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Variations in the requirements of environment parameters by solitary Desert Locust in Algerian Sahara

MAHDJOUBI Djillali[1], OUTTAR Fahima[1], GUENDOUZ BENRIMA Atika[2], KIROUANI Abderrezzak[1], PETIT Daniel[3]

[(1)] University of Medea, Department of Natural Sciences and Life, Algeria 26000.
[(2)] University of Ghardaia, Department of Agronomy, Algeria
[(3)] UMR 1061, INRA, University of Limoges, 123 avenue A. Thomas, 8706 Limoges France.

***Corresponding Author**: Mahdjoubi Djillali, *University of Medea, Department of Natural Sciences and Life, Algeria* **Email**: djillalimahdjoubi@gmail.com
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Abstract

To test the influence of local conditions on the density and frequency of solitary Desert Locust (*Schistocerca gregaria*), we performed 466 samplings in different areas of Algerian Sahara during surveys conducted between 2007 and 2013. For each sampling, a quantitative analysis of flora, vegetation, soil humidity and Desert Locust was undertaken. It turns out that the relationships between environmental descriptors and adult density at the local scale vary according to populations. The mountain of south east Algeria is considered as refuges for autumn populations as they presence is conditioned neither by soil humidity nor by vegetation. In Central Sahara near Adrar, the spring populations are very sensitive to humidity and vegetation composition, and also result from local reproduction and immigrations from south east mountain areas, rather than south Saharan areas. In southern Algeria, the populations found in summer result from an admixture of local and exogenous populations coming from central Sahara and Sahel countries.
Keywords: *Schistocerca gregaria*, vegetation, Sahara, density

الملخص

لاختبار تأثير العوامل البيئية لمناطق مختلفة على كثافة وتردد الجراد الصحراوي (*Schistocerca gregaria*)، أجرينا 466 عينة في الصحراء الجزائرية من خلال المسوحات التي أجريت بين عامي 2007 و2013. عملية التحليل الكمي رطوبة التربة، الجراد الصحراوي والغطاء النباتي أوضحت وجود علاقات بين العوامل البيئية للنباتات، كثافة اليرقات، البالغين يعتبر اعالي جبال جنوب شرق الجزائر مأوى لمجموعات الخريف حيث أن وجودهم غير مشروط برطوبة التربة ولا بالنباتات. في الصحراء الوسطى بالقرب من أدرار، تعتبر مجموعات الربيع حساسة للغاية للرطوبة وتكوين الغطاء النباتي، ينتج الأجيال من التكاثر المحلي والهجرة من المناطق الجبلية الجنوبية الشرقية، بدلا من مناطق جنوب الصحراء. في جنوب الجزائرعلى النطاق المحلي يختلف باختلاف المجموعات الموجودة في الصيف الناتجة عن مزيج من الأفراد المحليين والخارجيين وينتجون أيضًا عن القادمين من وسط الصحراء ودول الساحل.
الكلمات المفتاحية :الجراد الصحراوي، الصحراء، النبات، كثافة

Introduction

Of locusts in Africa, *Schistocerca gregaria*, or Desert Locust, is the most harmful species from an economic point of view, in reason of the extent of its invasion area and the damages it can cause (Popov et al. 1984; Duranton and Lecoq, 1990). Invasions are a major spectacular phenomenon and the extent of devastation, in the midst of invasion, can be considerable. The ravages of this species have been known since antiquity and medieval chronicles certify that its ravages continued uninterrupted, as successive crises. Since 1860, eight periods of successive plagues have been recorded in Sahara: 1860-1867, 1869-1881, 1888-1910, 1912-1919, 1926-35, 1940-47, 1949-1962 and 1967-1971 (Waloff, 1976; C.O.P.R., 1981). Over the past forty years, the further invasions were at a somewhat lower level as a result of more efficient outbreak controls: 1972-1977, 1978-1984, 1993-1995 and 2003-2005 (Ceccato et al., 2007; Magor et al., 2008).

This gregariapt locust can live at solitary phase, but as a result offavorableweather conditions, multiplies rapidly and progressively reaches the gregarious phase (Uvarov, 1966). The factors involved in phase transformation, i.e., the transition between solitarious to gregarious states include the climatic conditions (Uvarov, 1966) but also the pattern of vegetation (Baba and Sword, 2004; Despland et al., 2000; Sword et al., 2010).

Field works on the solitary phase has been conducted in different African countries, including Mauritania (Culmsee 2001, 2002; Babah and Sword 2004), Morocco (Bouaichi et al., 1996), Libya (Guichard 1955), Sahelian countries (Gray Tappan et al. 1991), Sudan (Van Der Werf et al., 2005, Van Huis et al. 2008, Woldewahid et al. 2004, Omer 2006). As for Algeria, several studies have been undertaken and we can cite, among others: Ould El Hadj 2004, Guendouz-Benrima 2005, Guendouz-Benrima et al., 2007, 2010). In remission periods, the solitarious populations of Desert Locust are found at low densities in suitable habitats (Uvarov, 1977). According to erratic desert rains, this locust can settle on these habitats during variable periods of the year. The temporal irregularity of suitable areas conducted the Desert Locust to disperse over great distances within a general framework resumed by C.O.P.R. (1981) and Magor (1995). In summer, populations from Sahel (mainly Niger and Mali) migrate and reach the south and may be the center of Algerian Sahara where they stand during winter. In Spring there is a back migration toward south Sahara and Sahel. This scheme is obviously imprecise and may vary according to the year.

Our aim is to survey the principal areas of Desert Locust presence in Sahara after the 2003-2004 invasion period, and to characterize locally their ecological requirements. The objective is to understand the nature of the biotopes where the locusts are found. Broadly speaking, the question addressed is whether a given biotope represents a reproduction area, only a trophic source area, or even a crossing temporary place. The study of these habitats needs first to provide information on the status of locust populations: local reproduction and phase state of adults. In other side, the associated stations must be characterized by the fine description of plant communities as defined by Barry and Celles (1972, 1973, 1976, 1981), and by physical parameters of soil (granulometry and moisture). These habitats have to be considered also at the region level, motivating us to explore four different areas in Algerian Sahara, differing by their climate, altitude, and geographic position. Two of these regions (Adrar, Tamanrasset and Bordj-Baji-Mokhtar) were chosen as they were identified as centers of locust outbreaks in the past 20 years by the Algerian DLAA (Département de Lutte Anti-Acridienne). The fourth one (Djanet) hosted the Desert Locust but it does not seem to reproduce regularly each year (if any) (Sitouh 1976; Guendouz-Benrima et al., 2005).

Materials and Methods

The different samplings were carried out in four regions (fig. 1) belonging to three areas of the Algerian Sahara (Central, South Western, Southern) considered as hosting high frequency of locust activity (reproduction and crowding). According to the latitude of these areas, the influence of Mediterranean or tropical climate has more or less pronounced effect on the rainfall regime (Sitouh, 1976; Chara, 1998, Guendouz-Benrima, 2005; Guendouz-Benrima, 2007).

In Central Sahara, the records were conducted largely around Adrar, and more precisely at Abalessa, Aoulef and Reggane stations, between 300 and 800 m of altitude. These stations are characterized by a stable annual rainfall less than 100 mm and a period of rainy season running from October to February, indicative of dominant Mediterranean influence. In contrast, in the Southern part of Algeria, the area of Bordj-Badji-Mokhtar (BBMk) is above 20° of latitude, at around 500 m of altitude, and the rainfalls are focused on the month of August, reflecting a tropical regime. The two remaining areas occupy intermediary latitudes and their rainfall regime is loosely related to Mediterranean or tropical influence. The stations near to Tamanrasset were situated around 22° of latitude, between 600 and 1000 m. The rainfalls can occur in any season, but slightly prevail in August and at a lesser extent in June. Djanet is in the south-eastern part of Algerian Sahara, around 25° of North latitude, at an altitude between 1000 and 1800 m A.S.L. The rainfalls are scarce and show the same pattern as in Tamanrasset but with very low amounts.

During 2007 to 2011, the samplings were carried out in a remission period for the spatio-temporal dynamics of Desert Locust. For each sampling the phase state of 10 adults was estimated by morphometrics ratios: tegmina over hind femur lengths and hind femur length over head width (Uvarov, 1966). The dates of samplings followed the alert message send by the persons of the

Algerian DLAA. The habitats considered were flat depressions and Oued edges. Plant associations was described by Mahdjoubi et al. (2017).

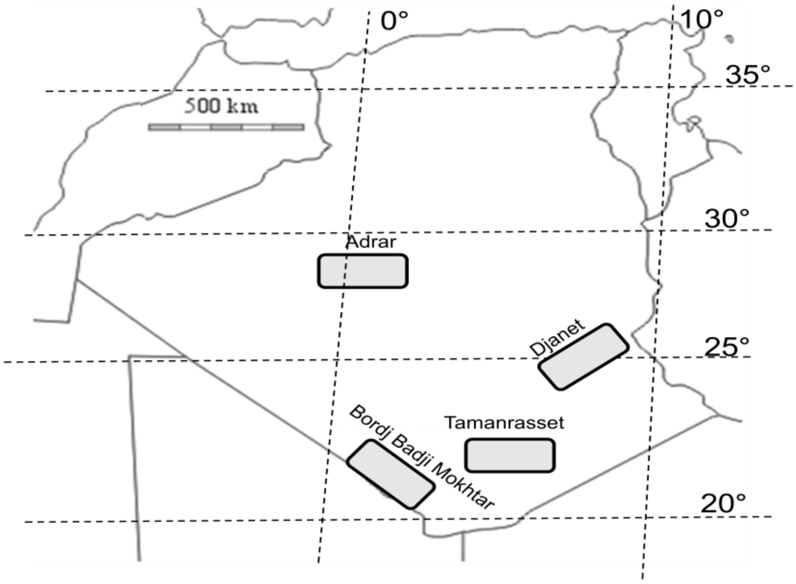

Figure 1. Position of the 4 regions surveyed in Algerian Sahara.

Floristic survey

To characterize the habitats and to identify potential for locust breeding in southern Algeria, we conducted floristic surveys in three Saharan zones (northern, central and southern) using Quézel and Santa (1962-1983). Plant nomenclature was updated with tela-botanica database (www.tela-botanica.org/). The flora composition is a power ful integrator of environmental constraints that characterize a community. Each habitat is characterized by a list of quantified plant species that determines the physiognomy of vegetation. Each floristic sampling was conducted on a floristically homogeneous area of one hectare, noting for each species, the abundance-dominance coefficient of Braun-Blanquet (1965), using the scale of Lemée (1967). Among these species, it is important to highlight those that are of particular interest (shelter, food) for the locust. In its solitarious phase, this insect prefers certain plant species and neglects others. The appreciated species are listed in Guendouz-Benrima et al. (2010).

Soil surveys

To better estimate the reproductive potential of the biotope, we also recorded for each station the soil moisture. To estimate the humidity, we dug hole until reaching the depth of moisture measured from the surface in cm. The critical depths considered are moisture at the surface, at 10 cm, 20 cm, 30 cm, and more than 30cm.

Locust surveys

For each sampling conducted in the different stations in central and south Algerian Sahara, two descriptors were taken into account: the population density, estimated per square meter for grouped populations or per hectare for diffuse populations, and the surface of the biotope. We also recorded the presence of egg pods and instars, and the phase state of adults.

To estimate locust adult densities calculated for a surface of 100 m², different methods were undertaken. The first one, preferred in case of undulating or rough surfaces, consisted in defining a strip of 1m wide and 100 m long, and repeating the counting over a dozen bands (Ould El Hadj, 2004, Duranton et al., 1982). To determine the presence of winged individuals over large areas, such as erg (sandy plain), or large vegetation-covered area, we conducted vehicle-based transects according to Dobson (2001). It consisted in driving in the direction opposite of the wind for at least 1 km. During each transect, we counted adults that fly in front of the hood of the vehicle and we recorded the distance using the odometer. This method was applied only when the temperature was above 20 °C and the wind speed less than 6 m/s. Thirdly, when we met a relative abundance of Locust on rather flat areas, we chose the quadrat technique to obtain accurate counts of Locust adults. Within each surface of 2 ha defined as homogeneous for vegetation, the sampling consisted in ten replicates of 10 m² each (Ould El Hadj, 2004).The choice in the number of samples depends on many factors most of them are

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related to geo-morphological characteristics of the station including among others: the vegetation physiognomy lurking, topography, and soil moisture gradient.

Statistical methods

The coefficients of abundance-dominance of plant species of the whole dataset (466 samplings x 91 species) were subject to ad trended correspondence analysis (DCA) to assess the relationships between the flora composition of the three areas. To test the difference in floristic composition between the three regions, it was necessary to perform an ANOSIM (analysis of similarity) based on a permutation test (Clarke, 1993), considering the Bray-Curtis index as a measure of distance. To order the species according to their contribution in the composition differences between regions, a SIMPER (SIMilarity PERcentages, Clarke, 1993) analysis was conducted. To provide an overview of factors that may have an effect on locust abundance on the 466 samplings, we conducted a General Linear Model (GLM) using region, humidity depth and altitude as factors. The altitudes were log-transformed to normalize their distribution. Except graph density, all the tests were conducted using PAST 2.17 software (Hammer et al., 2001). Density graph of Desert Locust were obtained by considering the x, y coordinates of stations provided by DCA, and the density of locust as z, using Systat 12.0 (SPSS, 1997).

Global approach of Desert locust abundance

The analysis of all the dataset by GLM shows significant effects of the three factors, in the following decreasing order: region, altitude and at humidity depth. As for region influence, the mean abundances per 100 m² in Adrar were close to 4 per survey, around 1 at Djanet, less than one in BBMk and extremely rare from Tamanrasset ($Fr_{3,462} = 144.796$, $p<0.001$). It should be noted that the periods of locust presence varied according to the regions. In natural habitats of Adrar, numerous instars were observed in the beginning of May whereas the adults were encountered during all this month. Almost the totality of locust population migrated from the second fortnight of May to reach nearby irrigated cereal crops where they stay until the beginning of July. However, the presence of instars in these anthropized areas was much lower than in natural habitats. In Djanet, adults were observed in March and April, then from October to December, but no instars were ever recorded. In BBMk, the adult records were limited in January on the one hand, and from July to October in the other one. Indeed, few instars were observed in October at the end of the rainy period, indicative of a local reproduction.

To compare the regions by their flora, we undertook in a first step a DCA with the whole data set (466 samplings x 91 plant species). A clear distinction between the flora of Adrar, BBMk and Djanet, was shown (figure 2A) but a clear overlap was detected between the floras of these three regions and the one observed in Tamanrasset. The result of ANOSIM with 10000 permutations supported significant differences between each combination of regions with a p-value $< 10^{-3}$. The 30 species that have the highest contribution to differences between the four regions were described by Mahdjoubi et al. (2017). It reveals a strong originality of each region, but a certain affinity between the plants of the two Southern regions, revealed by ANOSIM (data not shown).

In a second step, it was necessary to study the relationship between locust densities and floristic samplings. Thus, we recorded the x, y coordinates of stations obtained by the DCA on floristic dataset and the density of locust as z axis. Given the very low values of locust densities in Tamanrasset, this last station was not considered. The density graph obtained with SYSTAT 12.0 (Figure 2B) shows a strong homogeneity in the densities observed in Djanet and BBMk but regularly higher values in Adrar.

Variations in each region

The question is to understand the variations in *S. gregaria* density according to the stations. We conducted a GLM to assess the influence of each environment variable on adult density. These variables were as follows: altitude, humidity depth (in cm), total plant cover (sum of abundance coefficients of plant species), total richness of plant species, and richness of preferred plants.

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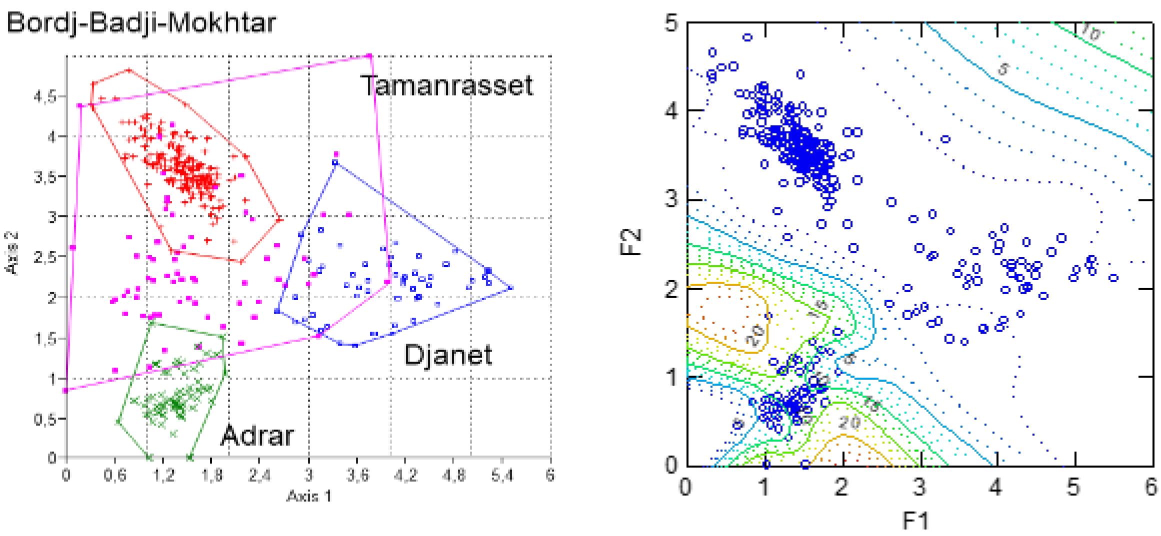
In Adrar region, the GLM analysis showed a significant and positive effect of richness of preferred plants, and a negative one for total plant cover and humidity depth. The locusts are thus more abundant when humidity is near the surface, with increasing number of preferred plants, but avoids the stations where the total plant cover is high especially when the number of preferred plants is low. Altitude has no effect.



A B

Figure 2: Projection by DCA of floristic samplings surveyed in Algerian Sahara. 2A: the 4 regions are considered; 2B: Density graph constructed with the coordinates of DCA as x and y, and locust densities as z. The isoclines define the space with identical locust densities.

In BBMk region, the altitudes of the different stations are very close to 500 m and were not introduced in the model. The results indicated in table 1 show a strong negative effect of humidity depth and a positive effect of total plant cover (N = 192). However, the richness of preferred plants does not seem to impact adult abundance.

Table 1: General linear model for BBK region (N = 192)

	Coeff.	p	R^2
Constant	0.9876	$1.4\ 10^{-5}$	0.0000
Humidity depth	-0.0370	$1.1\ 10^{-7}$	0.1466
Total richness of plants	-0.0367	0.2959	0.0306
Total cover of plants	0.1031	0.0176	0.0420

In Djanet region, there was a weak range of altitudes comprised between 1000 and 1080 m, leading us to remove this parameter from analysis. GLM conducted on other environmental variables showed a significant and negative effect of total vegetation cover, but a positive one of total richness of plants. In contrast to other regions, neither humidity depth nor preferred plant cover (or richness, data not shown) has an effect on adult abundance. About humidity, the absence of significant results was due to the low variability in the depth (about 80 % of samplings equal to 20 cm).

Discussion

It is important to characterize the areas hosting solitarious locusts during the remission periods. The four Saharian prospected regions of Algeria can be assigned to different regimes according to the seasonal distribution of rainfall (Barry, 1982; Barry et Celles, 1972-1973). Although the Desert Locust has been recorded from 1997 to early 2000s in this last area (Guendouz-Benrima, 2005), this species was considered as exceptional between 2007 and 2011.

Our results in Algerian Sahara highlight some ecological requirements of solitary populations in each studied area form 2007 to 2011. Given the possibility of local reproduction, the periods and geographical situations of locusts, we suggest some hypotheses on the possible ways of locust's dispersal through the Sahara.

The ecological preferences in each area were deduced from correlations analysis using 466 samplings. Based on the dates of presence of adults and the rainfall periods in each region, the presence of locusts in Bordj-Badji-Mokhtar (Altitude = 500m), during July and October can be attributed to the humidity and to the total cover of plants, irrespective of preferred species. We interpret the role of plant cover as a protection against extreme drought of habitats and as perches for moulting: the reproduction was limited but effective given the few instars recorded in October, as noted previously by Guendouz-Benrima et al. (2007). We suggest that the conditions are so extreme that the level of preference for plant species as trophic source is very low.

In Djanet area (Altitude = 1000m), the adults were recorded in spring and late Autumn, such distribution is shown under Mediterranean climate. The non-significant effect of soil humidity on locust density proposed that other factors such as the atmospheric humidity coming from the mountains, could be a favorable environment for the locusts subsistence. Moreover, their density is positively correlated with the total richness of plants but not with the richness of preferred species. This suggests that these populations are in transit between more suitable environments. Guendouz-Benrima et al. (2007) reported the same conclusion using different methodology, as they compared the chorologies of plants and that of Desert Locusts. We observed neither egg-pods nor instars, indicating that the populations of adults found in Djanet area are all resulted from immigration flights.

In Adrar, our observations about the locust activity were limited to May following the alerts sent by the algerian DLAA. In the first fortnight of this month. Several instars and adults were recorded, proving a local reproduction of the species favored by the rains occurring from March to May in this area. This view is confirmed by the significant influence of soil humidity on locust density. In this case, the total richness of plant has no effect on Locust density, in contrast to the richness of preferred plants. This last finding supports the idea of a major local self-renewal of populations. The negative effect of plant cover on adult density indicates that the Desert Locusts stand on their favorite plants to find a trophic resource, and do not only search protection against heat. In the end of May, the populations living in natural habitats tend to move toward cereal fields watered by pivots. In these anthropized areas, some instars can be encountered but lesser than those found in natural environments.

Considering all studied areas, the ecological descriptors of sites hosting locust adults vary according over space and time. We can highlight the opposition between two categories of habitats. In crossing areas of mountains, as Djanet, the adults remain inactive during late autumn but take advantage of a relative coolness and atmospheric humidity. In these conditions, the Desert Locust does not express any preferences for vegetation and soil. In contrast, in the areas where adults can mate and reproduce, as in central Sahara, the presence of Desert Locust is conditioned by soil humidity. In Adrar where the conditions are more suitable than in BBMk, the adults are sensitive to preferred plants but avoid relatively high plant cover. Whereas in BBMk, they are only sensitive to the total richness of plant species. The analysis of corresponding plant associations was treated by MAHDJOUBI et al. (2017).

Guendouz-Benrima et al (2006), mentioned that there are dispersal events of locust populations during the season. Depending on the years, the adults living in BBMk from July to October show a moderate mating activity, giving rise to the instars and the adults observed in October and January respectively, as ever mentioned by Guendouz-Benrima et al. (2007). A fraction of these adults could move in the end of autumn and reach the relative cool mountain conditions near Djanet. This dispersal event over about 850 Km could take at least 3 nights as the adults can move by 100 to 400 Km in a night (Symmons and Cressman, 2001). Mark-recapture experiments (Waloff, 1963) should be undertaken to test this hypothesis. In BBMk, the low density of adults in January could be explained by the second generation produced locally. In January, these adults could migrate again during spring to reach Djanet, and later Adrar at the end of April through a 1000 Km travel. In central Sahara, After the reproduction cycle, a part of population stays, however the other one migrates back to south Sahara, to take advantage of summer tropical rain falls in BBMk area (Figure 3). Although some egg-pods and instars were encountered in this area, the rate of reproduction is not the unique factor explaining the relative abundance of local adult populations. According to Guendouz-Benrima et al. (2007), and following the general model of C.O.P.R. (2001) and Magor (1995), these populations probably result from flying immigrant adults coming from southward localities situated in the Sahel (mainly Mali and Niger).

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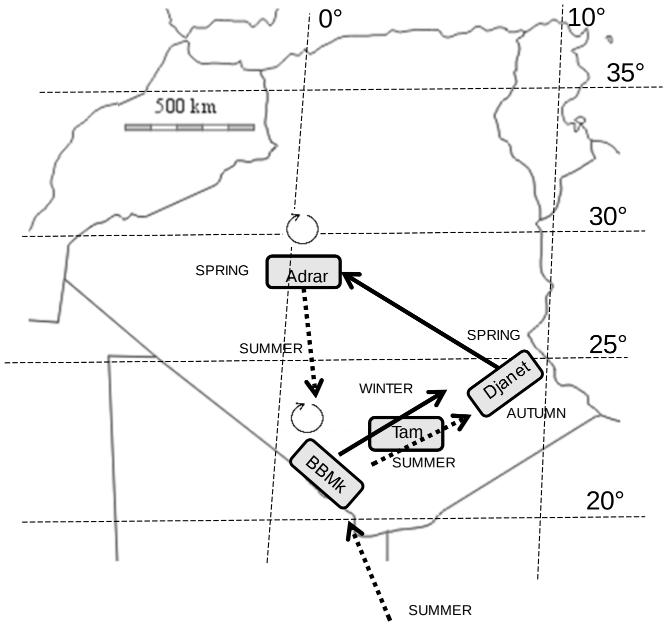

Figure 3. Synthetic view of Desert Locust cycle and migrations between the three regions of Algerian Sahara. The solid arrows correspond to winter and spring migrations, and the dashed one to summer migrations. The bent arrows indicate local reproduction events.Tam: Tamanrasset , BBMK: Bordj Badji Mokhtar

Conclusion

The south Saharan BBMk summer populations may result from a mixing between different sources: a local one by reproduction and immigrants from central Sahara and from Sahel countries. In parallel, spring Adrar populations in central Sahara have several origins, including local reproduction and possibly immigrations from mountains located in the south eastern part of Algeria. It is unlikely that south Algerian Saharan or Sahel populations contribute much to enrich these Adrar populations. The complex nature of Desert Locust populations in Algerian Sahara participates to explain the very little genetic structuring revealed by microsatellite analyses (Chapuis et al., 2014).

The authors declare no conflicts of interest.

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