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Original Research Article

Fluctuation of *Lymantria dispar* (Lepidoptera: Lymantriidae) populations during gradation phase in sub-humid and semi-arid cork oak forest (Algeria)

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The last gypsy moth (*Lymantria dispar* (Linnaeus, 1758): Lepidoptera: Lymantriidae) gradation has been studied in sub-humid and semi-arid bioclimatic areas; respectively at Bouarfa and Tamentout cork oak (*Quercus suber* L.) forests. This study was to reveal the various aspects of the *Lymantria dispar* population dynamics. A analytical study focused on the egg masses of *Lymantria dispar* populations was conducted to determine the importance of their temporal evolution. The results analysis regarding the clutches and eggs of different generations allowed to synthesizing the evolution of the gypsy moth gradation in both cork oak forests explored. Progradation phase lasted from 2006 to 2007 in Bouarfa forest area, and 2006 to 2009 in the Tamentout cork oak forest. The peak of the infestation characterized both cork oak forests in respectively 2007 and 2009. Demotion phases were recorded during the period 2008 to 2010 in Bouarfa area and 2009 to 2011 in Tamentout cork oak forests. Actually, gypsy moth populations were in latency phase in all the areas surveyed.

Keywords. *Lymantria dispar,* dynamic, clutches, eggs, Algeria.

INTRODUCTION

Cork oak forests are an important reservoir of biological diversity, with which various defoliators species are associated (Clavijo et al., 2017). Among the Fagaceae, *Quercus suber* L. is the preferred host of the gypsy moth, *Lymantria dispar* (Linnaeus, 1758: Lepidoptera: Lymantriidae), which is the most abundant and damaging defoliator of this species in the Mediterranean area, particularly in Algeria (Chakali and Ghelem, 2008). The gypsy moth is well known as a phyllophagous and polyphagous of more than 300 trees species and shrubs (Duan et al., 2011). It feeds on the oak leaves (Limbu et al., 2017; Wittman and Aukema, 2019; Milanović et al., 2020).

This pest performs small cyclical periods of persistent populations and large infestations over time. The epidemics occur with one generation per year. Densities vary and fluctuate from each year depending on climatic conditions (Wittman et al., 2019). The first phase of cyclical gradation, which lasting about 2 to 3 years (Luciano and Lentini 2005). During this period the population density continues to increase, thus, the infested area expanding with a large intensity of defoliation (Martin 2007). This situation is followed by the culmination period, which almost varying between one to two years, in this period the pest can exceeds the local capacity to ensure their development, just one year may enough to cause a complete defoliation of cork oak forest. However, a generalized famine is noted towards the end of the infestation and causes a consequent mortality of individuals (Villemant, 2003; Cocco et al., 2010; Bodini et al., 2012). The lack food and the poor nutrition are often accompanied by the nuclear polyhedral virus epidemic and the propagation of active parasitoids (Gray, 2010; Contarini, 2016). In addition, a sharp decrease in the

population usually occurs within a year, which is characteristic of the regression phase (Luciano and Lentini, 2005). Consequently, the insect has a latency period varying from 5 to 8 years, when it is undetectable. Its population grows progressively over the following years. The period between two peaks of epidemics has been estimated between 6 and 12 years (Herard, 1984). In degraded cork oak forests, the most grazed, infestations are repeated every 5 to 6 years ((Luciano and Lentini, 2005). This main research was carried out in the Bouarfa and Tamentout cork oak forests from 2007 to 2015. The gypsy moth eggs were sampled during the last gradation to obtain information's on the fluctuations of this population. The gypsy moth is able to adapt to various feed conditions that regulate its populations (Villemant, 2003).

The study of the temporal and spatial fluctuations of *L. dispar* populations is determinant to develop an effective management strategy of forest ecosystems, using scientific knowledge to translate historical trends and provide a model of scenarios.

Thorough information's of the spatial and temporal distribution of egg masses and eggs of gypsy moth in its natural environment will help us to develop a management approach and effective monitoring based on the analysis of the variables described in this research.

MATERIAL AND METHODS

Study sites

The Bouarfa cork oak forest

Bouarfa cork oak forest is a part of Atlas blideen forest and is located at an elevation of 600m (36°43'90N and 2°80'00E). This area characterized by a sub-humid bioclimatic stage in the winter with precipitation ranging from 600 to 900mm per year. Drought is primarily felt in the summer. The annual average temperature is around 17°C with a minimum average in January less than 6°C. The forest chosen consisted of young oak trees with the species: *Cistus crispus*, *Cistus salvifolius (*Cistaceae), *Erica scoparia* and *Erica arborea* (Ericaceae). The area of this site is estimated at 99 hectares.

The Tamentout cork oak forest

The cork oak in this forest is pure stands about 3176 hectares, where the trees have an average age of 80 years old. The area was located at 780m (36°33'00N and 5°49'60E), and was, characterized by a Northern exposition in the semi-arid bioclimatic stage with a cold winters receiving an average of 500 mm of rain. The recorded average temperatures were about 15°C, the minimum average of the coldest months is 2°C.The area of cork oak forest consists mainly of the cork oak. The associated vegetation varies from place to place and is represented mainly by herbaceous species such as grasses and some shrubs such as rockrose and heather.

METHODOLOGY

Sampling and counting egg masses

Egg masses of *L. dispar* were counted and collected from Bouarfa forest in 2007 and 2008, and from Tamentout cork oak forest, between 2008 and 2010 at the end of the summer period (Fraval and Herard, 1975; Villemant, 2003), The counting of egg masses was carried out from the base of the trees, by traversing glance the main branches, by exploring the trunk and its cavities for 30 trees for each site. Each tree was considered as a sampled unit which taken as a systematic online selection in the cork oak forest Bouarfa, based on Fraval and Herard, 1975 method who performed a selection of 30 trees randomly. The cross device approach was used in Tamentout cork oak forests. This device was located in the middle of the study plot to avoid edge effects. This methodology was also adopted in Sardinia by Luciano and Prota (1982) and Luciano and Prota (1986). According to Fraval (1989), this method was considered as the most suitable for the study of the gypsy moth populations and their monitoring. The method of counting is still questionable and depending on the selected forest stands.

Preparing of the egg masses

Depilation of eggs was performed by rubbing them with a fine brush into a funnel provided with a filter. The mesh of the screen of about 0.8mm retaining fragmented eggs, and passing hairs was proposed by Herard and Fraval (1980).The counting of different categories of eggs: viable, broken, rolled, dried and parasitized was performed for each clutch separately using a binocular lens (Figure 1). The nonviable eggs can be separated from viable eggs at the laboratory, using stereomicroscope (Motic Digital Microscope).

According to Fraval (1989), the categories of eggs could be defined as follows:

- Viable eggs characterized by a pink-orange color when laying and become blackish brown thereafter. They are full and turgid.
- The dry eggs are opaque brown-black and contain dried young caterpillars. They are often slightly flattened.
- Flattened eggs are unfertilized eggs with the dead embryo.
- Parasitized eggs are recognizable by transparent chorions and are easily distinguished by the presence of the circular exit hole of the adult parasite.
- Broken eggs are fragments pieces of parasitized eggs or eaten by the predators.

Latency phase monitoring

The monitoring of *Lymantria dispar* populations using pheromone traps is carried out regularly during the butterfly flight period, in the two sites studied from 2009 to 2017.

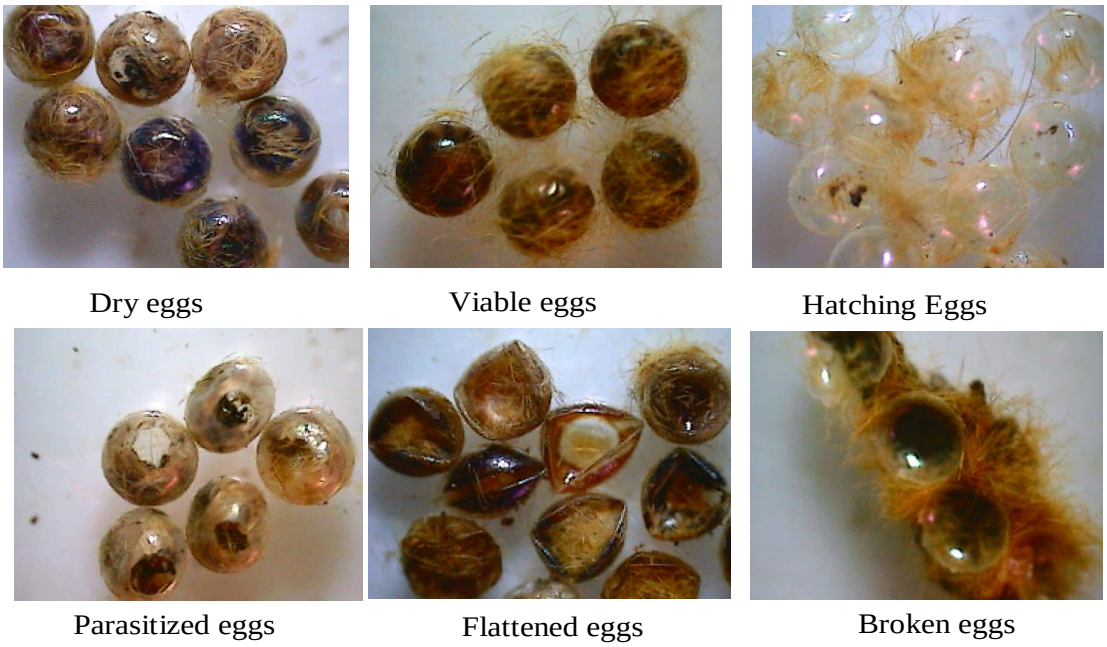

Figure 1: *Lymantria dispar* eggs categories

Table 1. Gypsy moth egg masses and eggs in Bouarfa forest

Parameters	Years	
	2007	2008
Sampled trees	30	30
Number of egg masses	4110	870
Number of egg masses / tree	137	29
– Min-Max	331-75	49-5
Number of eggs masses examined	30	30
Total eggs counted	19040	6786
Eggs / clutch, average	635	226
– Min-Max	237-990	97-350

Statistical analysis

To test the difference between the females fertility for each generation, and in each station, a simple descriptive analysis and ANOVA analyses were conducted using Excel stat package and Statistica software (Statsoft Inc. 2001; version 6.0) on data from egg masses numbers about thirty trees in each station, as well as counts of *Lymantria dispar* eggs.

RESULTS

Eggs and egg masses of gypsy moth in Bouarfa cork oak forest

The eggs and clutch counted during the years 2007 and 2008 showed a remarkable regression of gypsy moth populations (Table 1).

The data obtained during the two years of the study showed a great variability in the distribution of egg masses between trees and eggs through the clutches.

The test ANOVA showed a highly significant difference of the number of eggs per clutch between years between years ($F_{(1, 58)}$=97.363, p< 0.0001) (Figure 2).

Eggs's categories in the clutches from the cork oak at Bouarfa forest

The results of the counting of different eggs types (Table 2) show a strong regression at 2008 years. The numbers of parasitized and broken eggs are the most important, these results may explain the typical end of the gradation pattern.

Eggs and egg masses of gypsy moth in Tamentout cork oak forest

The average values of the egg masses counted were consistent, with respective averages of 15, 46, 14 for the generations 2008, 2009, and 2010 (Table 3). In 2009, the

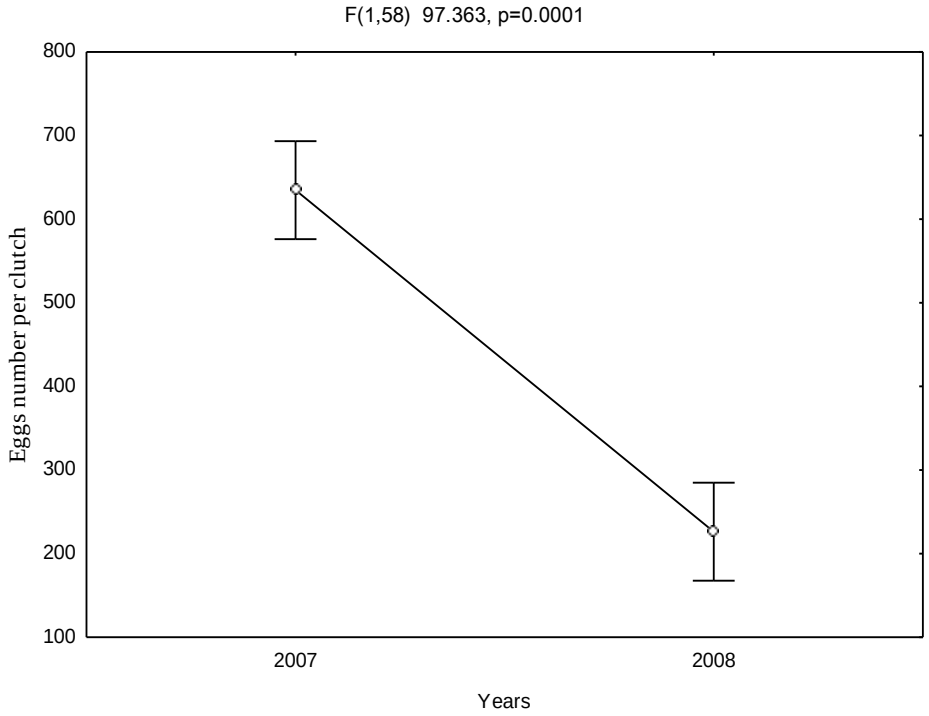

Figure 2: Comparison of average number of eggs per clutch

Table 2. Egg distribution from the cork oak forests at Bouarfa area

Categories	Years	Total number of eggs	Mean per clutch
Hatched	2007	8490	283
	2008	0	0
Broken	2007	180	6
	2008	2660	89
Flattened	2007	240	8
	2008	363	12
Dried	2007	2070	69
	2008	584	19
Parasitized	2007	4620	154
	2008	3111	104

Table 3. Parameters of egg masses and eggs in the Tamentout forest area (2008–2010)

Parameters	Years		
	2008	2009	2010
Sampled trees	30	30	30
Total of egg masses	450	1380	420
Number of clutches / tree	15	46	14
Min-Max	1 - 65	6 - 162	1- 67
Number of clutches	60	84	33
Total number of eggs	20090	30991	9094
Eggs / clutch, average	335	369	275
Min-Max	108-613	90 – 669	87-459

average number of egg found was three times more than in 2008. In 2010, it was a remarkable regression of spawning populations about 14 clutches per tree.

Temporal regression of populations showed a significant difference in 2010, when we were marked seen a collapse of the population in Tamentout forest area.

The same scenario is observed for the variations in the average number of eggs during the years of graduation. The ANOVA analysis highlight the difference on the average number of eggs per clutch among three study years

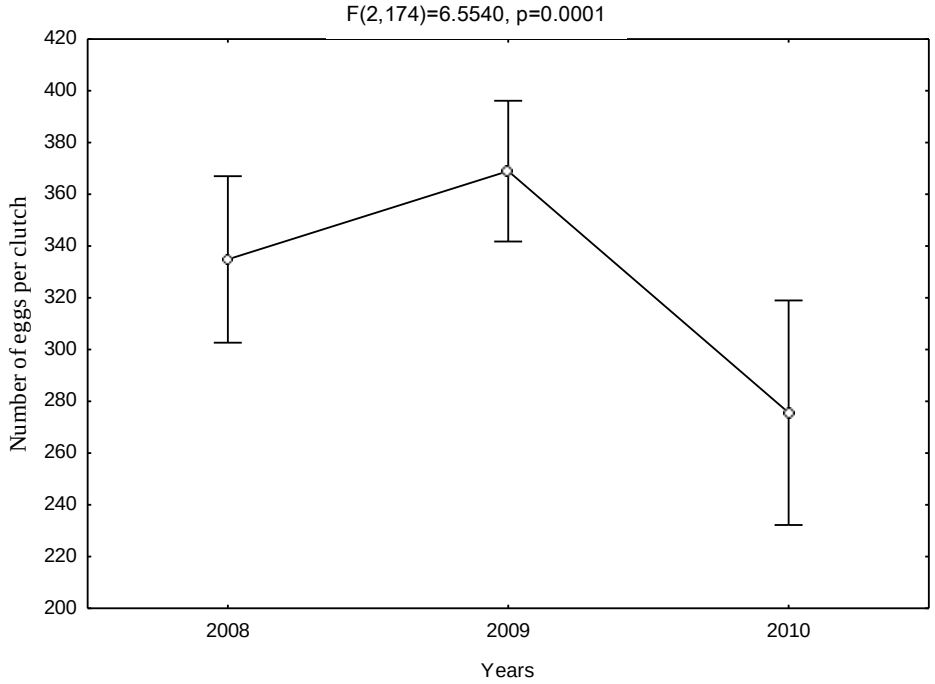

Figure 3: Chronological analysis of eggs per clutch for three generations

Table 4. Analysis of Eggs from the cork oak forests of Tamentout

Eggs categories	Years	Number	Mean number of eggs per clutch
Hatched	2008	10594	176
	2009	15850	118
	2010	3438	131
Broken	2008	276	5
	2009	29	0.35
	2010	87	3
Flattened	2008	562	9
	2009	1614	19
	2010	173	5
Dried	2008	1983	33
	2009	3640	43
	2010	718	22
Parasitized	2008	6675	111
	2009	9858	117
	2010	9094	114

As shown in Figure 3.

Egg categories in the clutches from the cork oak at Tamentout forest

High variability in the numbers of different categories of eggs was recorded during gradation (Table 4).

Gradation analysis in Bouarfa cork oak forest area

The larvae of Gypsy moth in Bouarfa cork oak forest were recorded during the summer of 2006. During this period, a considerable effectives of larvae were invaded the foliage of the cork oak trees. A significant average of 72 clutches per cork oak tree was noted in the Bouarfa cork oak forest. The outbreak of *L. dispar* was caused a total defoliation in Bouarfa cork oak forest during 2007. In 2008, time lag between hatching and bud burst of cork oak was observed during our investigations that influenced the survival of the population and the density of the next generation. We registered significant mortality, which led to the collapse of gypsy moth populations at the end of 2008 (Figure 4a).

During the gradation years, the eggs counting let us obtain information on the fertility of gypsy female's moth in this period (Figure 4b).

Culmination period was registered in 2007, when the females of the gypsy moth population laid maximum eggs. In the regression phase, that corresponding to the year

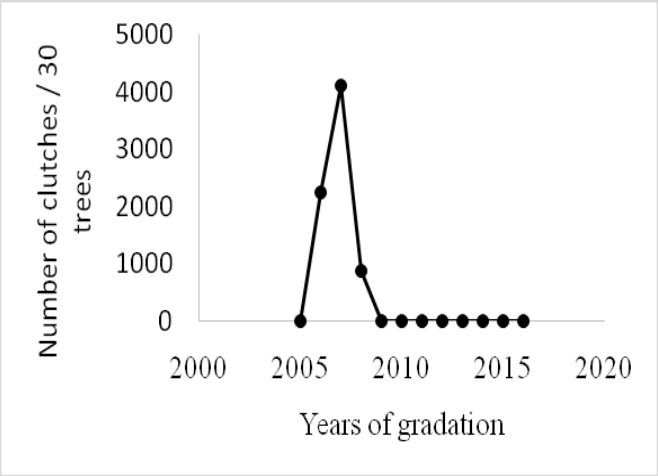

Figure 4a: Clutches per 30 trees

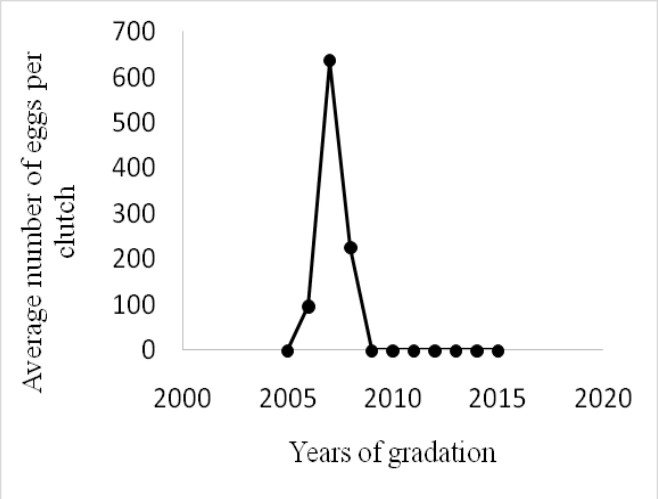

Figure 4b: Eggs number per clutch

Figure 4: Dynamics of egg masses and eggs per clutch during the last gradation in Bouarfa cork oak forest (2005–2016)

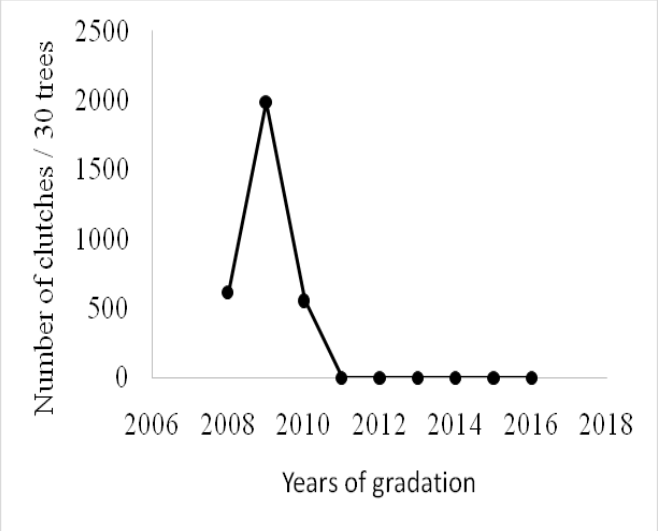

Figure 5a: Number of clutches per 30 trees

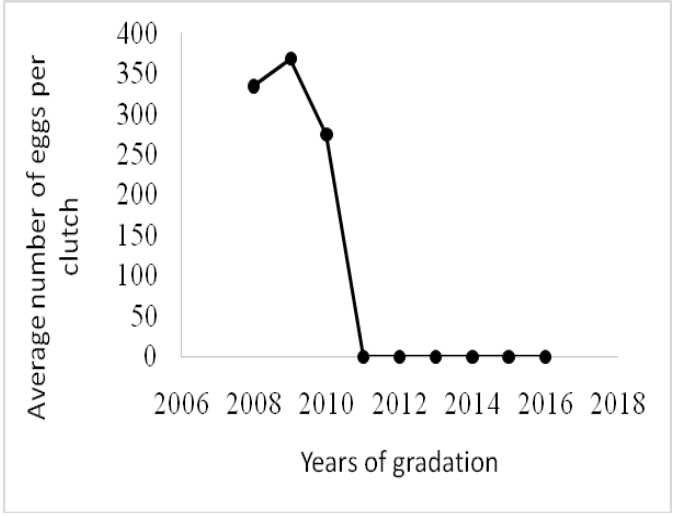

Figure 5b: Eggs number per clutch

Figure 5: Dynamics of egg masses and eggs per clutch during the last gradation in Tamentout cork oak forest (2007–2016)

2008, the females were malnourished and had low fertility. They had a very limited in number and in surface with a small number of eggs. Between 2009 and 2017, surveys and monitoring based on specific pheromone of gypsy moth, carried out in the cork forests of the Atlas Blideen did detect only some adults of *L. dispar*.

Gradation analysis in Tamentout cork oak forests area

According to surveys carried out in Tamentout cork oak forest, the first outbreaks of gypsy moth began early between 2006 and 2007, while, in 2008, the counting performed gave an average of 15 clutches per tree. In 2009, the average number of assessed clutches was tripled, and a total defoliation was registered in the Tamentout cork oak forest (Figure 5a). A sharp decrease in the gypsy moth population was recorded in 2010, as a result of a decrease in female fertility following the lack of food. Since 2011, the Tamentout site has experienced a latent phase.

In 2008, an average number of 335 eggs per clutch were counted and 369 eggs per clutch in 2009, while it decreased to 275 eggs in 2010 (Figure 5b). The gradation in Tamentout cork oak forest was spanned to six years.

DISCUSSION

The economic impact of the gypsy moth was related to the density of the population and varied with forest features and the gradation phase of the insect (Kamal, 2010; Hlasny et al., 2015). The density of the gypsy moth population of the Bouarfa cork oak forest decreased significantly between 2007 and 2008 from an average of 137 clutches per tree in 2007 to 29 clutches per tree in 2008. In Tamentout cork oak forest, the gypsy moth populations was increased clearly in 2009, the average number of egg masses was

augmented from 15 egg masses per tree in 2008 to an average of 46 in 2009. At the same site in Tamentout forest in 2010, the recorded average fell to 14 clutches per tree. This decrease reflected the typical pest gradation pattern through pro-gradation phases of culmination, regression with a latency period noticed since 2011. Gypsy moth outbreak began in 2006 in the both considered cork forests, where the defoliation of cork oak was observed. In 2007, a total defoliation was registered in all stands of Bouarfa cork oak forests. A similar situation was observed in Tamentout cork oak forests in 2009. The periodic observations which carried out in the gradation period showed a relationship between the attack density and the availability of foster foliage, Khous (1991) noted the same observations in Tikjda holm oak forest. in the gradation phase of the insect population dynamics, the synchrony between egg hatching in the host tree appeared the determining factor in the collapse of the population and the cause of mortality for the first three larval instars which were considered as a critical phase in the development of the insect (Fraval, 1989).

One year after the total defoliation of cork forests, a lag between hatching and bud trees was noted, which influenced both the survival of gypsy moth populations and generation density. A reduction in average number of clutches and eggs, was observed between 2007 and 2008 in Bouarfa cork oak forests and between 2009 and 2010 in Tamentout cork oak forests. These results were explained by episodic evolution of the insect gradation (Soukhovolsky, 2016). The years, 2007 and 2009 represented the culmination phases in considered cork oak forests respectively, where the females laid a maximum eggs on a larger surface. In the regression phase, for the years 2008 and 2010 respectively the females were malnourished and laid fewer eggs by number and the surface of clutches. Khous and Demolin (1997) were noted that the duration of outbreaks was usually lasted for 3 to 4 years in littoral cork forests and it was limited to 2 years in the mountainous native oak forests. However, the infestation was spread over a period of around 5 years in Tamentout cork oak forests. The counting of gypsy moth eggs shows spatial and temporal variability with an average of 275 eggs per clutch recorded in 2010 at the cork oak forests of Tamentout and an average of 635 eggs per clutch in 2007 at Bouarfa cork oak forests. About this subject, Luciano and Lentini (2005) were determined that the number of eggs was varied from 100 to 1000 eggs per clutch depending on the gradation phase and the area features. Furthermore, various authors noted that the number of eggs depended on the availability of food and gradation phase, it was higher before and at the beginning of the outbreak than during the regression phase. Villemant (2003) was reported that during the infestation phase, egg masses were larger than 30 mm and contained 500 to 800 eggs. In 2008, the eggs counted in the cork oak forest were represented less than 50% of the value obtained in the previous year in 2007. The same observations were noted on the egg numbers counted in the Tamentout cork oak forest between 2009 and 2010 that confirming the regression population phase of gypsy moth in the cork forests prospected.

The gypsy moth has a large distribution in all oak forests of northern Algeria, it showed periodically by spectacular defoliation in several cork forests. Since 2006, the attacks of gypsy moth have reappeared in various oak forests in Central and East Algeria. The study in both areas cork oak, Bouarfa and Tamentout since 2007 highlighted the ecological and biological characteristics of the insect gradation phase. The counting of clutches in Bouarfa cork oak forests during the years 2007 and 2008, and in Tamentout forest for the period which varying from 2008 to 2010 facilitates to trace the schema of outbreak in both sites. Similarly, a count of eggs from cork oak was carried out both consecutive years in Bouarfa cork oak forest and in three successive years in Tamentout cork oak forests. The clutches collected in 2007 in Bouarfa cork oak forest contained more eggs than those collected in 2008. The counting of the eggs from the cork oak forests presented two opposite situations, increasing between 2008 and 2009 followed by a decrease in 2010.

Periodic visits and control through the use of pheromones between the years 2011 to 2017 testify to the latent phase, which deserves special attention to detect a new epidemic in the next years.

Conclusion

Gypsy moth, *Lymantria dispar* is developing an environmental evolution strategy throughout its range. Despite the studies conducted on the various aspects of its biology and its ecology, permanent spatial and temporal monitoring of populations must be carried out to better manage the protection of oak in the event of an infestation.

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Conflict of interests

The authors declare that they have no conflicting interests.

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