.2	103.9
Thalpomena algeriana algeriana	126.6	61.5	158.7
Anacridium aegyptium	78.3	0.0	87.3
Oedaleus decorus	0.0	54.9	0.0
Pamphagus djelfensis	0.0	45.0	0.0
Euryparyphes sitifensis	0.0	30.1	0.0

Table 6: The species listed in the site of Lazrou and their cover rates

Family	Species	Cover rates
Amaranthaceae	*Beta vulgaris*	2.52%
Apiaceae	*Aegopodium podagraria*	2.55%
Asteraceae	*Scolymus maculatus*	2.36%
	Anacyclus clavatus	1.84%
	Asteriscus spinosus	3.68%
Chenopodiaceae	*Atriplex halimus*	3.68%
Fabaceae	*Melilotus macrocarpa*	1.06%
	Medicago truncatula	3.52%
Liliaceae	*Asphodelus albus*	4.41%
Poaceae	*Avena fatua*	7.65%
	Hordeum murinum	7.7%
Rosaceae	*Malus communis*	34.74%
Zygophyllaceae	*Peganum harmala*	4.29%
Bare ground		20.00%
Total		100.00%

Table 7: The plant species listed in the site of Djerma and their cover rates

Family	Species	Cover rates
Asparagaceae	*Drimia undulata =Urginea undulata*	1.99%
Asteraceae	*Artemisia herba-alba*	3.96%
	Calendula arvensis arvensis	1.99%
	Carduus macrocephalus	1.59%
	Centaurea calcitrapa	0.57%
	Picris sp	0.79%
	Carduus pteracanthus	1.19%
	Carthamus lanatus	0.58%
	Artemisia campestris	0.79%
	Reichardia picroides intermedia	0.79%
	Onopordon arenarium	1.19%
	Urospermum dalechampii	0.79%
Apiaceae	*Daucus sp*	0.39%
Boraginaceae	*Borrago officinalis*	1.59%
Brassicaceae	*Diplotaxis erucoides*	1.99%
	Matthiola fruticosa	1.19%
Convolvulaceae	*Convolvulus cantabrica*	1.99%
Cupressaceae	*Juniperus oxycedrus*	1.59%
	Juniperus phoenicea	1.19%
Dispsacaceae	*Scabiosa sp*	0.43%
Fabaceae	*Genista microcephala*	3.78%
	Medicago truncatula	1.58%
	Hedysarum coronarium	2.78%
Globulariaceae	*Globularia alypum*	2.96%
Lamiaceae	*Rosmarinus officinalis*	1.59%
	Salvia verbenaca	1.19%
	Marrubium alysson	2.39%
Papaveraceae	*Papaver hybridum*	0.79%
	Papaver rhoeas	1.35%
	Fumaria densiflora	0.97%
Poaceae	*Stipa tenacissima*	7.34%
	Avena fatua	1.35%
Primulaceae	*Lysimachia arvensis*	0.36%
Ranunculaceae	*Adonis dentata*	0.73%
	Ranunculus sp	0.79%
Resedaceae	*Reseda alba*	2.39%
	Reseda arabica	2.58%
	Reseda decursiva	1.59%
Bare ground		33.12%
Total		100.00%

Table 8: The species listed in the site of Hamla and their cover rates

Family	Species	Cover rates
Apiaceae	*Eryngium tricuspidatum*	0.62%
Asteraceae	*Artemisia herba-alba*	1.62%
	Onopordum arenarium	0.74%
	Anacyclus clavatus	3.01%
	Asteriscus spinosus	1.72%
	Inula conyza	1.74%
Brassicaceae	*Sinapis arvensis*	1.18%
Cupressaceae	*Juniperus oxycedrus*	2.17%
	Juniperus phoenicea	2.87%
Fabaceae	*Astragalus armatus Willd*	1.17%
	Genista microcephala	1.69%
	Calicotome spinosa	1.72%
Fagaceae	*Quercus ilex*	2.62%
Lamiaceae	*Teucrium polium*	1.29%
	Marrubium alysson	0.86%
Asparagaceae	*Asphodelus ramosus*	3.77%
Malvaceae	*Malva sylvestris*	0.68%
Poaceae	*Hordeum murinum*	2.34%
	Avena fatua	8.62%
Primulaceae	*Lysimachia arvensis*	0.12%
Zygophyllaceae	*Peganum harmala*	1.44%
Bare ground		58.01%
Total		100.00%

Table 9: List and percentages of grasshopper species recorded in the three sites

Families	Sub-families	Species	Lazrou	Djerma	Hamla
Acrididae	Acridinae	*Truxalis nasuta* (Linnaeus, 1758)	5.79	6.11	-
	Calliptamininae	*Calliptamus wattenwylianus* Pantel, 1896	8.68	7.42	10.07
	Cyrtacanthacridinae	*Anacridium aegyptium* (Linné, 1764)	6.75	-	8.46
	Gomphocerinae	*Dociostaurus jagoi jagoi* Soltani, 1978	8.81	8.44	13.35
		Dociostaurus marrocanus (Thunberg, 1815)	-	-	0.07
	Oedipodinae	*Acrotylus patruelis patruelis* (Herrich-Shaffer, 1838)	12.6	9.42	-
		Oedaleus decorus (Germar, 1826)	-	6.77	-
		Oedipoda caerulescens sulfurescens Saussure, 1884	-	-	10.07
		Oedipoda fuscocincta Lucas, 1849	-	5.99	8.83
		Oedipoda miniata miniata Pallas, 1771	-	8.8	11.24
		Thalpomena algeriana algeriana (Lucas, 1849)	10.91	7.58	15.37
Pamphagidae	Pamphaginae	*Euryparyphes sitifensis* (Brisout de Barneville, 1854)	-	3.71	-
		Ocneridia nigropunctata (Lucas, 1849)	-	-	13.35
		Ocneridia microptera (Brisout de Barneville, 1850)	-	-	8.80
		Ocneridia volxemii (Bolivar, 1878)	8.41	-	-
		Pamphagus auresianus Massa, 1992	8.98	2.34	-
		Pamphagus batnensis Benkenana & Petit, 2012	8.87	6.52	-
		Pamphagus djelfensis Vosseler, 1902	-	5.54	-
	Thrinchinae	*Tmethis cisti* (Fabricius, 1787)	8.65	6.60	-
Pyrgomorphidae	Pyrgomorphinae	*Pyrgmorpha conica conica* (Olivier, 1791)	5.69	5.91	-
		Pyrgmorpha vosseleri Uvarov, 1923	5.88	5.06	-

Table 10: Monthly lags between the subfamilies in the three sites

	Lazrou		Djerma		Hamla	
	lag	p value	lag	p value	lag	p value
Pyrgomorphinae/Pamphaginae	0	$2.2\ 10^{-8}$	0	$2.2\ 10^{-8}$		
Pamphaginae/Calliptaminae	-2	$7.8\ 10^{-10}$	-3	$1.8\ 10^{-5}$	-2	$4.2\ 10^{-3}$
Calliptamininae/Thrinchinae	0	$1.4\ 10^{-14}$	0	$1.6\ 10^{-13}$	0	$1.7\ 10^{-13}$
Thrinchinae/Oedipodinae	0	$2.3\ 10^{-15}$	0	$1.9\ 10^{-9}$		
Oedipodinae/Gomphocerinae	0	$3.0\ 10^{-14}$	0	$7.3\ 10^{-7}$	0	$3.3\ 10^{-8}$
Gomphocerinae/Acridinae	0	$1.6\ 10^{-8}$	0	$1.2\ 10^{-9}$		
Gomphocerinae/Cyrtacanthacridinae	-1	5.4 10-7	-1		-1	2.2 10-6

4. Discussion

The inventory of grasshopper fauna in the Batna region revealed twenty-one grasshopper species, which are distributed into three families (Pamphagidae, Pyrgomorphidae and Acrididae). This result is comparable to the inventory of [38] who recorded 22 species in the same region. This fauna can be compared to the one described in Southern Europe. For example, in the mountains of France, it shows some affinity to the Mediterranean fauna described by [39, 40] for Mont-Ventoux and the Alpes respectively. In the case of the Alpes, the xerophile taxa spread within the July isotherms 13 to 25 °C are not identical to Aurès fauna but correspond at the subfamily level, with a dominance of Oedipodinae: it has been recorded *Calliptamus barbarus*, *Oedipoda c. caerulescens* and *Oedipoda germanica*. The Aurès fauna is even closer to the one of Mont-Ventoux, for species recorded under 590 m ASL: added to the cited taxa, the authors encountered *D. maroccanus*, *D. genei* (close to *D. jagoi*), *O. decorus* and *P. conica*. It can be deduced that mountain fauna of Aurès roughly corresponds to the Mediterranean fauna of plains in South France, and is very different from its montane and subalpine faunas, dominated by Gomphocerinae [40]. However, the fauna of Aurès mountains is enriched in Pamphagidae taxa, which are particularly developed in North Africa, but sporadic on the northern side of Mediterranean Sea [32].

There are several factors possibly involved in the difference of composition and richness of grasshopper in the sites of Aurès mountains, acting at different scales [41], raising several questions: (i) why there is a peak of diversity in Djerma? (ii) why the diversity in the site having the highest elevation is so low?

As regard Djerma richness, flora is an important local factor as this site hosted the two thirds of total flora richness, i.e. about two times as much as in the other ones, and contains the lowest percentage of plant indicators of disturbance. This last feature could be linked to the presence of several rare grasshopper species in Djerma site. However, flora richness and disturbance indicators do not explain the greater grasshopper diversity at Hamla than at Lazrou. Plant and grasshopper diversities do not vary in parallel, as ever found in Montana [42]. Moreover, the effect of disturbance on insect diversity depends on the taxa as what ever found in the case of butterflies and grasshoppers in Swiss montane wetlands [43]. Nevertheless, it should be remembered the high percentage of bare ground in Hamla, near 50%, greater than in the two other sites. In conclusion, unless imagining a complex compromise between bare ground and cover of suitable plant species, the vegetation at the local scale has a limited explanatory power on grasshopper diversity.

On the other hand, the climate can act as a limitation factor through the cycle pattern of grasshopper species. The results of [11] are supported as the proportion of cycles adapted to arid Mediterranean climate is the highest in Lazrou, but these proportions cannot drive by themselves an impoverishment of a particular site. More interestingly, the shortage of the growing season [18], broadly estimated around 3 to 4 weeks in Hamla relatively to the two other sites, counter-selects the univoltine species peaking in spring and the bivoltine ones. This fact objectively explains the weak number of grasshopper taxa in Hamla, but does not tell anything on the variation of diversity in Hamla and Lazrou.

The consideration of mid-domain effect was constructive as about 65% of richness variation was explained by this effect. It is true that the mid-domain site, Djerma, shows a greater diversity than the other sites. The modality of this effect must not be considered as acting on the insects solely, but also through vegetation. The rationale of this theory being geometric, the plants also are affected. As a result, the mid-domain effect acts directly on insect distribution [20] but indirectly as well, through vegetation (local effect).

In conclusion, the different scales of factors are intricated and play different and complementary roles on insect diversity, but more sites should be explored to precise the contribution of each.

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