Central Saharan populations of *Locusta migratoria cinerascens* (Orthoptera: Acrididae) in irrigated perimeters: is it a recent colonisation event?

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Abstract. *Locusta migratoria cinerascens* became a potential pest in irrigated cereals under pivots, in the Touat region (Algerian Central Sahara), since the indication of the first crowding in June 1994. Morphometrics and bioclimatic approaches revealed the homogeneity between North and South Algerian populations, suggesting a recent colonisation of Central Sahara, aided by the development of large acreage perimeters. We studied the populations of this acridian from 1995 to 2004 and show that they belonged to the solitarious or *transiens* phase and never reached the gregarious one. The absence of this last phase is discussed in the light of heterogeneous densities observed in the successive generations.

Résumé. Populations centre-sahariennes de *Locusta migratoria cinerascens* (Orthoptera : Acrididae) dans les périmètres irrigués : est-ce une colonisation récente ? *Locusta migratoria cinerascens* est devenu un ravageur potentiel dans les cultures de céréales irriguées sous pivots, dans la région de Touat (Sahara Central algérien), depuis l'indication des premières pullulations en juin 1994. Des approches morphométriques et bioclimatiques révèlent une homogénéité des populations du nord et du sud algérien, suggérant une colonisation récente dans le Sahara Central, à la faveur de la mise en valeur de grandes surfaces agricoles. Nous avons étudié des populations de cet acridien de 1995 à 2004 et montrons qu'il s'agit d'individus de phase solitaire ou *transiens*, n'ayant jamais atteint l'état grégaire. L'absence de cette dernière phase est discutée à la lumière des fortes variations de densités observées entre les différentes générations.

Keywords: Phase state, Algeria, bioclimagram, morphometrics.

Among the locusts, *Locusta migratoria* L. is the species showing the largest ecological plasticity and geographical extension (Launois-Luong & Lecoq 1993). In its gregarious form, this acridian causes many damages since its outbreak spreads in the steppe zones from Europe, Asia as well as tropical areas of Africa and Madagascar (Balachowsky & Mesnil 1936; Duranton *et al.* 1982). Several subspecies of *Locusta migratoria* are described in the Old World, some of them being recently genetically characterized (Chapuis *et al.* 2008).

The subspecies *L. m. cinerascens* Fabricius 1781 is common in waste land, humid environments with reeds, and rush beds around the Mediterranean Sea (Chopard 1951; La Greca 1959; Deveci 1996; Thorens & Nadig 1997; Boitier *et al.* 2006). The French individuals of this subspecies are clearly characterized by their size smaller than those of the subspecies *L. m. migratoria* present in the French Languedoc littoral and in Corsica (Defaut 2005, 2006; Boitier *et al.* 2006, Harrat & Petit 2009). In contrast to the sub-Saharan African subspecies *L. m. migratorioides* (Reiche & Fairmaire) which is very "gregariapte" sensu Uvarov (1966), the subspecies *L. m. cinerascens* was almost always observed in its solitary form in nature. To our knowledge, the only exception relates to an episode in 1936, near Naples in Italy, where individuals harbouring gregarious colours and forming temporary bands appeared, but without any flight (Jannone 1936).

In Algeria, *L m. cinerascens* is a taxon characteristic of the littoral areas and plains of the Tellian Atlas, as well as of South Saharian Atlas (Chopard 1943; Benfekih & Petit 2008). In the Algerian Central Sahara, recent development of new perimeters irrigated by pivots on a large scale resulted in the frequent crowdings of *Schistocerca gregaria* and *L. m. cinerascens* on summer cereals, particularly in Adrar region (Ould ElHadj 2002). In this area, the first indication of this last species was mentioned in 1994 around Touat (SW

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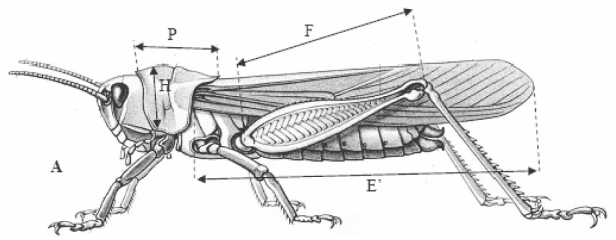

Figure 1
Position of morphometrics measurements.

of Adrar Wilaya, 1500 km South of Algiers) (Drias 1994). This acridian is settled in crops under palm plantation and in cultures irrigated by pivoting system in oasian zones. It can exceptionally be retrieved on rocky environments, as we observed in Biskra region between the Saharian Atlas and the Northern Sahara (Benfekih *et al.* 2002; Benfekih 2006).

The aim of this work is to test the homogeneity of the populations from North and South Algeria by morphometrics and bioclimatic approaches. Would it be possible that the populations of the South belong to a different taxon? How different are the climatic requirements of South and North populations? In addition, we tested if the observed crowding events were accompanied by a phenomenon of gregarisation.

Table 1. Studied specimens for morphometrical measurements. Samples studied for phase variations in *L. m. cinerascens.*

Localities	males	females
Adrar 1995	35	35
Adrar 1997	40	20
Adrar 2002	30	30
Adrar 2003	30	30
Adrar 2004	18	40
North Algeria	35	20

Lastly, the origin of these populations from the Central Sahara is a question we want to address: did they exist locally in a sporadic way or did they come from a recent colonization moving from the center of Algeria?

Material and methods

Bioclimagram

The distribution of *Locusta migratoria* in Algeria was synthesized from recent inventories, contained in many works and theses published between 1988 and 2003, covering various areas from the Mediterranean littoral until the extreme south (references in Benfekih 2006). For each of the 49 listed localities, we took into account the values of m (average of the minima of the coldest month, in °C), M (average of maxima of the hottest month, in °C), P (annual rainfalls, in mm) and Q2 (pluviothermal coefficient of Emberger-Sauvage, (Sauvage 1963), according to the Q2 formula = 3.43 P / (M - m). These climatic data relate to the interval 1971–2003 and were extracted from the National Meteorology Office, and from various theses dealing with the Algerian orthopterofauna.

The bioclimagram of *L. migratoria* was established by calculating the frequency of the species. We indicated the position of each locality in a 2 dimensions graph, with m° C in X-coordinate and Q2 in Y-coordinate. The presence-absence of *L. migratoria* was coded by 1-0 and used as a 3rd dimension. The SYSTAT 7.0 software (S.P.S.S. 1997) calculated and plotted the iso-frequency curves (probability of presence) in the 2-dimension bioclimagram.

Characterization of the Algerian subspecies

We carried out 5 measurements (fig. 1) on individuals from North and South Algeria (tab. 1, 2). The recent individuals were collected in the area of El-Taref (NE Algeria) in August 2007, and in irrigated perimeters in the Central and North Sahara around Adrar and Ouargla (1995–2004). The older specimens (1946–1956) come from the North of Algeria, kept in the zoological collection of the National Agronomic Institute of El-Harrach (NAI). We compared these data with the measurements taken on individuals belonging to the subspecies *L. m. cinerascens* and *L. m. migratoria* collected in continental France and Corsica, kept in the zoological collection of the University of Limoges and of the CIRAD in Montpellier.

The measured parameters were as follows. C: maximum width

Table 2. Studied specimens for morphometrical measurements. Samples studied for subspecies characterization.

Subspecies	Population		C	P	H	E	F
L. m. migratoria	Herault (N=13)	Mean	7.23	11.20	9.99	46.52	27.76
		Stand. dev	0.32	0.67	0.62	2.09	1.86
	Corsica (N=8)	Mean	7.58	11.71	10.23	49.94	29.19
		Stand. dev	0.47	1.69	1.26	5.94	3.32
L. m. cinerascens	South France (N=10)	Mean	5.55	8.42	7.92	40.21	22.33
		Stand. dev	0.45	0.53	0.46	2.12	1.29
	North Algeria (N=16)	Mean	5.55	8.05	7.74	39.58	22.16
		Stand. dev	0.50	0.45	0.44	2.37	1.34
	South Algeria (N=25)	Mean	5.93	8.31	7.98	39.37	21.54
	(Adrar 1995)	Stand. dev	0.24	0.52	0.35	1.00	0.91

of the head, at the cheek level; P: length of the pronotum; H: maximum height of the pronotum, in the mid part of the prozone; F: length of the posterior femur; E: length of the tegmen, until the disappearance of the radial vein under the pronotum.

Determination of the phase state

To determine the phase state of the Algerian populations, we took into account the ratios E/F and F/C defined by Uvarov (1966) which specify the limits of the solitary and gregarious phases for *L. migratoria cinerascens*. We measured 188 males and 175 females (tab. 1, 2) collected from the irrigated perimeters of Adrar between 1995 and 2004, and from the zoological collection of the NAI for North Algerian specimens. We reported the calculated ratios as well as the limits of both phases on the abacus of Duranton *et al.* (1990).

We consulted the *L. migratoria* records from the files of the National Institute for Crop Protection (NICP) and of Adrar Inspection of Plant Protection (AIPP) between 1994 and 1999. These files mention the geographical coordinates, the locality name, the date, the infested surface, the crop, and the adult density of locusts.

Statistical analyses

We tested the significance of the climatic factors on the presence-absence of *L. migratoria* using logistic regressions conducted with JMP software vers. 5.0 (S.A.S. 2002). Morphometrics data were analysed using a component analysis (P.C.A.) conducted with PAST software vers. 1.78 (Hammer *et al.* 2001). The various Saharan populations and the collection specimens of North Algeria north were compared by using a discriminant analysis with SYSTAT version 7.0. (S.P.S.S. 1997).

Results

Bioclimagram of *L m. cinerascens*

The graph of figure 2 shows a high frequency of this species in two discontinuous areas, one in North Algeria and the other in the Sahara (Touat region). In the northern part, *L. m. cinerascens* is mainly observed in the sub-humid and humid Mediterranean stages with mild winter temperatures and in semi-arid stage with warm winter temperature. In the southern part, the species is confined on the Saharian stage with mild to warm winter temperatures. The frequency of *L. migratoria* significantly increases, at least marginally, when m°C is elevated, in North Algeria (fig. 3A: logistic regression, N = 38, p = 0.056) as well as in the South (fig. 3B: logistic regression, N = 12, p = 0.028). Thus, this locust is related to an average m around 5 °C in both parts of Algeria. In contrast, its frequency depends neither on annual precipitations (P, in mm) nor on the pluviothermal coefficient Q2. For both parameters P and Q2, the logistic regressions gave N = 38 and p > 0.1 and N = 12, p > 0.2 in the northern and southern parts respectively.

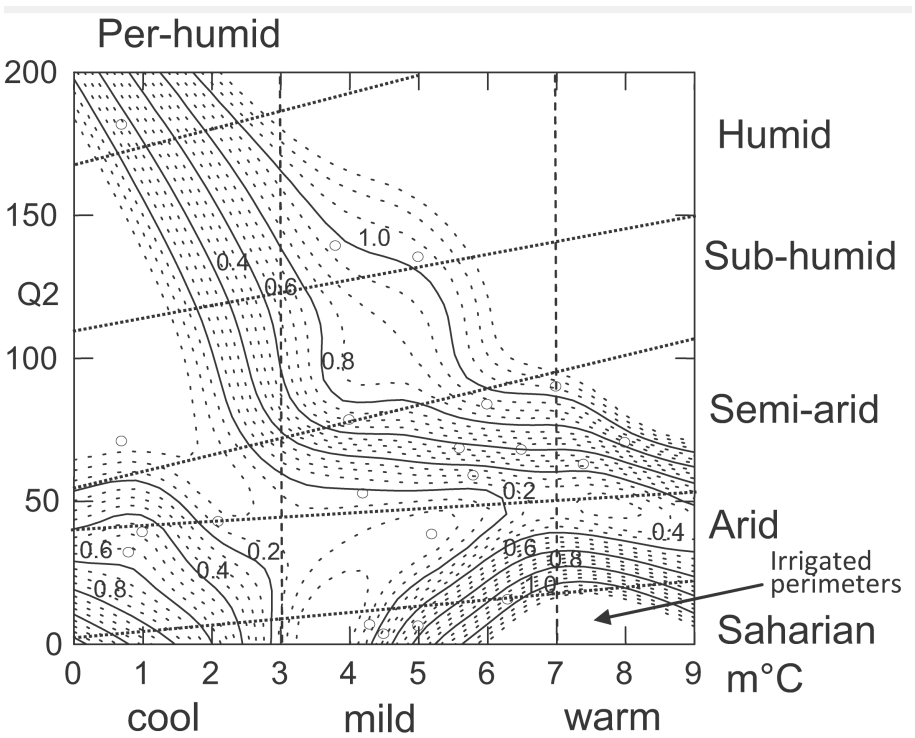

Figure 2
Iso-frequency curves of *Locusta migratoria* in the bioclimagram in Algeria. The stage limits are established from Daget (1977).

Systematic characterization of the Algerian populations of *L. m. cinerascens*

The morphometrics measurements of the solitarious males from France, South and North Algeria, analysed by P.C.A., gave the projection graph on the F1-F2 ordination plane bearing more than 90 % of variance (fig. 4). There is an opposition between the subspecies *L. m. migratoria* and *L. m. cinerascens*, the last one being characterized by their low size values (P, F, H, and E). The populations from France, North and South Algeria are relatively homogeneous with a strong covering of their envelopes. The South Algerian populations

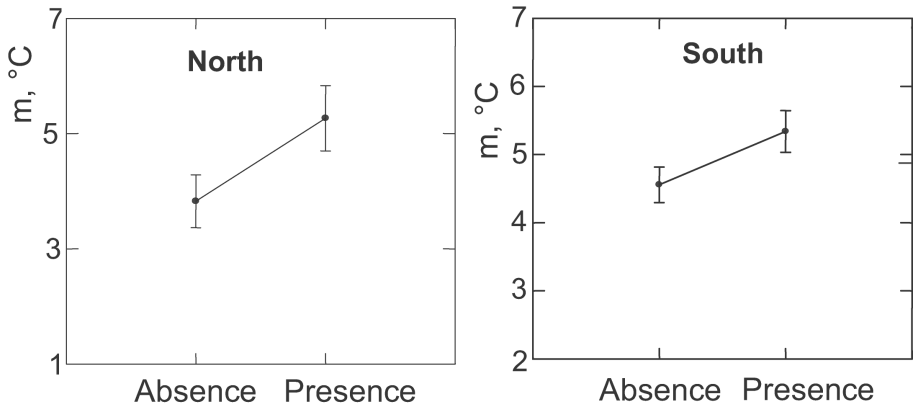

Figure 3
Frequency of *L. migratoria* according to the minima means of the coldest month. A: North ; B: South.

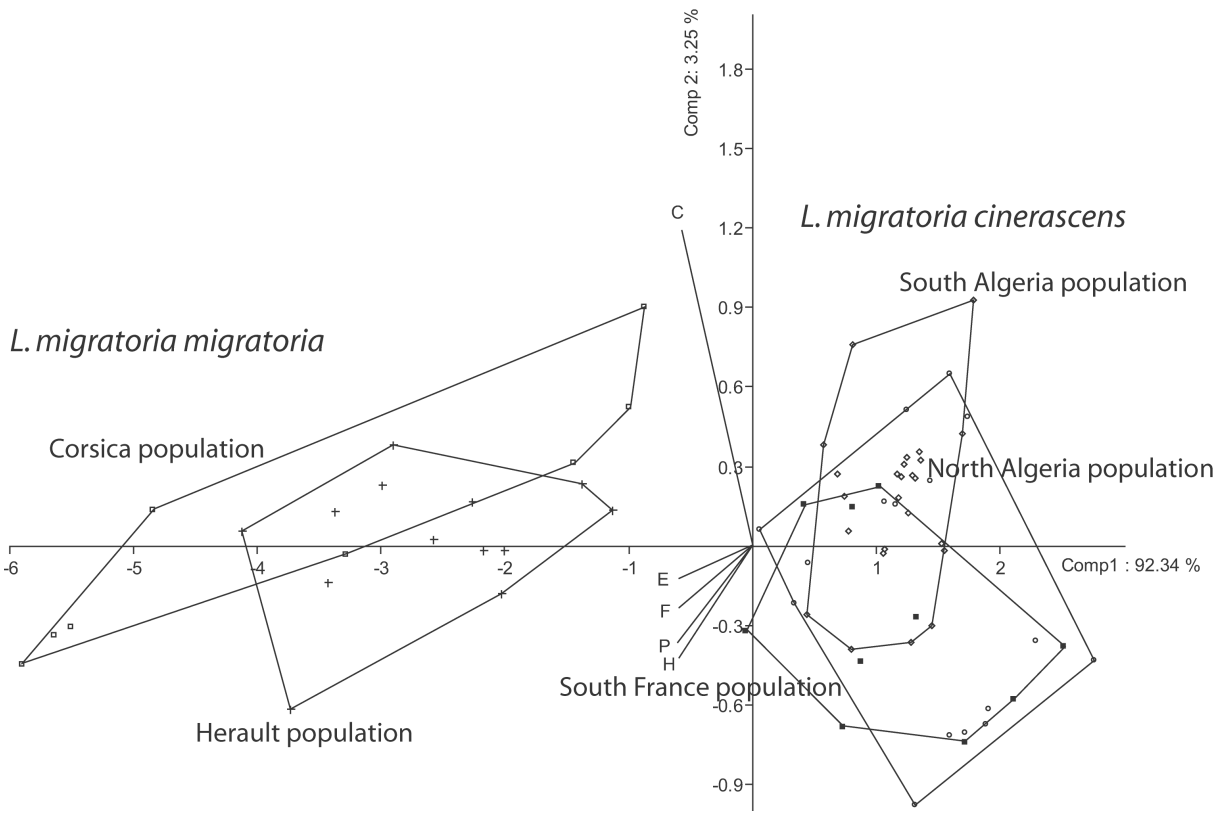

Figure 4
Projection of *L. m. migratoria* and *L. m. cinerascens* male individuals on the F1-F2 ordination plane of PCA.

have broader heads than the others. Moreover, the specimens from North Algeria have intermediate values for tegmen and femur lengths, less than the ones collected in South France and more than the ones found in Sahara. In conclusion, if the populations of France and South Algeria are different, the populations of North Algeria seem to represent a gradual transition between South Algerian and French populations.

Variation of the phase polymorphism of *L. m. cinerascens* populations

The morphometrics abacus of Duranton *et al.* (1990) shows that the locust populations collected in the irrigated perimeters in Central Sahara belong to solitarious or *transiens* types (fig. 5). In the males, the *transiens* phase is the *congregans* type, more particularly in 1995, 1997 and 2002. In 2003, this *transiens* phase tends to approach the solitary phase. The isolated position of the 2004 population is difficult to qualify, since its trajectory heads away as much from the solitary phase as from the gregarious one. Otherwise, the Northern populations are very close to the solitarious phase.

The discriminant analyses dealing on both ratios showed very significant differences between the populations of the North compared to the South population ($p < 1‰$). According to the inter-annual phase variations within South populations, we note a slight change between 1995 and 1997 ($Fr_{1,73} = 2.61$, $p = 0.07$ %). The variation is clearer between 1997 and 2002 ($Fr_{1,68} = 3.34$, $p = 0.04$), ditto between 2002 and 2003 ($Fr_{2,58} = 3.36$, $p = 0.04$) and especially pronounced between 2003 and 2004 ($Fr_{2,46} = 26.50$, $p < 1‰$). The measurements undertook on the females revealed similar results (data not shown), except that the 1995 population was closer to the solitarious phase than for the males.

The examination of NICP and AIPP files revealed a progressive decrease in the number of localities infested by the locust in Adrar region: 66 sites in 1995, 46 in 1996, 21 in 97, 2 in 1998, 14 in 1999 and 2 in 2000. In parallel, irrigated cereal perimeters progressively decreased from 4500 ha in 1995 to 3000 ha in 2002.

Discussion

Homogeneity of *L. migratoria cinerascens* Algerian populations

Most works dealing with morphometrics focused on the subspecies *L. m. migratorioides*, *migratoria*, and *manilensis* but only few on natural populations of the subspecies *L. m. cinerascens* (Kang *et al.* 1989, Kang & Yonglin 1991; Lecoq 1991). To our knowledge, no systematics study in Algeria was carried out on this locust since the synthesis of Chopard (1943). Our comparisons between solitary populations of South and North Algeria and populations from France show that the subspecies *L. m. cinerascens* is homogeneous on both sides of the Mediterranean Sea. It is easily distinguished from the subspecies *L. m. migratoria*,

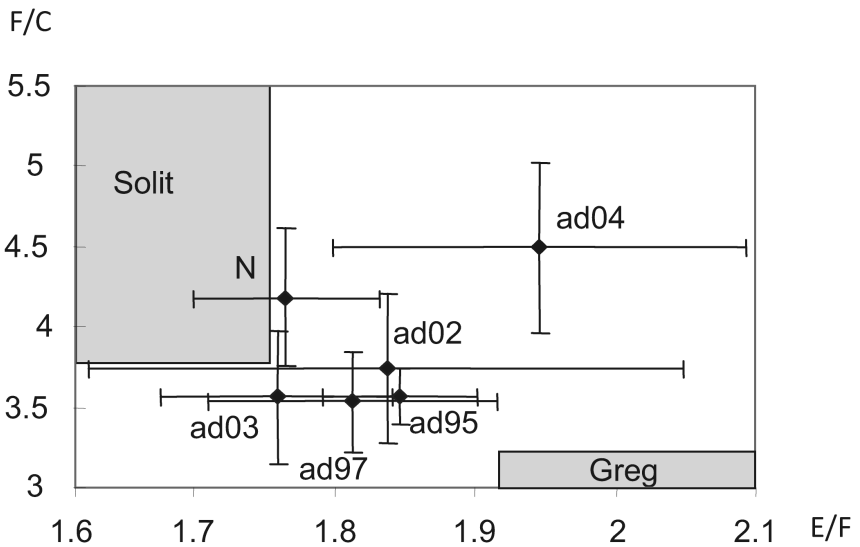

Figure 5
Phase transitions in males (means ± standard deviations) (after Duranton *et al.,* 1990, modified). Abbreviations : Greg : *gregaria* ; Solit : *solitaria* ; ad : Adrar populations in different years

also known as the "criquet de Palavas", by an overall lower size, as was also demonstrated by Defaut (2005). Based on the fact that both subspecies coexist in Corsica, Defaut (2006) suggested that populations are reproductively separated and hence have to be treated as valid species. In contrast, another hypothesis could be that the greater specimens, assigned to the subspecies *migratoria,* result from a supernumerary larva stage, but this should be tested.

The bioclimagram of *L. m. cinerascens* in Algeria was established using the observations of the adults in various localities. It is noticeable that many localities recorded for the old specimens kept in the zoology collection of the NAI were retrieved in recent inventory works. This similarity at many years interval indicates that the obtained bioclimagram would be reliable. This pragmatic consideration is also applied by the researchers who build models of species distribution (see the review article of Guisan & Thuiller 2005). The disjunction of the bioclimatic area between the North and South populations is explained very simply insofar as the irrigation of the cereal perimeters constitutes a hydrous compensation to the very low annual rainfall. The bioclimagram obtained in North Algeria corresponds probably to the best ecobiological and physiological requirements of the locust (Benfekih & Petit, 2008). In contrast, the presence of this species in irrigated perimeters of Central Sahara is essentially due to artificial anthropic factors. Moreover, the homogeneity of *L. m. cinerascens* populations is underlined by a common optimum winter climatic parameter m around 5 °C in North and South Algeria.

A recent conquest of the South?

Given all available sources of information, the species was only recorded in the Algerian Sahara in 1991 (Ould ElHadj 1991), near Tamanrasset, but whether there has been a confusion with *L. m. migratorioides* is not clear, as no specimen was kept to verify the identification. More recent observations made by Guendouz-Benrima (2005) during her thesis field work on crops perimeters in this area did not mention any migratory locust. We thus hypothesize that the occurrence of the locust, whatever it is, in the Algerian extreme South was occasional, due to a possible migration event from Sahel adjacent countries. Later in 1994, *L. m. cinerascens* has been reported in the irrigated perimeters of Zaouiet-Kounta (Adrar) by prospection teams of the NICP (Drias 1994). The two most southern localities of *L. migratoria cinerascens* recorded in 1943 by Chopard are Laghouat (Saharian Atlas) at about 740 Km and Biskra (North Sahara) at about 980 Km from Touat. Can we deduce that the species was absent in the Central Saharan localities before 1994? We cannot exclude that it was present as isolated individuals and thus unnoticed. Benfekih (2006) in her thesis defined 17 acridian species associated to *L. m. cinerascens* from recent inventory works. Among these species, Chopard (1943) reports *Duroniella lucasi, Heteracris harterti* and *Acanthacris ruficornis* in Ouargla (North Sahara), two other associated species (*Acrotylus patruelis* and *Aiolopus strepens*) in In-Salah region (Central Sahara), but not *L. m. cinerascens* itself. An insect of such a big size and showing a remarkable flight when frightened is easily detected. Thus, we can reasonably deduce that it is unlikely that *L. m. cinerascens* was present in Adrar region many years before 1994.

In summary, as the locust was probably absent in North Sahara (Ouargla and Ghardaïa), and in Central Sahara (Adrar) until 1943, the colonisation event from Central Algeria was perhaps aided by agricultural installations with irrigated perimeters in the mid-eighties. The strong morphological proximity between the populations of Adrar and Ouargla and the populations of North Algerian supports a recent colonization.

Phase variations of the South Algerian populations

The concentration of irrigated perimeters around the West of Adrar region, especially in Stah Azzi plateau, shelters most crowded populations of the locust. However, these crowdings have never led to a gregarious phase recognizable by morphometrics, colour and behaviour criteria. We show that the populations which approached this phase are those of 1995, maybe due to the highest number of infested sites. The decreasing following numbers of infested localities parallel the transition of population towards solitarious phase. However, the question why *Locusta migratoria cinerascens* was never shown in a gregarious state in North Africa (Chopard 1943) is raised. Curiously, this subspecies can easily become gregarious under controlled conditions of the laboratory (Nicolas *et al.* 1979). As for the Malagasy subspecies *L. m. capito*, very "gregariapte", favourable local conditions constitute only one step towards the transformation to the gregarious phase. They must be necessarily preceded by immigration of solitarious populations, involving an important concentration of parental layings. An outbreak can occur in less than 2 or 3 successive generations for this subspecies (Lecoq 1991). In the case of Adrar populations, important larvae densities were observed in the summer-autumnal generation, while the spring and spring-summer ones showed only low densities (Benfekih & Petit 2010). As for adult densities per ha in the 1995–1997 period, mean and median values observed were about 5000 and 1300 in the summer-autumnal generation, but about 2500 and 10 respectively in the spring generation, and only

700 and 70 in the spring-summer generation. Uvarov (1966) argued that more than 2000 individuals per ha are required to the development of gregarism in *L. migratoria* s.l. As such a high density level is not maintained in the 3 successive annual generations, we hypothesize that it is the main reason for the non-appearance of complete gregarious phase.

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References

Balachowsky A., Mesnil L. 1936. *Les insectes nuisibles aux plantes cultivées, leurs mœurs, leur destruction*. T. II, vol. III, Etablissement Busson, Paris, p. 1141-1921.

Benfekih L. 2006. *Recherches quantitatives sur le criquet migrateur Locusta migratoria (Orth. Oedipodinae) dans le Sahara algérien. Perspectives de lutte biologique à l'aide de microorganismes pathogènes et de peptides synthétiques.* Thèse de Doctorat Université de Limoges, 140 p.

Benfekih L., Chara B., Doumandji-Mitiche B. 2002. Influence of anthropogenic impact on the habitats and swarming risks of *Dociostaurus maroccanus* and *Locusta migratoria* (Orthoptera, Acrididae) in the Algerian Sahara and the semiarid zone. *Journal of Orthoptera Research* **11(2)**: 243-250.

Benfekih L., Petit D. 2008. Distribution altitudinale de *Locusta migratoria ssp. cinerascens* dans le nord algérien: y a-t-il un effet du changement climatique global? p. 33-42 *in*: **Boitier E., Sourp E., Petit D.** (**eds**). *Insectes d'altitude, insectes en altitude. 1 Actes des premières rencontres entomologiques du Massif Central*, ed. PNR Livradois-Forez and Société d'Histoire Naturelle Alcide d'Orbigny, St-Gervais-sous-Meymont, Aubière.

Benfekih L., Petit D. 2010. The populations of *Locusta migratoria cinerascens* (Orthoptera: Acrididae: Oedipodinae) in Algerian Sahara: life cycle. *Annales de la Société Entomologique de France (N.S.)* **46** (3–4): 351-358

Boitier E., Petit D., Bardet O. 2006. Contribution à la connaissance des Orthoptéroïdes de Corse (Orthoptera Phasmoptera Mantodea). *L'Entomologiste* **62(5–6)**: 129-145.

Chapuis M.P. 2006. *Génétique des populations d'un insecte pullulant, le criquet migrateur, Locusta migratoria*. Thèse de doctorat, Ecole Nationale Supérieure Agronomique de Montpellier, 72 p.

Chapuis M- P., Lecoq M., Michalakis Y., Loiseau A., Sword G. A., Iry P., Estoup A. 2008. Do outbreaks affect genetic population structure? A worldwide survey in *Locusta migratoria*, a pest plagued by microsatellite null alleles. *Molecular Ecology* **17**: 3640-3653.

Chopard L. 1943. *Orthoptéroïdes de l'Afrique du Nord. Faune de l'empire français*. Librairie Larose, Paris, 450 p.

Chopard L. 1951. *Faune de France. Orthoptéroïdes*. Lechevalier, Paris, 359 p.

Daget P. 1977. Le bioclimat méditerranéen: analyse des formes climatiques par le système d'Emberger. *Vegetatio* **34(2)**: 87-103.

Defaut B., 2005. Sur la répartition de *Locusta migratoria migratoria* (L.) en France (Caelifera, Acrididae, Oedipodinae). *Matériaux Orthoptériques et Entomocénotiques* **10**: 81-86.

Defaut B., 2006. Eléments pour la faune de France des Caelifères. 5. A propos de *Locusta migratoria cinerascens* (Fabricius, 1781) (Caelifera, Acrididae, Oedipodinae). *Matériaux Orthoptériques et Entomocénotiques* **11**: 59-61.

Deveci O. 1996. Observations on diapause of *Locusta migratoria cinerascens* (Fab.) (Orthoptera: Acrididae) in the Menemen-Izmir Plain population. *Turkish Journal of Zoology* **20(3)**: 255-259.

Drias A. 1994. *Rapport sur la situation acridienne dans la wilaya d'Adrar. Mois de juin 1994. Rapport de mission de prospection antiacridienne.* Ministère de l'Agriculture, INPV, n°76/94, 5 p.

Duranton J.-F., Launois M., Launois-Luong M.H., Lecoq M. 1982. *Manuel de prospection acridienne en zone tropicale sèche (2 vols)*. Groupement d'Études et des Recherches pour le Développement de l'Agronomie Tropicale (G.E.R.D.A.T.), Paris, 1496 p.

Duranton J.-F., Lecoq M. 1990. *Le Criquet Pèlerin Au Sahel. Coll.: Acridologie opérationelle, n°6, Ministère des affaires étrangères des Pays-Bas*, Ed. La Hague/Montpellier, 183 p.

Guendouz-Benrima, A. 2005. *Ecophysiologie et biogéographie du criquet pèlerin Schistocerca gregaria (Forskål, 1775) (Orthoptera, Acrididae) dans le sud algérien*. Thèse doctorat Inst. Nat. Agro. El-Harrach, 210 p.

Guisan A., Thuiller W. 2005. Predicting species distribution: offering more than simple habitat models. *Ecology Letters* **8**: 993-1009.

Hammer Ø., Harper D.A.T., Ryan P.D. 2001. PAST, Paleontological Statistics Software Package for Education and Data Analysis. *Palaeontologia Electronica* 4(1): 9 pp. http://palaeo-electronica.org/2001_1/past/issue1_01.htm

Harrat A., Petit D. 2009. Chronologie du développement embryonnaire de la souche „Espiguette" avec ou sans diapause de *Locusta migratoria* Linnaeus (Orthoptera : Acrididae). *Comptes Rendus de Biologies* **332**: 613-622.

Jannone G. 1936. Nuovi contributi alla conoscenza della fauna delle Isole Italiane dell' Egeo. V. Studio bio-ecologico e sistematico dell' Ortotterofauna con notiziesui Blattodei, Mantodei e Fasmoidei. Bollettino Laboratorio di Zoologia generale i agraria R. *Scuola superiore d' Agricoltura Portici* **29**: 47-248.

Kang L., Hongchang L., Yonglin C. 1989. Analysis of numerical character variations of geographical populations of *Locusta migratoria* phase solitaria in China. *Acta Entomologica Sinica* **32**: 418-426.

Kang L., Yonglin C. 1991. The analysis of numerical taxonomy to the inter-relationships among different geographic populations of *Locusta migratoria* (L.) phase solitaria (Orthoptera, Acrididae). *Sinozoologia* **8**: 71-82.

La Greca M. 1959. L'ortotterofauna pugliese ed il suo significato biogeografico. *Memorie di Biogeografia adriatica, Venice* **4:** 33-170.

Launois-Luong M.A., Lecoq M. 1993. *Manuel explicatif du code OMM de transmission des informations sur les criquets ravageurs*. Ed. CIRAD-PRIFAS, Genève, 31 p.

Lecoq, M. 1991. *Le criquet migrateur en Afrique et à Madagascar. Guide des principaux locustes et criquets ravageurs du monde entier*. Ed. CIRAD-PRIFAS, Montpellier, France, 131 p.

Nicolas G., Fuzeau-Braesch S., Djeddour K. 1979. Influence de la suppression du thermo-photopériodisme sur les caractéristiques morphométriques du criquet migrateur, *Locusta migratoria* L., élevé en groupe. *Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences, D* **288**: 343-346.

Ould Elhadj M.D. 1991. *Bioécologie des sauterelles et des sautériaux dans trois zones d'étude au Sahara.* Thèse Magister, Institut Natinal Agronomique, El Harrach, 85 p.

Ould Elhadj M.D. 2002. Les nouvelles formes de mise en valeur dans le Sahara algérien et le problème acridien. *Sécheresse* **13**: 37-42.

Sauvage C. 1963. *Étages bioclimatiques. Comité national de Géographie du Maroc.* Atlas du Maroc, notices explicatives, section II: physique du globe et météorologie, Planche n° 6b, 31 p.

S.A.S. 2002. JMP vers. 5.0. *Software and manual for Windows™.*

S.P.S.S. Inc. 1997: *SYSTAT 7.0 for Windows, statistics and graphics*.

Thorens P., Nadig A. 1997. Atlas de distribution des Orthoptères de Suisse: sauterelles, grillons, criquets (Orthoptera), mante religieuse (Mantodea). *Documenta Faunistica Helvetiae* **16**: 1-236.

Uvarov B.P. 1966. *Grasshoppers and locusts. A handbook of general acridology. Vol. 1, anatomy, physiology, development, phase polymorphism, introduction to taxonomy.* Cambridge University Press, Cambridge, xi + 481 p.