

# Modeling the effects of climate on date palm scale (*Parlatoria blanchardi*) population dynamics during different phenological stages of life history under hot arid conditions

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**Abstract** The date palm scale (DPS) *Parlatoria blanchardi* is a serious pest due to the damage it inflicts on its host tree (*Phoenix dactylifera*). To develop an effective control against DPS in arid regions, it is essential to know its bio-ecology including population dynamics and climatic factors influencing the duration and timing of life history and also the densities of different phenological stages (crawlers, first and second instars nymphs, adult males, and adult females). Monitoring of biological cycle and population dynamics of the pest were achieved through weekly counts of DPS densities on leaflets sampled at different position of date palm trees in an oasis of Ouargla region (Algerian Sahara Desert). Within this hyper-arid region, DPS established four generations per year, the most important was the spring generation. Two overlapping generations occurred in spring–early summer and two in autumn–early winter; these two pairs of generations were interspersed by two phases of high-mortality rates, the first corresponds to winter cold and the second refers to the extreme heat of summer. Statistical analysis of the effects of the studied climatic conditions (minimum, maximum and mean temperatures, precipitation, humidity, wind, rain days, and climatic indices) on the DPS densities at different phenological stages showed great variability from one stage to another. Among

these, adult females were the most affected by climate factors. For the total DPS population, high values of minimum temperatures negatively affected population density, while high maximum temperatures, hygrometry, and De Martonne aridity index showed a positive influence.

**Keywords** Date palm scale *Parlatoria blanchardi* · Date palm pests · Climate variability in drylands · Modeling population dynamics · Biological cycle · Arid agriculture

## Introduction

Agriculture in drylands has allowed the survival of millions of people for thousands of years, in particular through the cultivation of the date palm (DP) *Phoenix dactylifera* (Johnson 2010). DP is the typical fruit tree in hot desert regions where it grows naturally in oases that offer ideal living conditions. Indeed, the DP represents the main fruit crop in drylands of Arab countries, where it needs a warm climate with abundant sun and good irrigation (El-Juhany 2010). DP gives a wide range of products, mainly the fruits (dates) that represent a food of high energy value (Chao and Krueger 2007; Siddiq et al. 2013; Manickavasagan et al. 2012) for millions of people living in arid regions, where dates contribute considerably to their food security (El-Juhany 2010). It is noteworthy that the oases are refuges for many living beings, both plants and animals, where they find the suitable ecological living conditions under harsh arid climate (Chenchouni 2012a, b; Guezoul et al. 2013).

Date palm cultivation is subjected to various constraints, such as (i) abiotic stresses, including water scarcity, accentuated aridity, drawdown of groundwater, climate change, and soil salinization (Idder 2011; Manickavasagan et al. 2012); (ii) biotic interactions, such as insect pests and fungal and

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phytoplasmic diseases (Farrag and Abo-Elyousr 2011; Al-Deeb 2012; El-Shafie 2012); and (iii) anthropogenic perturbations, including all inappropriate human activities like the excessive use of fertilizers, abandonment of palm plantations, rural exodus, and expansion of urbanization (Idder 2011; Manickavasagan et al. 2012); which have all led to low yields of production and problems of product marketing (El-Juhany 2010; Manickavasagan et al. 2012).

Phytosanitary problems of DP are the main factor of productivity weakness of this crop, especially in arid areas where DP cultivation is the number one agricultural activity (Idder 2011; Al-Deeb 2012). The DP and its fruits are subject to attacks by several pests, which are well-adapted to the oasis environment (Zaid et al. 1999) and/or storing conditions (Abo-El-Saad and El-Shafie 2013). Scale insects and mealybugs hold an important place among pests of this crop in hot arid regions (El-Shafie 2012), especially in the Middle East and North Africa which produce 70 % of dates worldwide (El-Juhany 2010). The main pest species threatening DP cultivation in oases of Arab countries are *Parlatoria blanchardi*, *Ectomyelois ceratoniae*, *Oryctes agamemnon*, and *Oligonychus afrasiaticus* (Zaid et al. 1999; Idder 2011; Idder et al. 2011; El-Shafie 2012).

The date palm scale (DPS) *P. blanchardi* Targioni-Tozzetti 1892 (Homoptera: Diaspididae) is the most serious pest of DP in most areas producing dates, because it settles throughout the green parts of the tree, preventing and affecting photosynthesis, respiration, and transpiration of the tree (Bénassy 1990; Abivardi 2001; Blumberg 2008). The phenomenon of crusting usually results in death of young palm trees and weakening of older individuals (Smirnov 1957). In addition, the DPS is widely distributed in most DP growing areas of the world except in the USA and some countries of the southern hemisphere such as South Africa and Namibia (Zaid et al. 1999). Thus damage caused by this pest is considerable and leads to heavy economic losses at both regional and national scale (Smirnov 1957; Bénassy 1990; Talhouk 1991; El-Juhany 2010).

Several studies have been conducted on the biology and population dynamics of DPS, especially in Egypt (Salama 1972; Eraki 1998; Salman et al. 2013), Iran (Gharib 1973; Abivardi 2001; Latifian and Zaerae 2009), India (Swaminathan and Verma 1991), Israel (Blumberg 2008), Tunisia (Khoualdia et al. 1993; Ben Chaabane et al. 2008), Morocco (Smirnov 1952), and Algeria (Djoudi 1992; Nadji 2011; Belkhir et al. 2011; Idder 2011; Achoura 2013). These studies note that this bio-aggressor has a variable number of generations per year, usually between three and four generations, exceptionally two and five generations, depending on weather conditions, especially temperatures (Bénassy 1990; Khoualdia et al. 1993).

Climate factors, particularly the cold of winter and the heat and drought of summer, seem to have more importance to number of generations and species survival compared to other

abiotic factors of the habitat (Kausrud et al. 2012). Indeed, infestations of the species are very rare in mountainous or coastal areas, where the species has a patchy distribution corresponding to favorable microclimates (Huffaker et al. 1971). The growth of scale populations depends on, inter alia, fertility and mortality of individuals as well as development time, each of these parameters is itself influenced by climatic factors of the habitat. Among these factors, temperature and relative humidity, considered singly or in combination, are chosen to best characterize the selective influence of habitats on variation trends of scale populations (Latifian and Zaerae 2009; Chafaa et al. 2013b).

Few studies are carried out to determine the climatic factors influencing the population dynamics of DPS while infesting the DP, which is its host plant of choice. This is especially true in arid regions, where binding environmental conditions have a direct bearing on the bio-ecology of insects (Ben Chaabane et al. 2008; Chafaa et al. 2013b). To undertake an effective, efficient, and clean control against DPS, it is necessary to properly define the intervention periods, and therefore the knowledge of the population dynamics of this pest in palm groves is very important for the success of any control program (Idder 2011; Idder et al. 2011).

The purpose of this paper is to give the most accurate overview on the annual life cycle and reproductive biology of the DPS in Ouargla, located in a hot hyperarid climatic zone (northeast Sahara Desert of Algeria). In this region, where the climatic conditions are binding for common insects, we highlight the effects of certain climatic parameters on population dynamics of DPS. These investigations are carried out taking into consideration each phenological stage of the DPS biological cycle. In addition, we check the classical question of the sex ratio among adult individuals of DPS population and we check if the sex ratio differed between the overlapping generations and study months. Certainly, understanding the correlation between DPS population demography and the climatic conditions prevailing in arid regions would contribute for better outlining the differences that present the life cycle DPS in drylands and its potential for acclimatization in areas of the world with extreme climate conditions. Evoking such surveys will enhance our knowledge of this serious pest, and thus guide its control.

## Materials and methods

### Study area and sampled oasis

This experiment was conducted on the agricultural farm of “Institut Technologique d’Agronomie Saharienne” (ITAS) (31° 56' 26.60" N, 05° 17' 38.10" E, altitude 136 m a.s.l.), which is located 5 km southwest of the town of Ouargla (northeastern Algeria). The study palm grove covers a total

area of 28.8 ha, divided into eight sectors of 3.6 ha each. This research was conducted in sector 'A', which includes 220 DP trees with a uniform spacing of 9 m. Varietal composition is Deglet-Nour (67.1 %), Ghars (22.9 %), Dgoul (4.8 %), Degla-Beida (2.9 %), Tafezouine (1.0 %), and Dokkar (1.4 %). The oasis is surrounded by two active drains and three rows of live (Casuarina trees) and inert (dry palm leaves) windbreaks (Idder 2011).

The climate is typically hot-arid (BWh climate class according to Köppen–Geiger classification), where the dry period spreads throughout the year, with very low values of the De Martonne Aridity Index (1.21–4.91) (De Martonne 1925). Furthermore, values of Budyko's radiation index of dryness ranged between 21.4 and 42.6 (Chenchouni 2012a; Bradai et al. 2015). Average annual temperatures are high, with minima varying from 2 to 9 °C in January and absolute maxima in July–August may exceed 50 °C in the shade (Fig. 1). Precipitation, that falls as rain, mainly between October and February, is very low and erratic. Rainfall amounts vary from 1 year to another and during the same year.

#### Sampling design and data collection

The study was carried out on 30 trees of the variety Deglet-Nour. The sampled trees were selected so their distribution spread over the whole study plot and for tree uniformity in size and maintenance status. During an annual cycle, extending from November 1999 to October 2000, 24 palm leaflets were collected regularly every week from every palm tree. Since Khoualdia et al. (1993) reported that DPS infestations underwent large variations according to sampled leaflet positions inside the tree crown (i.e., four cardinal sides of the tree and basal/central positions of the crown), the collection of the 24 leaflets was not done randomly on each tree, but in respect to the four directions of tree crown (north, west, south, and east) and at the same time according to three levels in the crown of the tree (center, middle position inside crown,

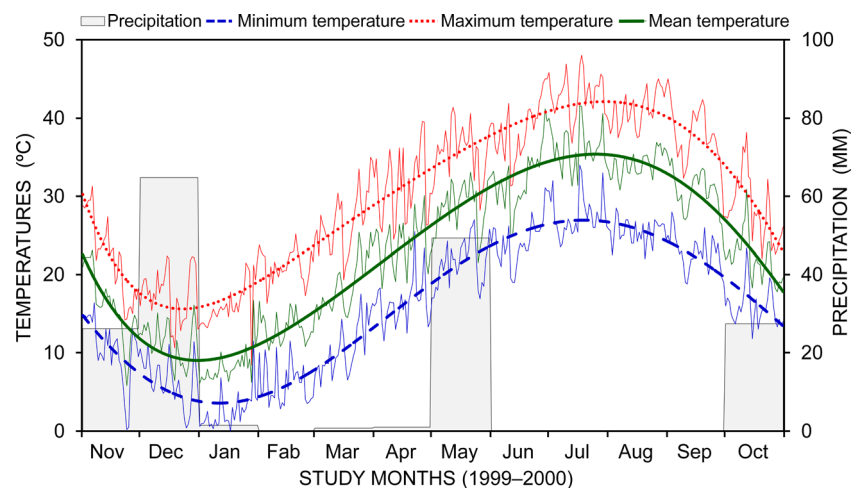
and basal crown). Therefore, sampling concerned two leaflets per orientation and position in the same crown. These leaflets were collected using a pruner then placed in Kraft paper bags and brought to the laboratory on the same day for examination and DPS counting.

#### Meteorological data and climatic parameters

The climatic parameters considered in this study originated from Ouargla weather station (WMO Id: 60580), located 10 km from the study site. The raw climate data represented daily observations of minimum, maximum and mean temperatures (°C), mean humidity (%), precipitation amount (mm), mean wind speed (km/h), maximum sustained wind speed (km/h), and daily indicator for occurrence of rain. Using these daily weather data, eleven climatic parameters were calculated based on the daily data of two months (60 days) prior to the date of weekly sampling of DPS:

- $T_m$ : average of minimum temperatures (°C).
- $T_M$ : average of maximum temperatures (°C).
- $T$ : average of mean temperatures (°C).
- $H$ : average of daily mean humidity (%).
- $PP$ : cumulated of daily precipitation (mm).
- $V$ : average of daily mean wind speed (km/h).
- $VM$ : average of maximum sustained wind speed (km/h) recorded during previous 60 days. The maximum sustained wind is the average of winds measured at a height of 10 m for 10 min.
- $RA$ : total number of rain days (i.e., at least 2 mm).
- $PP/T$ : average hygrometry expressed as the ratio between precipitation amounts ( $PP$ ) and average of mean temperatures ( $T$ ) of 2 months preceding the sampling date,
- $I_{DM}$ : De Martonne Aridity index ( $I_{DM} = PP/(T+10)$ ) was calculated based on precipitation amounts ( $PP$ ) and average of mean temperatures ( $T$ ) of 2 months preceding the sampling date (De Martonne 1925)

**Fig. 1** Daily variation of minimum, maximum and mean temperatures, and monthly precipitation amounts recorded at Ouargla region (Sahara Desert, Algeria) during the study period (November 1999–October 2000)



## Data analysis

Since the collected leaflets had different biometrics (mainly length and width), and in order to standardize the results, the method of Euverte (1962) was used to estimate the rate of DPS infestation at each leaflet. This technique consists in choosing three parts of each leaflet, 3 cm<sup>2</sup> each, which correspond to three levels of scale concentration (low, medium, and high density). All scales found on these 3-cm<sup>2</sup> samples were counted using a dissecting microscope at a magnification  $\times 4$  and  $\times 10$ . DPS were classified as live and dead individuals, according to four phenological stages of species development: (i) crawlers or mobile neonate larvae (ML), (ii) first and second instars nymphs or immobile larval stages (L1+L2), (iii) adult males, and (iv) adult females (Smirnov 1953; Watson 2002). The three count values on the leaflet in question were used to calculate the weekly average of the population density of each phenological stage. Subsequently, average densities were calculated by sampled tree and for the whole plot, and these weekly densities were summed per month to form monthly DPS densities. Finally, to study population dynamics during different phenological stages, frequencies of abundance were calculated as the percentage of the total number of individuals in a month rounded to the total number of collected individuals for each stage throughout the year.

Information on population sex ratio plays a key role in understanding the population dynamics of pest species (Kausrud et al. 2012; Dong et al. 2013), as it aids management of pests of date palm groves, especially in North Africa and the Middle East where the DPS is by far the most serious pest (Zaid et al. 1999). DPS females live 5–25 days and die upon completion of egg-laying, while males live 2–3 days upon reaching adulthood (Bénassy 1990). We therefore considered adults of both sexes as sexually active due to their short life span. Accordingly, the operational sex ratio (OSR) was deemed appropriate to be measured and monitored because it helps in the understanding of reproduction trends and thus population dynamics in animal species (Kvarnemo and Ahnesjö 1996). Hence, the OSR (male to female) of DPS was determined as the male proportion using monthly densities:  $OSR (\%) = \text{males}/(\text{males} + \text{females}) \times 100$ .

## Statistical analyses and procedures

The variation of weekly total densities (of all phenological stages) of DPS was tested using an analysis of variance type III (ANOVA) following the effect of three factors ‘phenological stage,’ ‘generation,’ ‘study month,’ as well as their various interactions in pairs. Afterward, in order to test the significance of density variation in time for both live and dead individuals of DPS, two-way ANOVAs were applied for each single phenological stage of DPS life cycle according the effect of generation and study month. After the application of

contingency test that determine the dependency or the independency of the two previous factors, the effect of each factor was considered individually without their interaction ‘Generation  $\times$  Month.’

Pearson’s chi square test was used to compare the observed operational sex ratios of DPS adults (males/(males + females)) to the expected OSR of 50 %, using monthly counts for the entire annual life cycle and using weekly data for each of the four generations.

We examined visually possible relationships between the monthly DPS total density values at all sampled scales (larvae and adults, dead and live individuals) and the various climate values. Prior curves plotting, both DPS data and climate variables were normalized to the unit using normal distribution transformation based on the average and standard deviation of each variable.

In addition, the effects of climate parameters on the fluctuation of DPS densities were tested using generalized linear models (GLM). In order to model these effects, the data used were weekly densities of DPS related to the eleven climatic parameters previously computed. The first GLM was performed on the total population (including live and dead individuals of all phenological stages) to model the effects of climatic variables on scale densities. However, because the effects of climate factors vary from one life stage to another in the same scale species (Chafaa et al. 2013b; Salman et al. 2013), the variation of weekly values of live population density of each DPS phenological stage was tested by a separate GLM for each stage. All GLMs were carried out using Poisson distribution with log link as we have count data. The effects of climatic parameters were computed using ‘glm’ function of R, and then the summary of each model was given as a table. Model simplifications were based on the Akaike information criterion (AIC) and Bayesian information criterion (BIC) values. Computations and statistical modeling were conducted using the R-commander ‘Rcmdr’ package working under R statistical software (R Development Core Team 2014).

## Results

### Population dynamics of *P. blanchardi*

The weekly monitoring of live scales densities in the Ouargla region revealed the existence of four partially overlapping generations per year (Fig. 2). The first generation, pre-winter, began from November to early January (~67 days). The second generation, in spring, started in early February and extended until early May (~112 days). It was the largest generation in terms of scale numbers, during which the mortality of individuals at first was relatively low then very high.



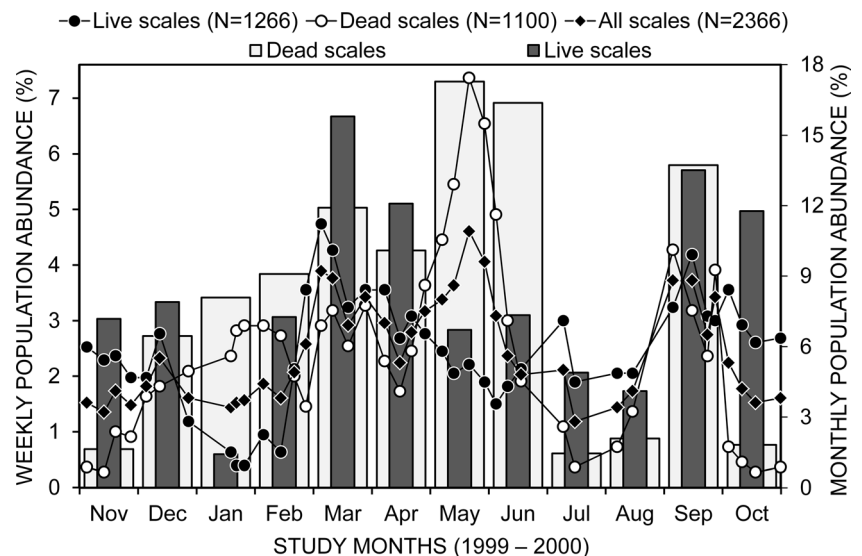
Overlapping with the previous one, the third generation appears longer since it lasted approximately 127 days (early May–early August), but it comprised lesser density of individuals compared to the second generation, given the high mortality rate occurring from the beginning. The fourth generation (~97 days) began in mid-August and ended in mid-October. During this autumn generation, the rate curve of dead individuals resembled that of live individuals.

The analysis of variance showed that weekly DPS densities differ very significantly following phenological stages, generations, months of the study ( $P < 0.001$ ), and as well the interactions between phenological stages with generations and study months (Table 1).

### Monthly population fluctuations of phenological stages

Population dynamics of live crawlers experienced two maxima (peaks), the first in April and the second in October (Fig. 3a). The mortality of these larvae was mainly observed in April and September, and at least level in January. Likewise, the density of mobile larvae was remarkably low during two periods January–February and July–August. Live instar larvae (L1+L2) showed four main periods of activity (Fig. 3b). The first exhibited a maximum in December and was relatively short. The second period began in early February and was longer because it overlapped the third period, which ends in late June. After 2 months (July–August) of low densities, comes the fourth period that climaxes in October. The high mortality rates of L1+L2 larvae were scored at the beginning of each generation, with four picks in December, March, June, and September–October. Population dynamics of live males identified three main peaks, the first in November–December, the second in February–March, and the third in June (Fig. 3c). Male mortality was very high during the period January–June, matching the second and third

**Fig. 2** Population dynamics of *Parlatoria blanchardi* in the area of Ouargla (northern Sahara Desert of Algeria). Weekly (curves) and monthly (horizontal charts) populations densities of both live and dead scales are pooled data of all phenological stages



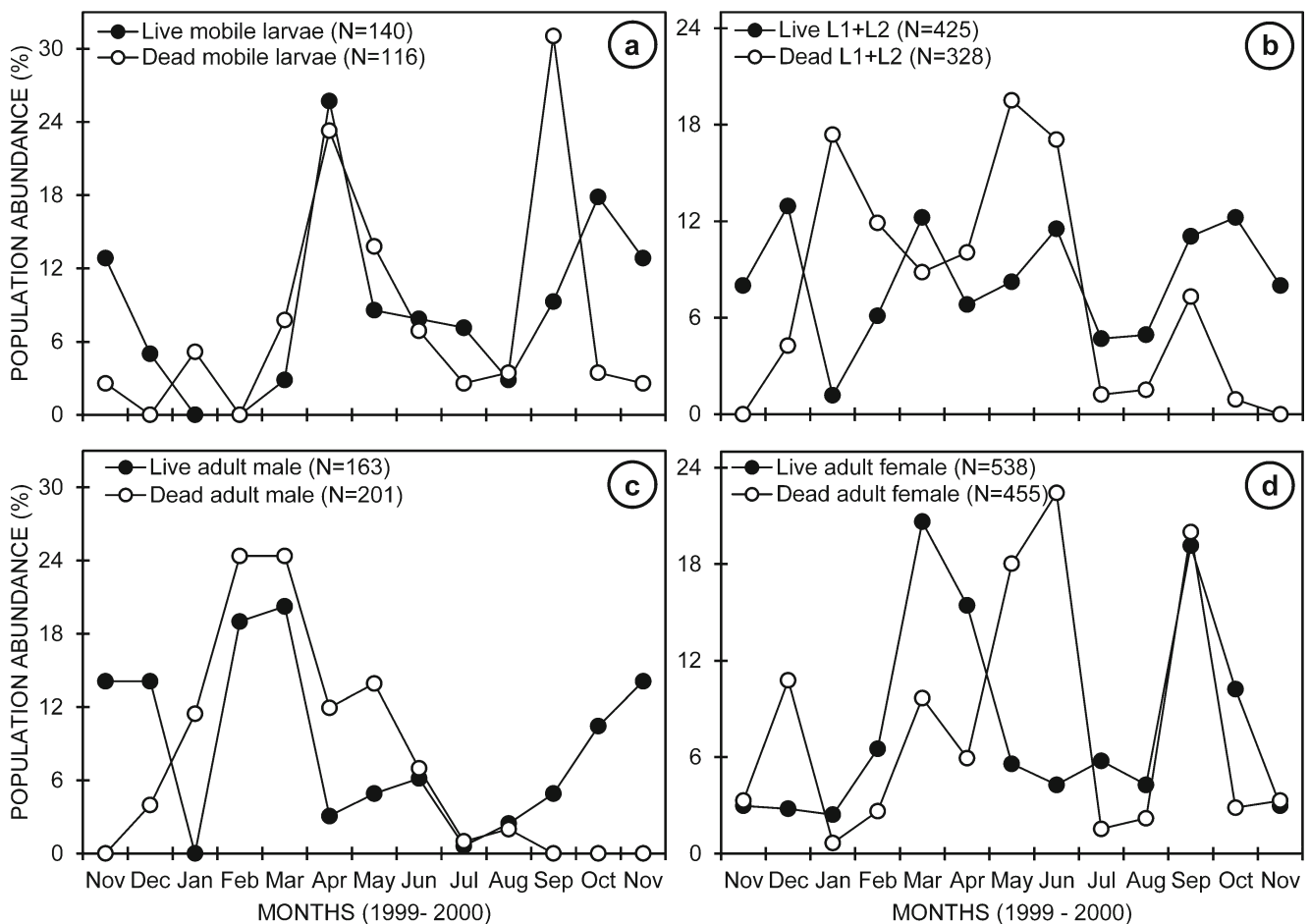
**Table 1** ANOVA testing the effect of factors ‘phenological stages,’ ‘generation,’ and ‘study month’ on dynamics of weekly population densities of live and dead individuals during different stages of *Parlatoria blanchardi* annual life history in the area of Ouargla (northern Sahara Desert of Algeria)

Sources of variation	df	SS	F value	P value
Phenological stages	3	2818.3	58.84	<0.001
Generation	3	293.4	6.13	<0.001
Study months	9	689.9	4.80	<0.001
Stages × Generation	9	1012.6	7.05	<0.001
Stages × Months	27	1417.5	3.29	<0.001
Residuals	112	1788.2		

generations. Finally, the population dynamics of live females indicated two phases of high activity, a spring (February–end of May) and the other in autumn (August–November), with a slight peak in July (Fig. 3d). Mortality among that sex was important during two periods in early summer (May–June) and in September, but with a lesser rate in December and March. It is noteworthy that the biological stages of DPS generally experienced two phases of density decrease, one in winter (January–February) and the other in summer (July–August).

### Temporal variation in DPS populations

The ANOVA revealed that the variation in densities of different life stages of the DPS was statistically significant between study months (Table 2). This variation was higher among dead individuals ( $P < 0.001$ ) compared to live individuals of L1+L2 larvae and adult males ( $P = 0.004$  and  $P = 0.021$ , respectively). Moreover, ANOVAs demonstrated that the factor generation statistically had a highly significant effect ( $P < 0.001$ ) on the variation of population densities of dead males and live



**Fig. 3** Monthly population dynamics of different stages of *Parlatoria blanchardi* life cycle in the region of Ouargla (northern Sahara Desert) during the annual cycle November 1999–October 2000. (a) Mobile larvae ‘crawler’, b first and second instars nymphs (L1+L2), c adult males, d adult females)

**Table 2** Two-way ANOVA testing the effect of factors ‘study month’ and ‘generation’ on population dynamics of live and dead individuals during different stages of *Parlatoria blanchardi* annual life history in the area of Ouargla (northern Sahara Desert of Algeria)

Life stage	Variations	df	Live scales			Dead scales		
			SS	F	P	SS	F	P
Mobile larvae	Generation	3	40.2	2.28	0.101	12.9	1.67	0.196
	Month	9	283.2	5.36	<0.001	259.7	11.20	<0.001
	Residuals	28	164.3			72.2		
L1+L2 larvae	Generation	3	49.9	1.25	0.309	111.7	1.84	0.163
	Month	9	432.6	3.62	0.004	1249.9	6.87	<0.001
	Residuals	28	371.6			566.4		
Adult male	Generation	3	60.1	1.99	0.139	327.4	23.06	<0.001
	Month	9	245.3	2.70	0.021	370.0	8.69	<0.001
	Residuals	28	282.3			132.5		
Adult female	Generation	3	1155.8	11.12	<0.001	84.2	0.65	0.593
	Month	9	1146.2	3.68	0.004	2475.8	6.33	<0.001
	Residuals	28	970.0			1217.5		
Total	Generation	3	1173.6	6.21	0.002	1462.9	6.94	0.001
	Month	9	2759.4	4.86	<0.001	8930.4	14.11	<0.001
	Residuals	28	1765.0			1968.6		

females. Overall, the total numbers of DPS (all life stages combined) varied significantly between generations and study months.

### Operational sex ratio of adult individuals

Based on monthly counts of DPS adults that totaled 163 males and 538 females, the operational sex ratio (OSR) in the study population was skewed to females (OSR ‘M:F’=23.25 %). Monthly values of OSR statistically differed between study months compared to the expected OSR of 50 % ( $\chi^2=120.5$ ,  $df=11$ ,  $P<0.001$ ) (Fig. 4). OSR values ranged from 3.1 % in July to 60.5 % in December with a monthly average of  $25.2\pm 20.3$  % and median=22.0 %. Males dominated females during the first generation (November–December), whereas female densities were higher during the rest three generations (January–October). The fluctuation curve of monthly OSR demonstrated that densities of males increased at the beginning of each generation then declined at its end (Fig. 4). For weekly counts of DPS adults, OSR differed significantly from 50 % M:F during each of the four generations ( $P<0.001$ ), where the computed chi square test revealed high values  $\chi^2_9=214$ ,  $\chi^2_{11}=235$ ,  $\chi^2_9=220$ , and  $\chi^2_8=235$ , for the first, second, third, and fourth generation, respectively.

### Periodicity of population dynamics and climate factors

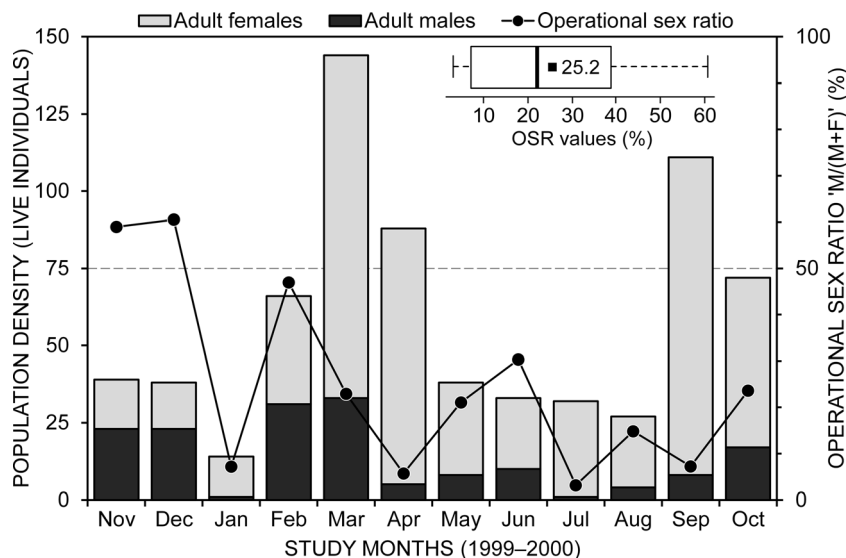
Numbers of DPS especially increased during spring when temperatures (Tm, TM, T) augmented after winter (Fig. 5a). The second population growth occurred in early autumn when temperatures began to decrease or were moderate. The population growth was much lower in the rest of the year when temperatures were either very high during the summer months or relatively low during the winter period. DSP population grew more during seasons when the wind (V, MV) blows

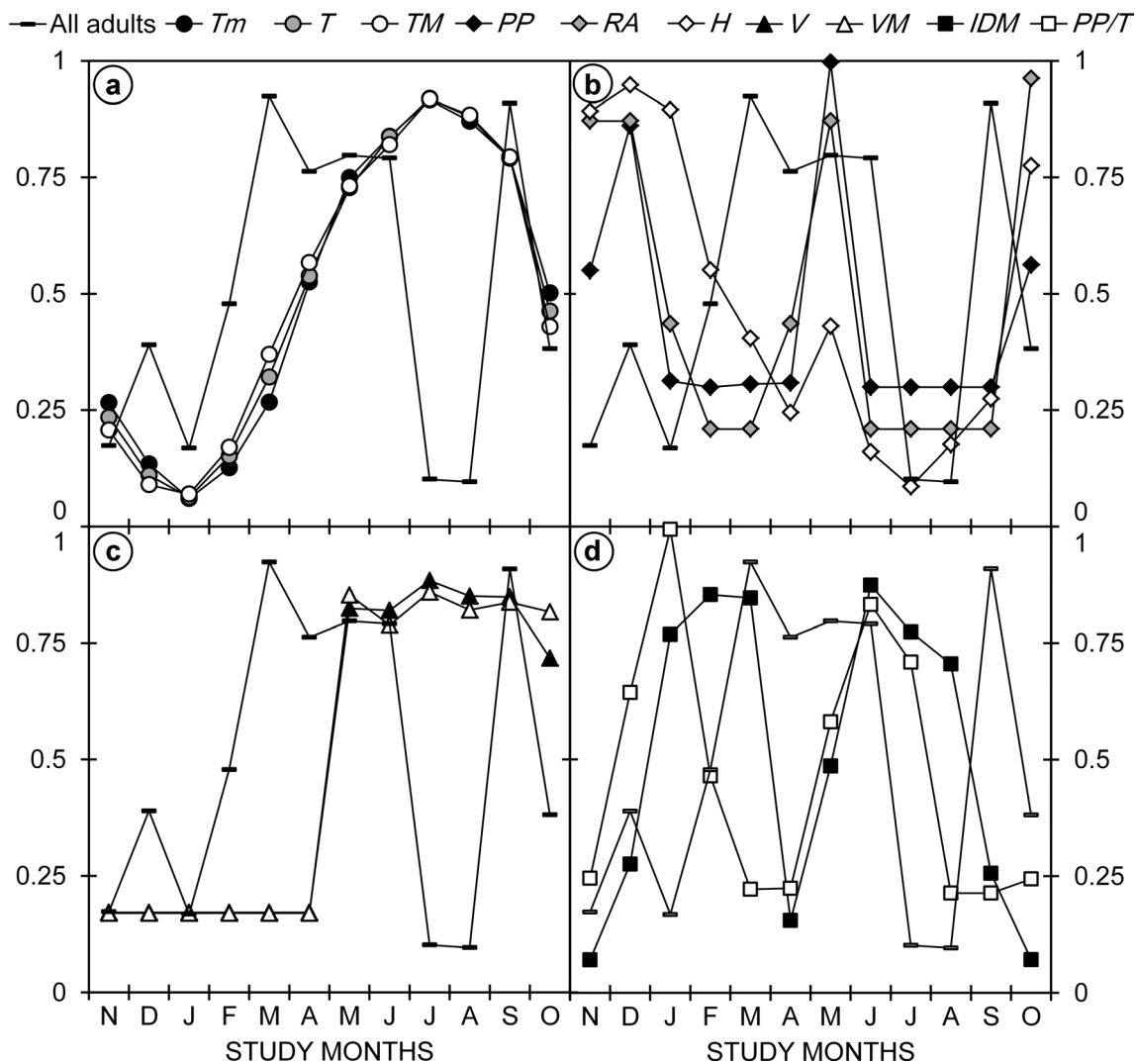
slightly (Fig. 5c). An inverse relationship was observed with rainfall and humidity; low densities of DPS were surveyed during periods of high rainfall or humidity (November–January, May, September), but also when they decreased significantly (June–August) (Fig. 5b). As for De Martonne aridity indices ( $I_{DM}$ ) and the average hygrometry (PP/T), they induced an increase in density when taking moderate values (Fig. 5d). Moreover, a substantial decrease or increase in these indices negatively acted on DPS population density. DPS densities underwent a significant decline during two periods, the first (November, January), i.e., when temperatures reduced, rainfall and humidity were high, and aridity indices were too low or too high. The second population decline (July–August) was likely connected to the effects of high temperatures, low rainfall and humidity, strong winds, and accentuated aridity (Fig. 5).

### Climatic parameters affecting population densities

The GLM applied for DPS total densities showed that climatic factors having a significant influence on the increase of densities were humidity, TM, PP/T, and  $I_{DM}$  (Table 3). However, the density significantly decreased with high values of minimum temperatures. This corroborates the results of Fig. 5 where we found that the population increased with increasing temperature in spring, but decreases with falling temperatures in winter, and in this case, the involved factors are TM and Tm, respectively. In addition, DPS populations significantly declined under extreme condition of aridity, i.e., when aridity severely increases/decreases (drought and heat/wet and cold: extreme values of PP/T and  $I_{DM}$ ). However, the GLM confirmed that an increase of the previous climatic indices had a favorable effect on population numbers (Table 3). Moreover, it can be argued that climate factors of Ouargla affect negatively DPS population density during the study period, because

**Fig. 4** Monthly variation of sex ratio of date palm scale *Parlatoria blanchardi* adults in the area of Ouargla (Sahara Desert of Algeria). The solid square inside the boxplot gives mean value of monthly sex ratio values





**Fig. 5** Monthly variation of normalized values of the eleven studied climatic parameters and total densities (larvae and adults, live and dead) of the population of *Parlatoria blanchardi* in the region of Ouargla (Algeria). All variables are transformed according to the normal

distribution. Abbreviations of climatic factors are reported in Table 3 and described in the “Meteorological data and climatic parameters” section. (a) Temperatures, b rainfall and humidity, c wind, d climate indices)

GLM intercept was negative and statistically significant (Estimate = -7.7,  $P = 0.008$ ).

The computed GLMs indicated that the surveyed climatic parameters did not have the same effects on densities of each DPS phenological stage (Table 4). The first GLM demonstrated that the variation of weekly densities of crawlers significantly ( $P < 0.001$ ) decreased with De Martonne’s aridity index ( $I_{DM}$ ) increase. Regarding L1+L2 densities, they increased significantly when precipitation (PP) increased, but they experienced a significant decrease with regard to increasing PP/T. Whereas, densities of adult males significantly increased as  $T_m$  and VM increase, whereas number of males decreased following increasing V, RA, and the ratio PP/T. Adult females was the phenological stage of DPS biological cycle, which was significantly negatively influenced by the studied climate parameters (Intercept = -17.14,  $P = 0.002$ ). Female densities

increased when TM, H, and V increased but decreased when  $T_m$ ,  $I_{DM}$  and VM increase (Table 4).

## Discussion

In the region of Ouargla, the DPS has four generations per year; spring and summer generations are the most abundant and long lasting. This almost identical annual life cycle occurs elsewhere in Algeria specifically in the Ziban region, with some uncertainties about the annual regularity of the fourth generation (Achoura 2013). Population dynamics of DPS on Deglet-Nour variety, the most cultivated variety throughout Algeria, revealed that it evolves in three annual generations in Biskra (Matallah and Biche 2011). Nadji (2011), showed



**Table 3** Modeling the effects of climatic factors on total population densities of DPS in the area of Ouargla, Algeria

Variables	Estimate	2.5 % CI	95 % CI	SE	Z	P
Intercept	-7.715	-11.724	-3.718	2.888	-2.67	0.008
T <sub>m</sub>	-0.499	-0.753	-0.244	0.183	-2.72	0.007
T <sub>M</sub>	0.696	0.484	0.910	0.154	4.53	<0.001
T	-0.156	-0.478	0.164	0.231	-0.68	0.499
H	0.046	0.019	0.073	0.020	2.35	0.019
PP	-0.003	-0.006	-0.001	0.002	-1.72	0.086
V	0.075	-0.031	0.182	0.077	0.98	0.328
VM	-0.042	-0.101	0.017	0.042	-0.99	0.321
RA	0.002	-0.058	0.061	0.043	0.04	0.970
PP/T	0.079	0.041	0.116	0.027	2.88	0.004
I <sub>DM</sub>	0.070	0.037	0.103	0.024	2.92	0.004
AIC	361.5					
BIC	382.0					

Goodness of fit:  $\chi^2 = 322.0$  on  $df = 40$

2.5 % CI, 95 % CI confidence intervals based on the profile likelihood, SE standard error, Z Z statistics, P P value, AIC Akaike information criterion, BIC Bayesian information criterion. T<sub>m</sub> minimum temperatures, T<sub>M</sub> maximum temperatures, T mean temperatures, H mean humidity, PP precipitation, V mean wind speed, VM maximum sustained wind speed, RA rain days, PP/T average hygrometry, I<sub>DM</sub> De Mantonne aridity index

that the pest species annually evolve through three generations, winter, autumn, and spring.

The main characteristic of DPS generations in Ouargla region is observed with the second and third generations, which start a little early (early February and early May, respectively), due to the early improvement of winter climatic conditions in the desert Sahara (Chenchouni 2012b) compared to other regions in the Mediterranean. Indeed, similar findings on the olive scale *Parlatoria oleae* confirmed the early reproduction of arid populations versus those of humid regions (Chafaa et al. 2013a). To compare and assess the variability of generation time with other regions similar to Ouargla in terms of arid climate characteristics, the studies performed on DPS at Biskra in Algeria (Djoudi 1992) and Tata in Morocco (Smirnof 1951, 1952) were reviewed in more detail. Although DPS establish four generations per year in both these regions, a difference is found for the start date and duration of generations, noting that the fourth generation is sometimes absent in Biskra. Thus (i) the first generation seems to begin and end later in Ouargla, but is of a shorter duration, (ii) the second generation begins and ends sooner in Ouargla, but lasts longer, (iii) the third generation also seems to begin sooner in Ouargla, especially compared to Tata, and lasts longer compared to Biskra, where 2 weeks have been estimated as difference, and (iv) the fourth generation seems to start later in Ouargla and ends earlier in Tata, it is shorter in Ouargla. These differences between the duration and timings of generations are certainly due to the seasonality of climate factors,

including the minimum and maximum temperatures (Kausrud et al. 2012; Dong et al. 2013). Nevertheless, in regard to the duration of generations, our findings are quite similar to those reported in Morocco, where the life cycle of DPS lasts between 72 and 110 days across three to four generations per year (Madkouri 1976).

On a broader scale within its range, the DPS generally has three to five generations per year, depending on the climatic conditions of the area (Bénassy 1990; Bounfour et al. 2005). But in most cases, the species develops four generations, the spring generation (March–June) is always the most important because of the favorable climatic conditions. During this generation, the damage is most obvious over all the green parts of trees (Khoualdia et al. 1993). In the Middle East, Kehat (1967) and Gharib (1973) reported that the species has three to four generations a year, in March–June, June–September, September–December, and from early October onwards, respectively, the fourth generation being partial since some of the third generation nymphs enter diapause in November. Not too far from our study area, in south-west Tunisia, Khoualdia et al. (1993) indicated that DPS underwent four generations per year, of which infestation rates on date palms were higher within the cultivar Deglet-Nour, during the spring generation, on the base of the crown of leaves, and on the southern crown side of the trees. However, our results differ from those recorded in Iran (Latifian and Zaerae 2009) and at Luxor in the Egyptian Sahara (Salama 1972), where DPS established only two generations a year, with a peak abundance in autumn (October), during which females produce more eggs due to the favorable conditions expressed by moderate temperatures and relative air humidity. Moreover, Abdul-Ahad and Jassim (1983) showed that DPS had five overlapping generations a year.

Our results are quite similar to those reported by Blumberg (2008), who states that the number of DPS generations per year as well as population sizes during each generation varied according to the climate, with DPS densities decreasing sharply in hot season and/or when drought is severe. The same findings as ours have led us to conclude that both the development and reproduction of DPS are delayed in summer but also in winter, which explains the low abundance of populations during different life stages because of the adverse climatic factors prevailing in these two seasons. Therefore, the DPS do not tolerate extreme weather conditions of both cold and heat, which characterizes the summer and winter in Algeria or Ouargla, and explains high their mortality rates.

Moreover, the monthly dynamics of crawlers in Ouargla are quite similar to that of Moroccan DPS populations, where their complete absence was reported in August (Smirnof 1952). The noteworthy decline of population densities in all DPS life stages during late summer is attributable to the following: (i) the hot climatic conditions (severe drought periods, changes in temperatures, strong wind, and low humidity

**Table 4** Effects climatic parameters on live population dynamics during different stages of *Parlatoria blanchardi* annual life history in the area of Ouargla (northern Sahara Desert of Algeria)

Climate Variables	Estimate	SE	Z	P	Estimate	SE	Z	P
	Mobile larvae (goodness of fit: $\chi^2_{40}=135.4$ )				Adult males (goodness of fit: $\chi^2_{40}=151.6$ )			
Intercept	-2.49	14.14	-0.18	0.860	14.78	12.72	1.16	0.245
Tm	-0.23	0.81	-0.28	0.777	1.74	0.86	2.03	0.042
TM	0.39	0.75	0.51	0.608	-0.14	0.68	-0.20	0.842
T	-0.15	0.97	-0.15	0.880	-1.57	1.11	-1.41	0.158
H	-0.01	0.09	-0.10	0.917	-0.01	0.09	-0.07	0.943
PP	0.05	0.03	1.76	0.078	0.01	0.01	1.24	0.215
V	0.11	0.34	0.32	0.747	-1.06	0.35	-3.07	0.002
VM	-0.07	0.19	-0.40	0.688	0.63	0.18	3.46	<0.001
RA	-0.02	0.25	-0.09	0.926	-0.63	0.17	-3.73	<0.001
PP/T	-1.17	0.90	-1.31	0.191	-0.49	0.17	-2.88	0.004
$I_{DM}$	-0.47	0.12	-4.03	<0.001	0.11	0.12	0.92	0.358
AIC	154.5				157.4			
BIC	175.0				177.9			
	L1+L2 larvae (goodness of fit: $\chi^2_{40}=94.0$ )				Adult females (goodness of fit: $\chi^2_{40}=285.1$ )			
Intercept	7.84	6.72	1.17	0.243	-17.14	5.57	-3.08	0.002
Tm	0.10	0.44	0.22	0.827	-1.23	0.36	-3.41	<0.001
TM	-0.52	0.34	-1.54	0.124	0.86	0.32	2.73	0.006
T	0.42	0.54	0.77	0.439	0.38	0.49	0.77	0.440
H	-0.01	0.05	-0.21	0.831	0.09	0.04	2.42	0.016
PP	0.01	0.00	2.00	0.045	0.00	0.00	0.72	0.474
V	-0.31	0.18	-1.78	0.075	0.40	0.18	2.18	0.029
VM	0.17	0.09	1.78	0.076	-0.20	0.10	-1.96	0.050
RA	-0.14	0.10	-1.31	0.190	-0.02	0.09	-0.27	0.790
PP/T	-0.25	0.07	-3.63	<0.001	-0.02	0.06	-0.38	0.706
$I_{DM}$	0.01	0.06	0.17	0.866	0.09	0.05	2.10	0.036
AIC	238.7				264.4			
BIC	259.2				285.0			

Abbreviations of climatic factors are reported in Table 3 and described in the “Meteorological data and climatic parameters” section  
SE standard error, Z Z statistics, P P value

levels) are extremely adverse for the development and survival of scales; (ii) mortality of palms of the outer ring of tree crown, either by natural aging or as a result of insect pests and fungal diseases (Farrag and Abo-Elyousr 2011; El-Shafie 2012); and (iii) bacterial diseases and mite predators that decimate almost all young females in late spring and early summer (Huffaker et al. 1971; Chafaa et al. 2013a). Moreover, high female mortality occurs just after egg-laying, while mature adult males live only 2–3 days (Bénassy 1990). The effect of predation on all DPS phenological stages by some natural enemies, such as insects (*Pharoscyrmus* spp., *Cybocephalus* spp., *Chrysoperla* spp.) and spiders, is not negligible (Idder 2011; Idder et al. 2011).

The significant variation of population density between study months and generations, during different DPS life stages, may be explained by the temporal variability of

climatic factors. Indeed, Blumberg (2008) indicates that population size during certain seasons, specifically summer, experiences large fluctuations depending on climatic factors, of which temperature (heat and drought) is deemed to be a limiting factor. Furthermore, Gharib (1973) reported that low temperatures do not allow pairing in winter, but reproduction starts in early spring (March) when temperatures are above 20 °C. Whereas Gharib (1973) reported that after the wintering season, DPS-pairing begins on the tips of the young leaflets in March at an average temperature of 20 °C.

Knowing that cold conditions also act as a limiting factor for the activity of several insects, many storage factories of dates use this feature to protect date fruits against attacks of pests and also fungal infestations (Manickavasagan et al. 2012; Siddiq et al. 2013; Abo-El-Saad and El-Shafie 2013).

Our findings on female-skewed sex ratio are in perfect agreement with data from the literature. Generally, the operational sex ratio in DPS favors females, with males usually forming less than 25 % of the population (Bénassy 1990; Watson 2002). Furthermore, with this study, the determination of how sex ratio fluctuates between generations and months may be good indicators of DPS pest character, demographical composition, and population dynamics; thus, it gives useful information for the effective development of an integrated pest management program.

Several studies have demonstrated that environmental factors of a given habitat influence the level of insect abundance, the number of generations, seasonal phenology of insect numbers, and life-history traits (Bénassy 1990; Khoualdia et al. 1993; Chafaa et al. 2013b; Salman et al. 2013). The life history of DPS is no exception as it also depends on the climatic conditions of the region that it colonizes. Indeed, the rate of development of the species is proportional to the amount of accumulated temperatures above 10 °C. This measurement is used to determine the number of DPS generations per year, insofar as each generation requires a total of about 1300 degree-days (Bodenheimer 1951). Thus, the region of Ouargla recorded a total of 4260 degree-days during the study period. This would equate to 3.3 generations, but given that there are two overlapping generations in spring–early summer and two in autumn–early winter; the number of generations is four.

Densities of live and dead DPS larvae and adults during the spring generation are higher than in other generations; whereas densities of the autumn generation come at second position. These differences in percentages would also be related to climatic conditions thereby to infer that the various climatic variables are more favorable during these periods; while they are most unfavorable during periods of low densities or high mortalities (the middle of summer and winter). It was demonstrated that population decrease during adverse periods is due climate factors inducing high rates of mortality and a slowdown development of the insect (Salman et al. 2013).

According to the GLM results, the tested climate factors affected total population density of the DPS. According to Laudeho and Bénassy (1969), the temperature is a primordial factor that influencing the duration of DPS biological cycle. In Egypt, Eraki (1998) demonstrated that the main climate factors affecting DPS populations were maximum, minimum and mean temperatures, and relative humidity. Population abundance was found to be significantly correlated with temperature and relative humidity (Salama 1972; Latifian and Zaerae 2009). Our findings are quite in concordance with these studies as well as with Laudeho and Bénassy (1969), which stated that DPS population density and infestation severity in Mauritania is affected by microclimate conditions, where maximum temperatures combined with low humidity and wind speed were very effective for the survival of crawlers.

Density and population dynamics of DPS are in close relationship with the local climatic conditions in the area of Ouargla. The findings show the high variability of the biology and ecology of the same species compared to other bioclimatic regions. In arid regions, for example, the DPS shows significant ability to withstand severe climatic conditions (high temperature and low precipitation), by matching its life cycle to the period of favorable conditions.

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