CEDAR TREE GROWTH (*CEDRUS ATLANTICA* MANETTI) IN CHRÉA NATIONAL PARK, ALGERIA, AND THE INFLUENCE OF DEFOLIATION BY THE PINE PROCESSIONARY CATERPILLAR (*THAUMETOPOEA PITYOCAMPA* SCHIFF.)

Mohamed SBABDJI[1], Oldache EL HADI[1], Ahmed HADDAD[2], Bachir KADIK[3] & Luc LAMBS[4]

RÉSUMÉ. — *Croissance du Cèdre* (Cedrus atlantica *Manetti*) *dans le parc national de Chréa, Algérie, et influence de la défoliation par la chenille processionnaire du pin* (Thaumetopoea pityocampa *Schiff.*). — Le Cèdre est une essence forestière d'altitude, endémique du Maghreb. La présente étude décrit les conséquences d'une forte attaque de *Thaumetopoea pityocampa* Schiff. sur des cèdres centenaires dans le parc national de Chréa, 50 km au sud-ouest d'Alger. La période de dommages a été déterminée par relevé des nids. Après deux épisodes consécutifs de défoliation, la réduction maximale du taux de croissance a été enregistrée un an après la première défoliation. Jusqu'à 50 % de réduction de la croissance ont été calculés pour une défoliation complète. La réduction du taux de croissance durant les années suivantes fut plus faible, les arbres récupérant leur croissance. Ces résultats peuvent contribuer à améliorer la gestion des infestations par les insectes et la protection des plantations de cèdres, et posent des questions sur l'augmentation potentielle des attaques d'insectes avec le changement climatique.

SUMMARY. — Cedar tree is a mountain forest species that occurs naturally in the Maghreb region. This study describes the consequences of a strong attack of *Thaumetopoea pityocampa* Schiff. on century-old cedars in Chréa National Park, 50 km southwest of Algiers. Period of damage was assessed by nest census. After two consecutive defoliation events, maximum reduction in growth rate was recorded one year after the first defoliation. Up to 50 % of growth lost were calculated for a complete defoliation. A reduction in growth rate in subsequent years was lower due to trees undergoing recovery growth. These results could contribute to improved management of insect infestations and the protection of cedar plantations, and raise questions about the potential increase of insect attacks with climate change.

The distribution of cedar forests (*Cedrus atlantica* Manetti; *Arz* in Arabic and *Idil* or *Begnoun* in Berberic) is strongly influenced by climate, and its tree-ring width has even been used to reconstruct precipitation amount over the past thousand years in Morocco (Till & Guiot, 1990). The natural distribution of this species during the wetter and colder Pleistocene period was more extensive in the Maghreb region, ranging from Morocco to Tunisia. With changes in climate and the advent of a warmer period, cedars have disappeared from Tunisia, and occur in Morocco and Algeria only in the higher mountain systems (Demarteau, 2006). Cedar trees grow between 1400 and 2200 m in altitude and need between 600 and 1500 mm of rainfall per year (Aussenac, 2002; Halatim, 2006). Adult cedars can survive with only 400-500 mm

[1] Agronomic National Institute, El Harrach, 16010 Algeria
[2] Forestry Departement, University of Tlemcen, BP 119, 13000 Algeria
[3] National Institute of Forestry Research (INRF), BP 73, Chéraga, Alger, Algeria
[4] Corresponding author. CNRS-ECOLAB UMR5245, 29 rue Marvig, F-31055 Toulouse cedex. Tel.: 00 33 562 26 99 94, Fax: 00 33 562 26 99 99. E-mail: lambs@cict.fr

Rev. Écol. (Terre Vie), vol. 64, 2009.

precipitation, but there is no natural regeneration (Halatim, 2006). About 160 000 ha of cedar forest remain in Morocco (in the Riff, middle and high Atlas) and about 30 000 ha in Algeria (in the Tellien Atlas and the Aures mountains) (Halatim, 2006; M'Hirit, 1993). In Algeria, the following cedar forests can be found (Fig. 1) from west to east on the Atlas Tellien: Theniet El Had (Ouarsenis), Chréa, Tala Guilef, and Tikjda (Djurdjura), and Babors. The following cedar forests occur in the Aures and Hodna mountains: Belezma, Boutaleb, S'Gag, Chelia, Ouled, and Yacoub (Zamoun & Demolin, 2004).

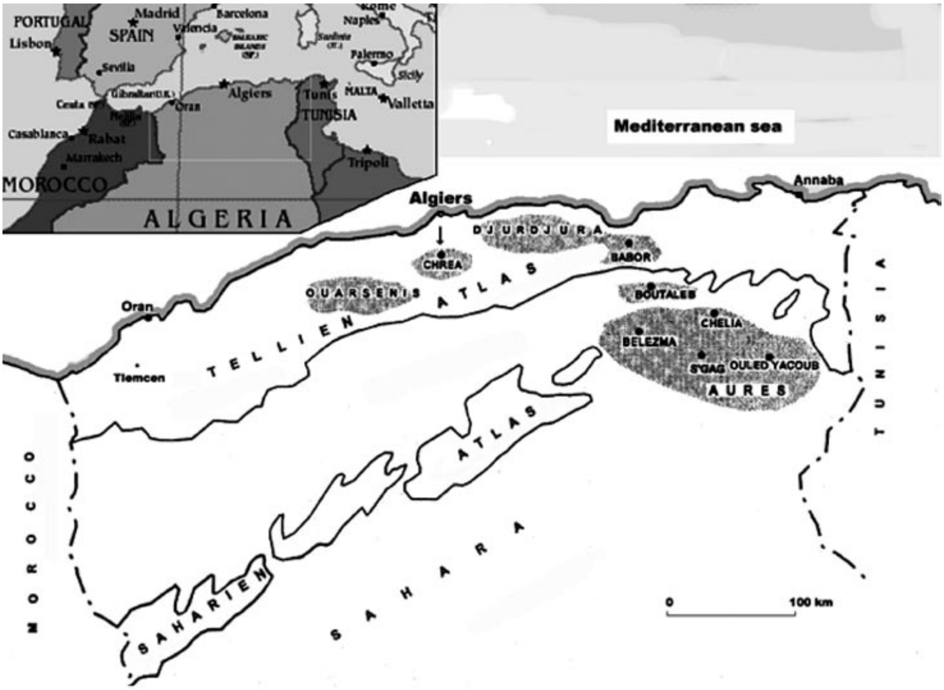

Figure 1. — General map of North Algeria with the location of the cedar forests. In the Tellien Atlas from West to East: Ouarsenis area (Theniet El Had), Chréa (studied in this paper), Djurdjura (Tikjda and Tala Guilef), and Babors. In the Saharan Atlas: Hodna area (Boutaleb) and Aures area (Belezma, S'gag, Chelia, and Ouled Yacoub).

The mean radial growth of these trees is in the range of 3-8 mm in the wetter areas such as the Morocco rif, and 0.8-3.5 mm in drier areas such as the east Atlas (Messaoudène *et al.*, 2004; M'Hirit, 1993). However, the climatic and edaphic conditions are not the only parameters affecting the growth of cedar trees: caterpillars and leaf miners can cause vegetative damage. In small areas, the best way to prevent damage is to water, fertilize, and prune the trees.

The principles for estimating decrease in radial growth of trees following defoliation used by various researchers are very similar. They are based on a comparison of the increase in width of the attacked and defoliated trees to reference trees. Nevertheless, the methods used to take measurements can be relatively different. Bouchon & Toth (1971) took measurements on the quadratic rays after the tree was cut down, whereas Lemoine (1977) measured the annual increase in circumference, which requires follow-up measurements over several years. Based on the same principle of estimation, Laurent-Hervouet (1986a, b), Du Merle *et al.* (1988), Alfaro & MacDonald (1988), Alfaro & Shepherd (1991) and Graf *et al.* (1994) carried out their measurements on annual rings. More recently in 2005, Kanat *et al.* (2005) calculated the loss on annual ring growth from wood cores.

Several authors have undertaken studies on the relationship between the defoliator and its host (Levieux, 1987; Mason *et al.*, 1988). Many studies have investigated the impacts of *Thaumetopoea pityocampa* Schiff., which affects several species of pines and the Atlas Cedar throughout the Mediterranean region (Cadahia *et al.*, 1970; Joly, 1970; Bouchon *et al.,* 1971; Lemoine, 1977; Laurent-Hervouet, 1986a, b; Kanat *et al.*, 2005).

Although repeated infestations of trees by caterpillars have been reported, their impact on the Atlas Cedar (*Cedrus atlantica* Manetti) has only recently been investigated. In Morocco, M'Zibri (1991) estimated the reduction in growth rates, and Graf & M'Zibri (1994) estimated the losses in productivity following infestations by *T. pityocampa*. In Algeria, damage caused by this defoliator is on the tree growth, in particular on the young plantation of Aleppo Pine and cedar used in the 'green belt' (Zamoun & Demolin, 2004). This project began in 1974 and involves reforestation in an arid and semi-arid zone of 3 millions ha in the north of Sahara.

Chréa National Park is located in the middle of Algeria, about 50 km south of Algiers. It is around 27 000 ha in size and it is the second largest park in the country. The park contains about 1200 ha of cedar forest at an altitude of 1300-1600 m, with a mean annual rainfall ranging from around 600 mm at the level of Blida to around 1100 mm on the mountaintop. The study area contains specimens of cedar species that are around 100 years old. Caterpillars have infested these forests on several occasions. Among these infestations, three attacks occurred during 1973-1994, and are the subject of this study. Reductions in growth rates were estimated using the method of the reference ring and the potential ring used by Lemoine (1977). Due to the importance of the Atlas Cedar in plantations, we attempt to estimate the reductions in growth rates following the defoliation of trees by processionary caterpillars.

MATERIALS AND METHODS

To avoid cutting down trees and considering the unavailability of circumference measurements from previous years, we chose to take measurements of annual rings from cores. This made it possible to quickly collect data covering several years.

Site

This part of the Chréa forest consists of a 1500 m high crest line on each side, with a slope of about 20-30 % formed by schistose soil. The cedar trees are between 80 to 120 years old, between 10-15 m in height, with a diameter of 40-50 cm and distance between trees of about 15-20 m. Because of the altitude, the undergrowth is mainly grass, rosebushes (*Rosa canina*), yew (*Taxus baccata)* and holly (*Ilex aquifolium*). Three observation sites were chosen to follow the defoliation by the caterpillars. The reference site (T) was located on the northern slope, which is wetter and colder, and quite free from caterpillars. Two severely attacked sites (A1 and A2) are located on the southern slope, which is more thermophilous and favourable to the defoliators. Caterpillars and moths compensate for the coldness from the altitude by concentrating on the southern slope. Distance between site T and site A1 is around 300 m, and between site T and site A2 is 100 m. In each site, 30 trees were sampled (one core per tree) during the end of 1994.

Bouchon & Toth (1971) report on the difficulty in finding uninjured trees beside attacked trees at the same site. If different sites are taken, the chosen trees should present similar growth profile during the periods without attack.

Attack periods

The last attack period was recorded during 1991-1993 and damage intensity was calculated by counting the number of caterpillar nests per tree. Some total defoliations were observed between 1991 and 1992, associated with high caterpillar mortality. Previous attack periods are known from foresters' reports. A period of 4-6 years is generally found between maximum infestations. Similarity between the attacked sites and the reference site was determined by the graphic synchronization of the relative average annual growth curves. This ratio was calculated by dividing the effective radial growth by the mean growth value of the site for each year.

Growth loss calculation

Once the similarity in growth rates of trees at attacked and reference sites had been determined during the period without infestation (non-infestation period), the relative potential ring could be determined with reference to the infestation year. This comparison was done by graphic superposition with the Excel program and the level of significance was calculated using Pearson's r.

The following calculation method was first introduced by Lemoine (1977) on circumferences, and uses the increase in growth in the first year after the attack as the reference ring. We adapted this method to measure beam and took the mean of several years during the known non-infestation period.

A’ = effective ring width of the attacked trees during the year of infestation (N).
A = sum of annual rings of the attacked trees produced during non-infestation periods / year duration.
B’ = ring width of the pilot site corresponding to the year of infestation (N).
B = sum of annual rings of the reference trees produced during non-infestation period / year duration.
(B - B’)/B = ratio between the change of the ring width produced during year (N) in the reference site and the average ring of the non-infestation period for the same site.

Where trees at the attacked site display similar growth rates as trees at the reference site, the two sites have the same change in ring width (B - B’)/B=(A - A’p)/A, and the potential ring (A’p) from the attacked site for year (N) is obtained by the following formula:

A’p (potential ring tree width relative to A’) = A – A(B – B’)/B

Then, the growth losses due to defoliations can be obtained as follows:

((potential ring width – real ring width) / potential ring width) × 100 = [1 – (A’B/AB’)] × 100

Statistical analysis

Mean values are reported along with the standard deviation. For the graphic correspondence, Pearson’s r correlation index was calculated using Excel (Microsoft Corp. Redmond, WA). Variance analysis was performed using Statistica (Statsoft, Inc., Tulsa, OK).

RESULTS

Growth rate

Until 1972, the 30 trees from the reference site displayed a mean radial growth of 2.75 mm/year over the first 60 years. Over the next 22 years, from 1973 to 1994 (see Fig. 2), mean annual radial growth was 2.01 ± 0.27 mm. On the individual tree level, mean growth ranged between 0.59 and 3.01 mm. For a given year, some trees increased their beam by 4.5 mm, whereas other trees increased by only 0.2 mm.

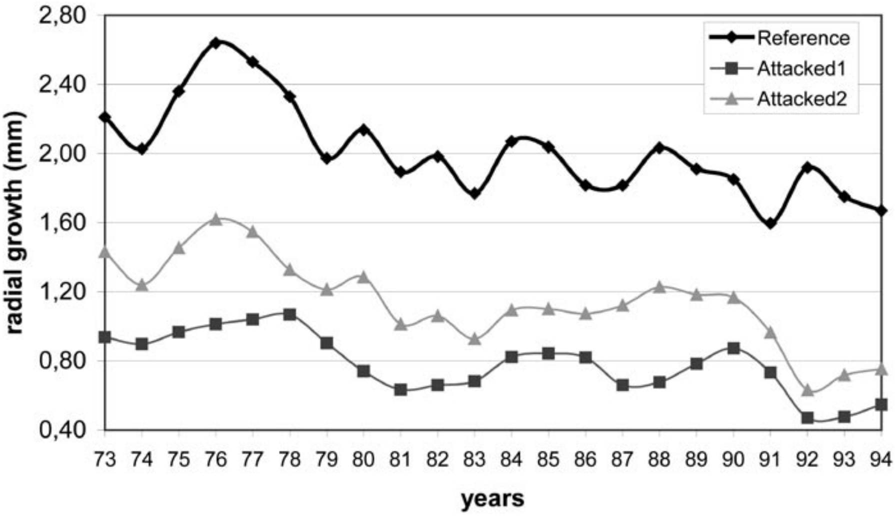

Figure 2. — Mean radial growth (mm) of 30 trees from the three sites during the 22 years studied as obtained from wood cores. *Reference* is the site located on the north side and not infested by the caterpillars; and *Attacked 1* and *Attacked 2*, are the two sites located on the south side and infested by the caterpillars.

For the attacked sites the profiles remain similar, as seen in Fig. 2, although the growth rate is much smaller. Site A2 was as low as 1.14 ± 0.25 mm per year, and site A1 recorded a mean annual drop of 0.78 ± 0.17 mm. If attempting to superimpose the attacks growth curve with the reference growth curve, a factor of 1.64 is needed for site A2 (r = 0.90) and a factor of 2.36 for site A1 (r = 0.87).

Determination of the damage intensity

Between 1991 and 1993, nest counting was performed on all 3 x 30 study trees at the three sites. The mean numbers are displayed in the Table 1. Nearly complete defoliation was observed when more than 15 nests per tree were recorded. This number was used to make an estimation of the defoliation percentage.

Table I

Mean number with standard deviation of caterpillar nests and estimation of tree defoliation at three sites in Chréa National Park

Site	years	Number of nests/tree (sd)	defoliation% (sd)
Reference T	1990-91	0,3 (±0,18)*	2% (3,85)*
	1991-92	0,2 (±0,16)*	1% (2,42)*
	1992-93	0,1 (±0,10)*	1% (2,65)*
Attack A1	1990-91	8,6 (±0,53)	57% (9,61)
	1991-92	18,6 (±1,26)	100% (0,00)**
	1992-93	0,8 (±0,32)	5% (5,72)*
Attack A2	1990-91	7,3 (±0,54)	50% (10,33)
	1991-92	15,5 (±0,96)	100% (0,00)**
	1992-93	2,3 (±0,43)	15% (10,5)*

*: high standard deviation for the low mean due to the minimal values 0 and 1
**: on the contrary for total defoliation (100%) there is no variation

Calculation of the effective damage periods

Forest administrators have noted the caterpillar attacks during the years 1980-1983 and 1987-1988, and we noticed attacks on our field trips during 1991-1993. We can now compare these with the effective radial loss in the wood cores. Figure 3 represents the relative radial growth (ratio of each year growth to the mean growth) during 1973–1994. After this normalization of the growth curves, the fact that the attack plots present a lower radial growth that the reference plot, means that the corresponding years are a damage period.

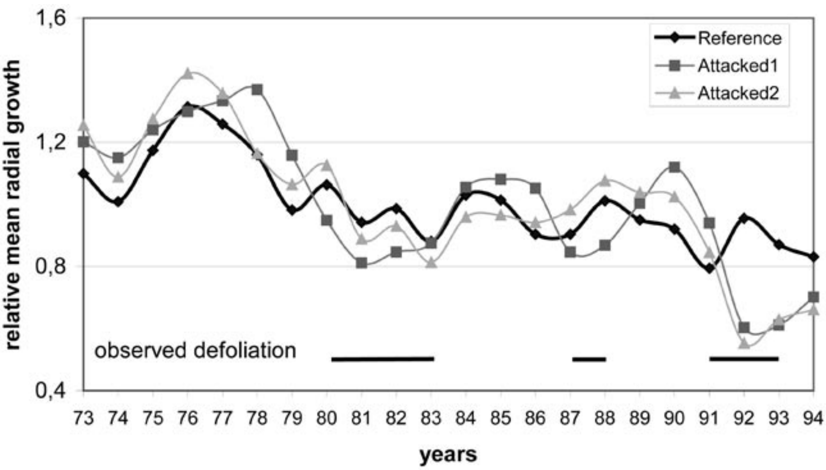

Figure 3. — Relative mean growth from the same series, obtained by dividing each radial growth rate by the mean radial growth rate of the corresponding site. The infestation period (observed defoliation) is added at the bottom of the figure.

Attacked site A1
- first damage: years 1980, 1981, and 1982
- second damage: years 1987 and 1988
- third damage: years 1992, 1993, and 1994

Attacked site A2
- first damage: years 1981, 1982, 1983, 1984, and 1985
- second damage: years 1992, 1993, and 1994

The periods of non-damage correspond to the remaining years over the whole period taken into account: [73 > 79] U [83 > 86] U [89 > 91] = 14 years for the first attacked site, and [73 > 80] U [86 > 91] = 14 years for the second attacked site.

Calculation of the radial growth losses

From the reference tree ring values obtained for the two cases corresponding to the sites, the losses were calculated by the formula indicated above, starting from the measured annual rings, which are defined as *A* for the attacked sites and as *B* for the reference site (Tab. II, Fig. 4).

TABLE II

Calculation of the annual average increases during the non-infestation periods, with A for the attacked sites and B for the reference site

Site	Period	Increase A	Increase B
A1	1973-9; 1983-6; 1991-3	0.88	2.07
A2	1973-80; 1986-91	1.27	2.08

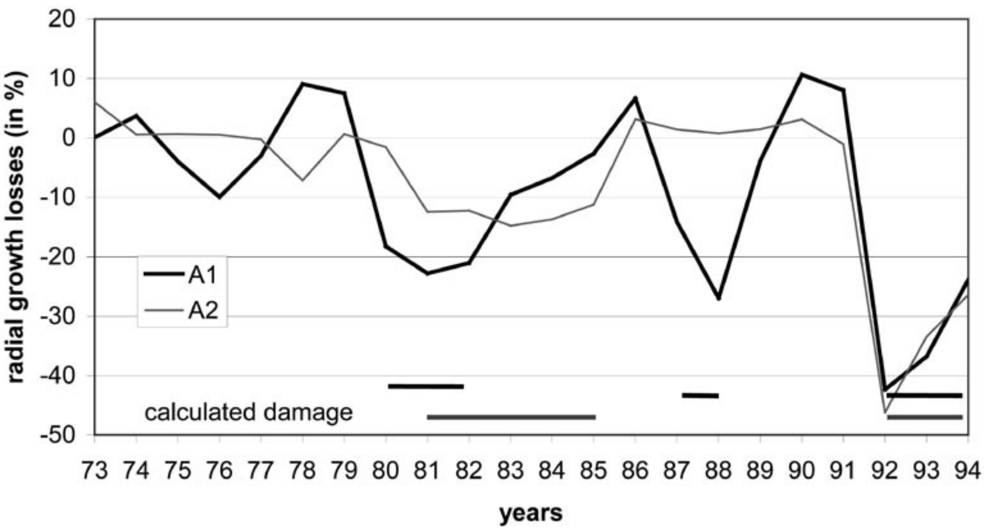

Figure 4. — Comparison of the calculated radial growth losses for the two attacked sites A1 and A2. The calculated damage period for each site have been added at the bottom of the figure.

It is necessary to specify that the sign (-) indicates a decrease and the sign (+) indicates an increase. Estimating these values for the non-infestation years will enable determination of the estimation error due to the small difference of annual increase that exists between the reference site and each of the two attacked sites.

THE EFFECT OF THE LOCALIZATION AND THE GROWTH LOST

As calculated from the non infestation periods, the similarity between the attacked sites and the reference site is not perfect. Although the values of gains and losses are low (< 10 %) we prefer to evaluate impact. For the first attacked site (A1), the variation of the growth was found equal to 0.45 % (sd = 6.8) when compared with the reference site. This value varies between a maximum gain of 7.25 % and a minimum loss of - 6.35 %. For the second attacked site (A2), this variation is 0.01 % (sd = 2.89), ranging from a maximum gain of 2.90 % and a minimum loss of - 2.88 % (Tab. III).

TABLE III

Growth loss (%) values caused by defoliation, with and without the correction of the localization effect

Site	First attacked site (A1)								Second attacked site (A2)							
Years	94	93	92	88	87	82	81	80	94	93	92	85	84	83	82	81
Raw losses	23.9	36.8	42.4	26.9	14.2	21.5	22.8	18.2	26.4	33.5	46.2	11.2	13.7	14.8	12.3	12.4
Corrected losses	24.3	37.2	42.8	27.4	14.6	22.0	23.2	18.7	26.4	33.5	46.2	11.2	13.7	14.8	12.3	12.5
Maximal losses	31.1	44.0	49.6	34.2	21.4	28.8	30.0	25.5	29.3	36.4	49.1	14.1	16.6	17.7	15.2	15.3
Minimal losses	17.5	30.4	36.0	24.3	7.8	15.2	16.4	11.9	23.5	30.6	43.4	8.4	10.8	11.3	9.4	9.6
Abs max losses	34.9	47.8	53.4	38.0	25.2	32.6	33.8	29.3	32.4	39.5	52.2	17.2	19.7	20.8	18.3	18.4
Abs min losses	14.5	27.4	32.9	21.0	4.7	12.1	13.4	8.8	19.2	26.3	39.0	4.0	6.5	7.6	5.1	5.2

The difference between raw losses and corrected losses (see Tab. III) was not significant: F = 0.0082 and 0.000004, p = 0.928 and 0.998 for the attacked sites A1 and A2, respectively, df = 14.

DISCUSSION

CEDAR GROWTH RATE

The growth rate obtained for the reference site (mean value around 2 mm) was comparable with the whole of Morocco (range 0.8-8.3 mm as reported by M'Hirit, 1993), and corresponds to the eastern Moyen-Atlas (0.8-3.5 mm). For Algerian cedar growth, a recent paper from the FAO-IUFRO (Nedjahi & Zanndouche, 2007) reported a mean growth of 2.04 ± 1.64 mm for the Chréa area, which is very close to our data of 2.01 ± 0.26 mm. On a wider scale, this paper reported a mean growth of 1.95 ± 0.44 mm for the Tellien cedar Atlas forest, and 0.88 ± 0.26 mm for the drier Saharan Atlas. Conversely, Atlantic Cedar displayed higher growth rates in wetter and better conditions in the south of France: 7.2-12.8 mm (south-east, M'Hirit, 1993) and 5.1-8.2 mm (south-west, Lambs & Pélissier, unpublished results).

The declining growth profile shown in Fig. 2 could be from the effect of age on tree-ring wideness, or from less water availability. As Messaoudène *et al.* (2004) reported a similar profile for young cedar trees in the nearby Djurdjura mountains, it is not only a problem of age. Labiod *et al.* (2006) showed that some trees in drier conditions can continue to develop and present progressive smaller tree-rings. In 2003, a report of the Climate Change Knowledge Network (Agoumi, 2003) showed the vulnerability of Algeria and the Maghreb region to climate change. In the past 30 years, a temperature increase of more than 1 °C has been recorded with an increase in drought frequency from every 10 years to around 5-6 years. The frequency of flood has also increased, with heavy rainfall during a few days, and little or no rainfall during the rest of the year. In 2007, Labiod *et al.* (2007) demonstrated that the declining of White Poplar (with increasing insect attack) in the Tlemcen area was due to the lack of water. This trend is also reflected in local meteorological data, the lowering of the water levels in the Béni Bahdal dam, and reductions of Aleppo Pine growth since the 1970s.

Growth rate reductions

For the first period, reductions in growth rates were moderate (around 20 % for A1 and 13 % for A2). These values are similar to those reported by Graf & M'Zibri (1994), who reported an average reduction in growth rate of 18.5 % over two years, for trees defoliated by 30-50 %. The greater distance between site A2 and the village could explain the longer infestation period observed at site A2, and as such it received less prophylactic care.

The second site (A2) was not affected by the second infestation (1986-1987) because of aerial treatment in 1987, which would have limited the damage effects. The importance of damage during the last period (third period) at the two sites is borne out by the combined effects of two consecutive defoliations: that of 1990-1991 being very significant, and the second in 1991-1992, which was complete. The absence of losses in 1991 is explained by a one-year shift between the defoliation and the appearance of the damage, an effect often noted by other authors (Lemoine, 1977; Alfaro & MacDonald, 1988; Alfaro & Shepherd, 1991). Values of maximal losses were recorded during the first year (the values are 42 % and 46 % for A1 and A2, respectively), and then the losses reduced during the following years. The results of Joly (1970) and of Cadahia *et al.* (1970) also show that the importance of the damage follows the rule: first year losses > second year losses > third year losses.

For the third period, our results are similar to those obtained by several authors. After total defoliation, Graf *et al.* (1994) reported a reduction in radial increase of 43 % for cedar trees. The average reduction values over the next three years were 34 % and 35 % and were not very far from the 25-30 % interval found by Bouhot-Delduc *et al.* (1994) for various tree species attacked by *T. pityocampa*. In this same context, Florent (1970) noted radial growth rate reductions of 30 % spread over three years. In our study, the recorded losses during the second year (1993) were 37 % and 33 % for the two sites A1 and A2, respectively, and are similar to those obtained during the corresponding year by Lemoine (1977) for the Maritime Pine (31 %).

Growth recovery

During the periods of non-infestation, the first attacked site (A1) displayed rather significant fluctuations in growth. These growths varied between a maximal loss of - 9.88 % in 1976 and a maximal gain of + 10.62 %. These fluctuations (losses and gains of growth) are due to small differences in growth rates between sites. Nevertheless, the gains observed in 1986, 1990, and 1991 are particularly significant (6.62 %, 10.62 %, and 8.01 %, respectively) and are correlated with the occurrence of defoliation. Thus, increases in growth rates after the loss periods are caused by various defoliator insects, which have been noted by several authors for the Atlas Cedar and insects other than *T. pityocampa* (Lemoine, 1977; Alfaro & MacDonald, 1988; Alfaro & Shepherd, 1991). Moreover, Alfaro & MacDonald (1988) noted that for Douglas plantations (*Pseudotsuga menziesii* Mirb), mostly defoliated by *Nepytia freemanii* Munroe), these trees exhibit the greatest significant increase after periods of recovery. According to Alfaro & MacDonald (1988), this extra increase after the recovery periods can be justified as follows: fertilization by caterpillar excrement, a smaller density of trees, and better penetration of light towards the lower foliage layers.

CONCLUSION

The growth of cedar trees in the Algerian forests remains quite low compared with the forests in Morocco and France, which are wetter, because this species is at its biogeographical limit. For a few thousand years, cedar forests were also found in Tunisia. Now, with the lower rainfall in the drier Aures mountains in East Algeria where some cedar forests cannot naturally regenerate, the cedar is becoming a relic tree. In the Chréa area, the southern slope receives more of the drier and hotter influence of the desert wind, which lowers cedar health and growth rates. In this work, the wood cores sampling allowed a non-destructive analysis to monitor tree growth. It also allowed quantification of the radial growth losses caused by tree defoliation. Even after severe defoliation, cedar trees are able to recover their growth. Would this still be the case if climate change continues? Nedjahi & Zanndouche (2007) have shown that Atlas Cedars from the Tellien and the Saharan Atlas differ genetically. Therefore, it would be interesting to test if the southern species is more resistant to the defoliator, and whether it should now be planted in the northern forests.

ACKNOWLEDGEMENTS

We are grateful to E. Tabacchi, Ecolab Toulouse, for statistical tests, and F. Guibal, IMEP Aix en Provence, on advices for dendro-chronology informations.

REFERENCES

AGOUMI, A. (2003). — *Vulnérabilité des pays du maghreb face aux changements climatiques*. www.cckn.net/pdf/north_africa_fr.pdf

ALFARO, R.I. & MACDONALD, R.N. (1988). — Effects of defoliation by the western false Hemlock looper on Douglas-fir tree ring chronologies. *Tree-Ring Bull.*, 48: 3-10.

ALFARO, R.I. & SHEPHERD, R.F. (1991). — Tree-ring growth of interior Douglas-Fir after one year's defoliation by douglas-fir tussock moth. *For. Sci.*, 37: 959-964.

AUSSENAC, G (2002). — Ecology and ecophysiology of circum-Mediterranean firs in the context of climate change. *Ann. For. Sci.*, 59: 823-832.

BOUCHON, J. & TOTH, J. (1971). — Etude préliminaire sur les pertes de production des pinèdes soumises aux attaques de la processionnaire du pin *Thaumetopoea pityocampa* Schiff. *Ann. Sci. For.*, 23: 323-340.

BOUHOT-DELDUC, L. & LÉVY, A. (1994). — Rôle de la chenille processionnaire du pin dans le dépérissement du pin maritime Landais en 1990 et 1991. *Rev. For. Fr.*, 46: 431-436.

CADAHIA, D. & INSUA, A. (1970). — Estimación de los daños producidos por *Thaumetopoea pityocampa* Schiff. en repoblaciones de *Pinus radiata* D. Don. *Bol. Serv. Plagas Forestales,* 13: 159-171.

DEMARTEAU, M. (2006). — *Réponse de* Cedrus atlantica *aux changements climatiques passés et futur.* PhD Thesis, University of Liège, Belgium.

DU MERLE, P. & GÉRAUD, D. (1988). — Estimation des niveaux d'infestation passés de la tordeuse du sapin *Choristoneura murinana* HB (Lép, Tortricidae) par analyse rétrospective des pertes de feuillage et de croissance des arbres. *Ann. Sci. For.,* 45: 357-381.

FLORENT, J (1970). — Le Mélézin. *Rev. For. Fr.*, 23: 211-215.

GRAF, P. & M'ZIBRI, M. (1994). — L'infestation du cèdre de l'Atlas (*Cedrus atlantica* Manetti) par la chenille processionnaire (*Thaumetopoea piyocampa* Schiff.) au Maroc et son impact sur la productivité. *Ann. Rech. For. Maroc,* 27: 613-624.

HALATIM, S (2006). — *Contribution à l'étude de la réserve utile en eau des sols de cédraies dans les Aurès: influence des facteurs édaphique.* PhD Thesis, University of Batna, Algeria.

JOLY, P. (1970). — Action des déprédations dues aux insectes défoliateurs sur le pin maritime. *Rev. For. Fr.,* 12: 205-210.

KANAT, M., ALMA, M.H. & SIVRIKAYA, F. (2005). — Effect of defoliation by *Thaumetopoea pityocampa* (Den. & Schiff.) on annual diameter increment of *Pinus brutia* Ten. in Turkey. *Ann. For. Sci.,* 62: 91-94.

LABIOD, M., HADDAD, A., BOUHRAOUA, R., KHELIL, M.A. & LAMBS, L. (2007). — Devenir du peuplier blanc dans le Nord-Ouest Algérien. *Forêt Méditerranéenne*, 28: 255-262.

LAURENT-HERVOUET, N. (1986a). — Mesures des pertes de croissance radiale sur quelques espèces de *Pinus* dues à deux défoliateurs forestiers. Le cas de la processionnaire du pin en région méditerranéenne. *Ann. Sci. For.,* 43: 239- 262.

LAURENT-HERVOUET, N. (1986b). — Mesure des pertes de croissance radiales sur quelques espèces de *Pinus* dues à deux défoliateurs forestiers. Cas du Lophyre du pin dans le bassin Parisien. *Ann. Sci. For.,* 43: 419-440.

LEMOINE, B. (1977). — Contribution à la mesure des pertes de production causées par la chenille processionnaire (*Thaumetopoea pityocampa* Schiff.) au pin maritime dans les Landes de Gascogne. *Ann. Sci. For.,* 34: 205-214.

LEVIEUX, J (1987). — La défense des forêts contre les insectes. Approches actuelles et perspectives. *Ann. For. Sci.,* 44: 277-302.

Mason, R.R. & Wickman, B.E. (1988). — The douglas-fir tussock moth in the interior Pacific north-west. Chap 10 *In*: Berryman, A.A. (ed.). *Dynamics of forest insect populations*. Plenum Press, New York.

Messaoudène, M., Loukkas, A., Janin, G., Tafer, M., Dilem, A. & Gonzalez, J (2004).— Propriétés physiques du bois d'éclaircie des cèdres provenant de l'Atlas du Djurdjura (Algérie). *Ann. For. Sci.*, 61: 589-595.

M'Hirit, O. (1993). — *Le cèdre de l'Atlas: présentation générale et état des connaissances à travers le réseau Silva Mediterranea*. FAO-IUFRO publication, Ifrane (Maroc).

M'Zibri, M. (1991). — *Bioécologie de* Thaumetopoea pityocampa *Schiff.* (Lep. Thaumetopoidae) *et son impact sur la productivité du cèdre* Cedrus atlantica *M. dans le rif central (Forêt d'Iguermelt).* PhD Thesis, University of Rabat, Morocco.

Nedjahi, A. & Zanndouche, O. (2007). — *Variabilité intraspécifique du Cèdre de l'Atlas en Algérie*. FAO-IUFRO publication, Arrezo et Rome (Italie).

Till, C. & Guiot, J. (1990). — Reconstruction of precipitation in Morocco since 1100 AD based on *Cedrus atlantica* tree-ring width. *Quaternary Res*., 33: 337-351.

Zamoum, M. & Demolin, G. (2004). — Possibilités de renforcement de la lutte contre *Thaumetopoea pityocampa* Denis et Shiffermuller (*Lep., Thaumetopoeidae*) dans les reboisement de *Pinus halepensis* du «Barrage vert». *Ann. Rech. For. Algérie*, 1: 18-24.