

CLIMATIC CHANGES IN ALGERIA AND RESPONSES FROM ACRIDIAN INSECTS

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Abstract

Since 1970, climatic changes in France are mainly characterized by an increase in maxima temperatures. As for rainfall, the variations showed different aspects according to the regions. In Algeria, we observe a parallel increase in maxima temperatures, affecting more the high plateaus than the Mediterranean coast. There is also a decrease in annual rainfall, especially in the north-west.

The consequences of these trends on insects were investigated through the example of grasshoppers. It seems that the fundamental cycle of these orthoptera is a single generation peaking in summer, but this feature is not well adapted to the Mediterranean climate, where the hottest season is also the driest one. The current climate change amplifies the difficulties linked to this fundamental cycle. Our works show that grasshoppers adopted several strategies in Algeria to avoid summer draught: a shift in the adult peak of the fundamental cycle, either toward spring or toward autumn, or a cycle comprising two generations, the interval being occupied by an egg stadium. Even if the shift toward a precocious development is not very pronounced, it can be demonstrated by the phenology of nymphs.

Key words: *climate change, Mediterranean climate, grasshopper, life cycle, phenology.*

INTRODUCTION

Climate change has been the subject of a huge amount of literature in the past decades, with a special emphasis on European and American countries. In the case of South Mediterranean countries, the documentation is less rich, essentially because of the lack of available information. However, the trend in shortage of rainfall has been pointed out by several authors, driving changes in agriculture methods [1, 2]. Works based on satellite pictures have

also provided useful data relative to the variations in the vegetation cover, resulting of man activity and climate changes [3].

In this work the Algerian data freely available from databases were analyzed, in comparison to some French localities, in the range 1980-2010. The consequences on insect life cycles are illustrated from recently published papers by my co-workers and I, with the example of Orthoptera, and especially grasshoppers.

MATERIAL AND METHODS

The climatic data were extracted from the site <http://www.tutiempo.net/en/Climate/europe.htm>, where annual maxima (TMx), minima (Tmn) and average (Tav) temperature means and annual rainfalls are recorded. Unfortunately, the monthly values were generally absent. Our concern is that monthly parameters are the most relevant ones for understanding insect life, as they usually act on critical stages of the cycle, at precise periods of the year. Nevertheless, this first approach should give a series of interesting observations.

In Algeria, the longest series of retained data correspond to 13 main cities in the northern part of the country. In France, we chose three Mediterranean localities (Montpellier, Marseille and Nice from west to east), and three non-Mediterranean ones (La Rochelle, Limoges, and Grenoble from west to east).

Annual variations are observed and some works pointed out the occurrence of extreme values to

assess climatic changes. In contrast, our strategy was based on regression analyses in order to highlight trends over the last 30 years. We considered that there is a significant increase or decrease for a parameter if the Pearson coefficient between years and that parameter is associated to a p-value less than 5%. When this condition was fulfilled, we then calculated the parameter values for the years 1980 and 2010, using regression equations (data not shown). All the tests were conducted using PAST 2.17 [4].

Variations in the distribution of species need to compare present and ancient collections or observations, following the example of Pr Camille Parmesan who was awarded the 2007 Nobel Peace Prize. The observations of Finot (around 1880), Werner (around 1910), Pasquier (around 1940), and more recently Fellaouine (around 1980 [5]), Benfekih (around 1990 [6]), and Benkenana et al. [7] constitute a valuable basis. Moreover, the specimens kept at the ENSA (Ecole Nationale Supérieure Agronomique) of Algiers [8] and in MNHN of Paris [9] enrich

considerably the sources of information.

About life cycle of insects, the variation in the population sizes of adults must be taken with care, given their movements favored by flight. The number of generations of species was deduced from variations in nymphal population sizes. The temporal shift of population appearances between two situations took into account the lag between the peaks (maximum abundances) of nymphal stages.

RESULTS

1. Climatic changes

The data relative to France localities are gathered in table 1. It reveals that the differences of TMx between 1980 and 2010 are systematically greater than that of Tmn for the same period. An average gain of 1.4°C was recorded for TMx when the six towns are pooled. No variation was considered as significant for the minima mean temperatures in two towns: La-Rochelle and Grenoble.

Table 1. Values of climatic parameters in France.

TMx = annual maxima means, Tmn = annual minima means. All the values were calculated from regression equations in the 1980-2010 range. Dashes = non-significant values.

	TMx-1980	TMx-2010	Diff.	Tmn-1980	Tmn-2010	Diff.
Montpellier	19.417	20.617	1.2	9.654	10.809	1.155
Marseille	19.35	21.315	1.965	9.937	11.158	1.221
Nice	19.041	20.154	1.113	11.842	12.757	0.915
La-Rochelle	16.354	17.329	0.975	-	-	-
Limoges	14.879	16.403	1.524	7.023	7.746	0.723
Grenoble	15.408	17.097	1.689	-	-	-

As for rainfalls, no variation was significant among the tested localities, except for Grenoble where the annual amount was 1102 mm in 1980 and 746 mm in 2010,

representing a decrease of about 350 mm in 30 years.

As for Algeria, the data relative to 13 towns distributed in the north part of the country are presented in

table 2. As non-significant variations are indicated by a dash, it is clear that the annual maxima temperature is the major parameter subject to positive variations.

Table 2. Values of climatic parameters in Algeria.

Tmx = annual maxima means, Tmn = annual minima means, P = annual rainfalls. All the values were calculated from regression equations in the 1980-2010 range. Dashes = non-significant values.

Towns	Altitude (m)	TMx-1980	TMx-2010	Diff.	Tmn-1980	Tmn-2010	Diff.	P-1980	P-2010	Diff.
Oran-Es-Senia	90	23.18	24.32	1.14	12.03	12.93	0.90	251.28	403.41	152.12
Annaba	4	23.15	23.70	0.56	-	-	-	-	-	-
Bejaia	2	22.65	23.28	0.62	-	-	-	554.04	919.98	365.94
Alger	25	23.54	24.34	0.81	-	-	-	-	-	-
Tlemcen	247	23.88	24.67	0.79	11.63	12.33	0.70	-	-	-
Mecheria	1149	22.24	23.71	1.47	-	-	-	-	-	-
Setif	1038	19.94	21.32	1.38	10.21	8.27	-1.93	-	-	-
Djelfa	1144	-	-	-	-	-	-	-	-	-
Batna	1052	20.49	23.50	3.01	-	-	-	-	-	-
Tebessa	813	21.95	23.68	1.73	-	-	-	679.29	821.65	142.36
Constantine	694	21.47	23.01	1.54	-	-	-	-	-	-
Biskra	87	-	-	-	-	-	-	-	-	-
Bechar	773	27.26	28.16	0.90	-	-	-	-	-	-

In the case of localities close to the Mediterranean Sea, we observe a moderate increase in annual maxima means, around 0.8°C, but Oran is a noticeable exception. In

contrast, the increase of this parameter is more than twofold, around 1.8°C, for the localities situated on high plateaus and steppes, at more than 700 m A.S.L.

As for northern Saharan localities, very little differences are observed between 1980 and 2010.

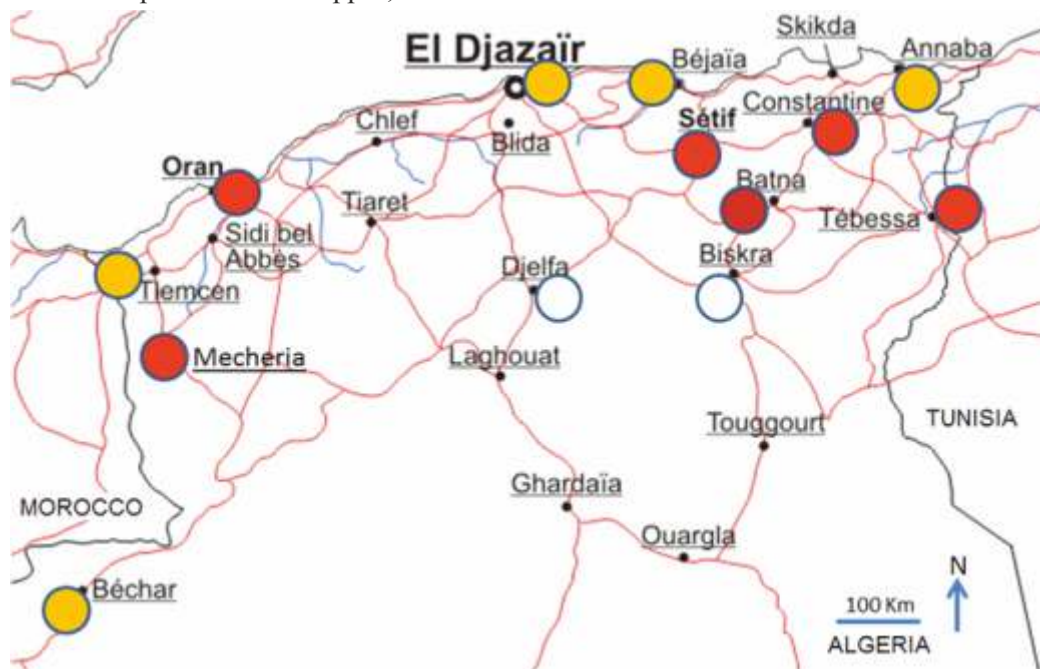


Fig. 1. Variations in TMx between 1980 and 2010.

Brown circle: > 2°C, red circle: between 1 and 1.5°C, yellow circle: between 0.5 and 0.9°C, white circle: non-significant.

The Algerian map in figure 1 points out the lack of data in the center, and enrichment in climatic series would strengthen the conclusions previously emitted.

1. Variations in the distribution of grasshopper as a result of climate changes

The distribution of grasshopper species is influenced by changes in vegetation and climate. The understanding of distribution

changes needs to address the climatic constraints suffered by species, evidenced by climagrams [10]. In the case of *Locusta migratoria cinerascens*, the latter authors showed that this species is limited by aridity and fresh winters. We predicted that the populations of this insect should be reduced in the localities where humidity is decreasing. To demonstrate this hypothesis, we observed that the

solitary populations of North Algeria progressively rarefied in sites distant from the Mediterranean coast, when we consider ancient and recent observations. We then showed that annual rainfalls decreased regularly in localities situated far from the sea. We finally obtained the variation illustrated in figure 2 [11].

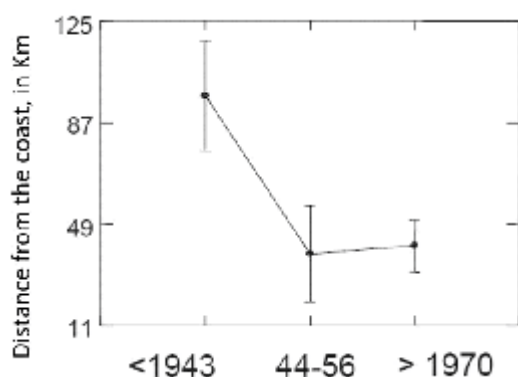


Figure 2. Variations in the distances from the sea of localities hosting *L. migratoria cinerascens* (photograph from E. Boitier).

In a second example, it is interesting to consider *Ocneridia volxemi*, a species living under sub-humid and humid Mediterranean stages, and limited by minima means of winter

above 6°C [7]. A survey of literature [6, 7, 12, 13] allowed recording 37 items including altitudes and dates since a century. In spite of uncertainties in some precise

sampling localities, we observe a significant shift of about 300 m in the mean altitude when we separate observations before 1943 and after 1980 (fig. 3).

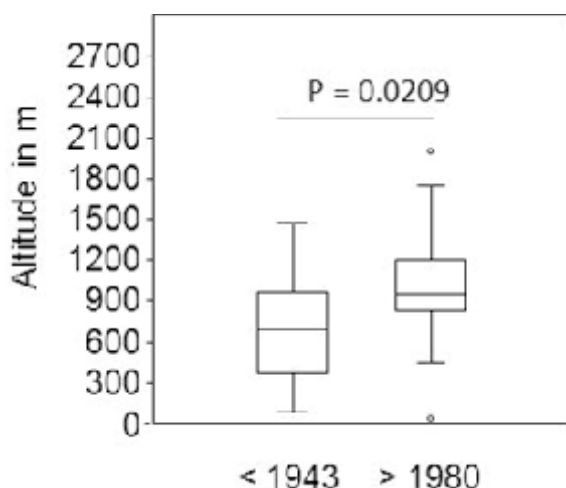


Figure 3. Variations in the mean altitudes of *Ocneridia volxemi* (photograph from D. Petit).

The limits of each box contain half of altitude values, and the central horizontal line is the median. The significance of differences was given by ANOVA (N=37).

1. Variations in the life cycle of grasshopper as a result of climate changes

Changes in the life cycles mean two different ideas, (i) plasticity of species as an adaptation to environmental constraints, and (ii)

replacement of more adapted species. We present here examples illustrating these points of view.

About plasticity, the lack of diachronic data concerning the phenology of species was supplemented with a comparison of sets of species living in close climatic conditions [14]. Koléa is a station near the Mediterranean coast, while Soumâa is more distant. The main climatic

difference lies in a drought in Koléa earlier than in Soumâa during spring. As a consequence, it was expected that for each species the occurrence of adults in Koléa should come earlier than in Soumâa. Several possibilities could be advanced as for nymph development: an earlier hatching, a faster succession of nymph stages, or a combination of both. In fact both solutions were found (table 3):

Table 3: Comparison of phenology of nymphs between Koléa and Soumâa.

The duration of development was measured as the number of months (days transformed in decimals) separating the peaks of nymphal stages 1 and 5. The peak of stage 1 is the mean value of month number (days transformed in decimals) assuming normal distribution of population.

Species	Duration of development		Peak of nymphs of stage 1	
	Koléa	Soumâa	Koléa	Soumâa
<i>Acrotylus patruelis</i>	3.09	2.87	3.91	4.13
<i>Aiolopus strepens</i>	3.24	2.95	3.93	4.33
<i>Docostaurus jagoi</i>	3.14	2.74	4	4.2
<i>Calliptamus wattenwylanus</i>	2.52	2.25	4.54	4.75
<i>Acrida turrita</i> G1	2.72	3.38	3.5	4.17
<i>Ochrilidia harterti</i> G1	2.67	3.33	4.14	3.25

The species *A. patruelis*, *A. strepens*, *D. jagoi* and *C. wattenwylanus* adopted the strategy to begin their nymphal life earlier at Koléa. In contrast, the first generation of *O. harterti* showed a faster nymphal life. As for the first generation of *A. turrita*, both strategies were used at the same time: faster development and earlier hatching.

About the replacement of species, we investigated the problem through the comparison of arid

stations near Biskra, differing by human irrigation [15]. The life cycle of the total grasshopper fauna was monitored in several oases (irrigated) and steppes (not irrigated) during a year. The generation number was deduced from the variations in population sizes of nymphs. We observed variations not only in the generation numbers but also on phenology of the spring generation.

The cycles were classified into several categories:

- 1G-July: there is only one

generation where the adult populations are peaking in July

- 1G-May: ditto but adult maximum abundance is in spring

- 1G-Sept: ditto but adult maximum abundance is in autumn

- 2G-May-Sept: there are two generations, one in spring and the other one in autumn

- 3G: at least three generations per year, or continuous reproduction.

The results are gathered in table 4.

Table 4. Variations in the number of species showing the different cycle types

Cycle	Oases (salty soil or not)	Steppes (sandy or stony)
1G-July	9	3-7
1G-May	1-2	2-4
1G-Sept	2	3
2G-May-Sept	2-4	2-3
3G	2-3	2
% 1G-May, 1G-Sept, 2G	29.4 - 42.1	50.0 - 61.5
% 1G-July	47.4 - 52.9	23.1 - 38.9

The oasis insects present a majority of species with a single generation centered on July, whereas those leaving in steppes rather avoid this type of cycle. They rather adopt several strategies, either one generation occurring in spring or in autumn, or two generations (grey box in table 4). As a result, steppe grasshoppers are more rare in summer than oasis ones.

DISCUSSION

About changes in Algerian climate, caution must be taken about our work as very few stations have been taken into account. However, we draw attention on the consequences of this preliminary finding. The bioclimatic stage as defined by Emberger-Sauvage [16] through the pluvio-thermic coefficient considers annual rainfalls in the numerator, but difference between the maxima means of the hottest month (M) and the minima means of the coldest month (m).

$$Q2 = 3.43 P / (M - m)$$

It is reasonable to put a relationship between the annual maxima means (Mx) and M on one hand, and between the annual minima means (Mn) and m on the other. It can be deduced that an increase in Mx strongly suggests an increase in M, leading to a decrease of Q2. As Mx gain is greater in high plateaus and steppes than in northern plains and Sahara areas, the aridity affects more dramatically the high plateaus. Other works have showed more directly a decrease in annual rainfalls since 1970 [17], particularly in the north-west [18, 19].

The popular works of Camille Parmesan on Butterflies [20] emphasized a northward displacement of the northern boundaries of 65% of European species. It could be interpreted by the limitation of population distributions on their north side due to cold temperatures. The southern

boundaries do not present a parallel shift as only 30% of the same species contracted their range toward the north. This last phenomenon was less simple to explain, and maybe involves a competition with the northern expansion of species for which they compete with. Another possibility is a physiological requirement of a cold period preceding winter frost, during which the insects progressively enter diapause. If the cold-hardening during autumn is not sufficient, the insect, generally at the egg state, will recover prematurely an activity during mild winter days and risk to die when tardive frosts occur? [21].

The example of *Ocnieridia volxemi* could illustrate this trend as there is a shift affecting the higher and lower parts of its range between the recent and ancient periods. It would be interesting to extend our view to the other Pamphagidae limited by mild winters [7]. Another interesting example to study would be *Chorthippus vagans africanus* and *Oedipoda fuscocincta* [22] in the north-east.

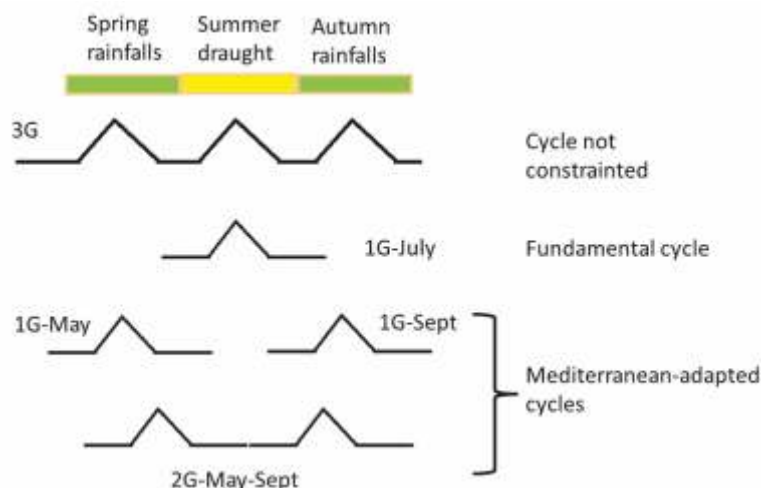
The example of *Locusta migratoria cinerascens* does not reflect the consequences of climatic changes recorded on European populations. In fact, their impact on this insect is mainly due to an increase of aridity in the recent decades. The distribution changes go in the sense of maintaining humidity needs, and hence to contract its range toward the coast. We can predict that some insect species could shift their distribution toward higher altitude not for temperature reason but rather for humidity requirements. Indeed, it has been observed that annual rainfall increased by 50 mm for 100 m increase in altitude, at least in the northern areas of Algeria [23].

The phenology of species is also modified as a result of climatic changes, as reviewed by Parmesan

and co-workers [24, 25]. Two aspects were considered here, the appearance of nymph stages and voltinism. It seems easy to interpret the lag between grasshoppers of Kolea and Soumâa. On the 6 species investigated, 5 reacted by an earlier hatching, and the remaining one by a later hatching (*O. harterti* in its first generation). This last odd response could be balanced by a shorter elapsed time between the first and last nymphal stages. These trends are correlated to an advanced occurrence of drought at the end of spring in Koléa. They probably represent a true adaptation, and are hardly explained by differences in temperatures between both stations, as January and July average and maxima temperatures are colder in Koléa. One could invoke the minima temperatures of these months that are effectively milder in Koléa than in Soumâa, but this view looks rather far-fetched. Other Mediterranean grasshoppers show a precocious generation, as emphasised by Schultner et al. [26] for the genus *Arcyptera* and by Benkenana et al. [7] for Pamphagidae.

As for generation number and phenology, we defined in Moussi et al. [15] three possible cycle types adapted to the Mediterranean climate: one generation centered on spring, or on autumn, or two generations. These features are in opposition to the hypothetical fundamental cycle observed in tropical and temperate (non-Mediterranean) areas, where there is a single generation centered on July. The shift of Mediterranean-adapted species is driven by the avoidance of summer drought. As for continuous reproduction or at least three generations per year, the species do not suffer climatic constraints. These views can be summarized in figure 4.

Figure 4. Variations in the generation numbers of grasshoppers in a Mediterranean context. The peaks of adults are symbolized by a sharp angle.



In conclusion, Algerian grasshoppers constitute a motivating group of insect to evaluate the impact of climate changes. However, the difficulties come from the availability of

climatic data, and the scarcity of historical collections. A lot of work is required to understand the intra-specific variations of cycle types, and phenology.

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