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The short version of a long study: fifteen years of effort to control white grub pests (Coleoptera: Melolonthidae) and achieve the forest management objectives in the regeneration of the Mamora Forest in Morocco

La versión corta de un largo estudio: quince años de esfuerzo para controlar plagas de larvas de escarabajos (Coleoptera: Melolonthidae) y lograr los objetivos de manejo forestal en la regeneración del Bosque Mamora en Marruecos

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ABSTRACT

Pest control requires extensive knowledge of the biology of phytophages, predators, parasites and entomopathogens, especially in the context of a large-scale forest regeneration program, with the planting of 1500 ha / year of young seedlings in large plots. This paper summarizes the results of a study to control the polyphagous larvae of the endemic species *Sphodroxia maroccana* (Coleoptera: Melolonthidae), which cause major damage to the roots of seedlings of cork oak (*Quercus suber* L.) in regeneration plots in the Mamora Forest, Northern Rabat, Morocco. Fifteen years of study were necessary to fully understand the biology of *S. maroccana*, which is endemic to this forest and has become a pest locally, due to an imbalance related to excessive human disturbance of the forest ecosystem. Specifically, uncontrolled grazing eliminates most of the plants that normally grow under cork oak trees. Thus, the feeding by larvae is mainly concentrated on the roots of young cork oak seedlings, thereby seriously compromising forest regeneration. An annual survey of *S. maroccana* density in each plot in the entire forest identified the potential risks to seedlings. Understanding the movement of the pest in relation to the soil moisture profile was crucial to its management. The results were used to identify key issues for sustainable management of the forest, namely: i) reduction of current anthropogenic pressures; ii) better consideration of the biology of the pest in reforestation activities; iii) changes in plantation practices to reduce the impact of the larvae by controlling their populations, but without eradication; and iv) the use of chemical control only when absolutely necessary.

Key words: cork oak forest, *Quercus suber* L., seedling mortality, roots attack, *Sphodroxia marrocana* Ley, larval density, annual survey, maps of potential risks, forest management.

RESUMEN

El control de plagas requiere un profundo conocimiento de la biología de los parásitos y los depredadores, especialmente en el contexto de un programa a gran escala de regeneración de parcelas de bosque con plantaciónes de 1500 ha / año de plantas de semillero. El presente trabajo resume los resultados obtenidos para el control de las larvas de *Sphodroxia maroccana* Ley (Coleoptera: Melolonthidae) que hacen considerables daños a las raíces de las plántulas de encinos (*Quercus suber* L.) en las parcelas de regeneración del bosque de Mamora, Norte Rabat, Marruecos. Se necesitaron quince años para conocer la biología de esta especie, que tiene la particularidad de ser endémica de este bosque. Esta especie se ha convertido en una plaga a nivel local, debido a un desequilibrio en relación con perturbaciones humanas excesivas, especialmente el pastoreo en el bosque, lo que causa la eliminación de la mayoría de las plantas que normalmente viven bajo los alcornoques. Así, la depredación por estas larvas polífagas se centra principalmente en las raíces de las plántulas del alcornoque, lo que compromete la regeneración natural o artificial del bosque. Un estudio anual de las densidades de larvas en todo el bosque ha definido para cada parcela los riesgos potenciales para las plántulas. La comprensión del movimiento de la plaga en relación con el perfil de humedad del suelo fue crucial para el manejo forestal. Los resultados se utilizaron para identificar los temas clave para el manejo sostenible del bosque, lo que requiere: i) la reducción de las presiones antropogénicas actuales; ii) una mejor consideración de la biología de la plaga en las actividades de reforestación; iii) cambios en las prácticas de plantación para reducir el impacto de las larvas mediante el control de sus poblaciones, pero sin la erradicación de esta especie endémica; iv) recurrir al control químico sólo en parcelas en las que es absolutamente necesario.

Palabras clave: Bosque de encinos, *Quercus suber* L., mortalidad de plántulas, *Sphodroxia marrocana* Ley, densidad de larvas, monitoreo anual, mapas de riesgos potenciales, manejo forestal.

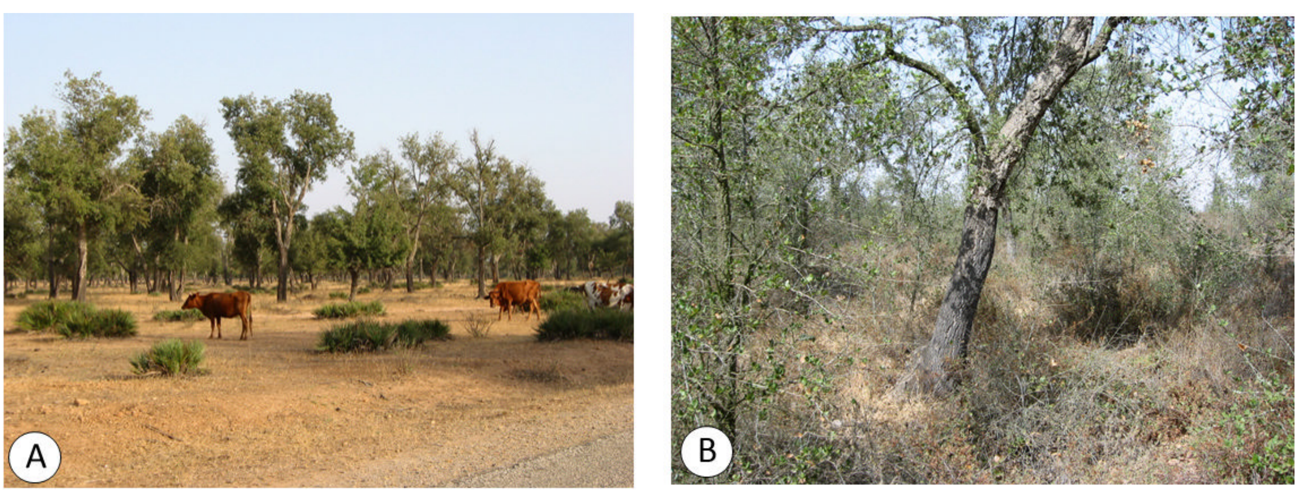
RÉSUMÉ

Le contrôle des ravageurs nécessite une connaissance approfondie de leur biologie, en particulier dans le cadre d'un programme à grande échelle de régénération de parcelles forestières avec la plantation de 1500 hectares par an de jeunes plants. Le présent travail résume les résultats obtenus pour contrôler les larves de *Sphodroxia maroccana* Ley (Coleoptera: Melolonthidae), qui font des dégâts considérables en s'attaquant aux racines des jeunes plants de chênes lièges (*Quercus suber* L.) dans les parcelles de régénération de la forêt de la Mamora, au nord de Rabat (Maroc). Quinze ans ont été nécessaires pour connaitre parfaitement la biologie de cette espèce, qui a la particularité d'être une espèce endémique de cette forêt, devenue localement un ravageur du fait d'un déséquilibre lié à des pressions anthropiques trop fortes. En particulier, le pâturage en sous-bois élimine une grande partie des végétaux qui poussent normalement sous les chênes lièges, la pression de prédation par les larves se reportant alors essentiellement sur les jeunes plants de chênes, compromettant ainsi la régénération de la forêt. Un recensement pluriannuel des densités des larves dans l'ensemble de la forêt a permis d'établir des cartes précises des risques potentiels. Comprendre le mouvement du ravageur par rapport au profil d'humidité du sol s'est avéré crucial pour la gestion de la forêt. Les résultats ont permis de mettre en évidence des questions clés pour une gestion durable de cette forêt : i) une nécessaire réduction des pressions anthropiques actuelles ; ii) une meilleure prise en compte de la biologie du ravageur dans les actions de reboisement ; iii) une modification des pratiques de plantation pour réduire l'impact des larves par un contrôle de leurs populations, mais sans éradication de cette espèce qui est endémique de cette forêt ; iv) une utilisation de la lutte chimique uniquement dans les parcelles où cela s'avère absolument nécessaire.

Mot-clés : Maroc, forêt de chênes lièges, *Quercus suber* L., attaque des racines, mortalité des jeunes plants, *Sphodroxia marrocana* Ley, densité larvaire, suivi annuel des parcelles, cartes des risques potentiels, gestion forestière.

The Mamora Forest (6°00'– 6°45' W; 34°00'– 34°26' N) in northwest Morocco covers a large area in the region of Sale, Kenitra and Tifelt. This forest is in marked decline (Bouslihim 1996), with many old *Quercus suber* L. trees in poor condition and serious problems with natural regeneration. In the 20th century, the forest lost nearly two-thirds of its original area, with an annual average loss of about 1,600 hectares between 1955 and 2000. At the end of the 20th century, the area occupied by cork oaks covered only 60,000 to 70,000 ha (Bendaanoun 1998; Benzyane 1998) and trees declined in number and health due to highly unsustainable exploitation, including clearing, pruning, stripping, collection of acorns and domestic animal overgrazing in the undergrowth, combined with insect attack on the foliage and wood (Fraval and Villemant 1997). Overall, the forest resembles a wooded park planted with even-aged stands of old oak trees, the foliage of which being periodically consumed below 2 meters by cattle and the lateral branches often pruned for cattle feed in drought periods. In this context, natural regeneration is very difficult (Dahmani 2005) (Fig. 1A). The regeneration of the forest primarily requires an exclusion fencing against animals wandering everywhere through the undergrowth, which is difficult to enforce locally. However, spontaneous regeneration is possible in sites where the vegetation is preserved, as in the hunting reserve of Ain Johra, which is located in the middle of the Mamora Forest. Domestic animals are prohibited (site enclosed by walls) and the ecosystem remained preserved since 1960. At Ain Johra Reserve, the vegetation is dense, with many herbaceous and shrubby species and trees of all sizes (Fig. 1B).

The original attempt to 'restore' the Mamora Forest was carried out primarily by using exotic species (*Eucalyptus*, pine and *Acacia*), especially in areas where the density of cork oak was less than 100 trees per hectare (DEFCS 1973). The introduction of fast-growing species and the continued deterioration of the cork oak forest in a harsh natural environment (sand substrate), triggered major environmental perturbations, especially to the soil (Benjelloun *et al*. 1997). In a subsequent attempt to rehabilitate the forest and to preserve both the original species and its ecosystem, the authorities decided to plant about 15,000 ha of cork oaks, mainly in blocks where previously *Eucalyptus* trees had been planted (Rachdi and Haddan 1998). The plantation was soon faced with the high mortality of cork oak seedlings, from 41% to 68% mortality during the first year, depending on the regeneration plot, due to the combination of intense summer drought and root attacks by Melolonthidae and Dynastidae (Coleoptera: Scarabaeoidea) larvae (white grubs) during the rainy periods (winter and early spring) (Montreuil *et al*. 2004; Ghaioule *et al*. 2007, 2010).



Figures 1A, B. (A) Mamora Forest, *Quercus suber* trees and clumps of the Mediterranean dwarf palm (*Chamaerops humilis*); (B) Natural vegetation in the absence of grazing (Ain Johra hunting Reserve).

The current paper summarizes the results of a 15 years regeneration effort in the Mamora Forest, including the control of white grubs. After an outline of the life traits of the major pest responsible for the high mortality of cork oak seedlings, we discuss the key issues for a sustainable management of Mamora Forest.

MATERIALS AND METHODS

1) Description of the study area

The highest elevation of the Mamora Forest is about 280 m at its southeastern extremity, with a general low slope towards the plain of Gharb in the north. The relief is constituted by a succession of dunes and small valleys, which are oriented from southwest to northeast. The soil profile consists of sand on clay, with the thickness of the sandy horizon ranging from 30 cm to 7 m. In some areas, the soil is hydromorphic, waterlogged in winter and very dry and compact in summer. These areas, where the Mediterranean dwarf palm (*Chamaerops humilis* L.) is abundant, are unsuitable for the regeneration and preservation of cork oak (Chlyeh *et al*. 1990). The climate, oceanic in the western part of the Marmora Forest, tends to become more continental eastward. For management purposes, forest technicians have divided it into 5 districts (cantons A to E) along this climatic gradient. Canton A and the western half of canton B are close to the sea and experience a sub-humid bioclimate with cool winters, whereas the oriental part experiences a semi-arid bioclimate with cool winters (cantons C, D, E).

2) Identification of the causes of mortality of cork oak (*Quercus suber*) seedlings

The cantons B, D and E were more particularly surveyed to assess the causes of seedling mortality as they were considered as the most representative of the different conditions along the bioclimatic gradient of the forest. Two regeneration plots have been identified in each of these three cantons, and followed with the same protocol. Two blocks of 500 planting holes were chosen randomly in the NE and SW parts of each plot. Each block consisted of five lines of 100 planting holes. Usually, 3 to 5 plants were counted per planting hole (but sometimes up to 12), which corresponded from 1500 to 2000 seedlings for each block. All seedlings were labeled and monitored monthly and when damage symptoms were observed, the soil around the seedlings was removed to identify the cause of damage (Lumaret *et al*. 2005).

3) Larval density between cantons

The surveys were performed during the wettest period of the year (December-March), when larvae were active near the surface. In each plot of the Mamora Forest, the soil was turned with a plow in parallel strips that were 100 m long, 50 cm wide and 40 cm deep, with 4 meters between the strips. Between 40 and 160 strips were surveyed per plot, corresponding to a sampled area of 2000 - 8000 m² per plot, with a total of 1760 strips surveyed every year across all cantons. Two people walked behind the tractor mounted plow and collected all the exposed larvae. The larvae from each strip were collected, identified in the laboratory at species level using a taxonomic key specially designed for white grubs of the Mamora forest (unpublished) and counted.

4) Activity of *Sphodroxia maroccana*

The activity of males was studied by using a bucket funnel trap (Arner trap) designed to capture moths when used with pheromone lures. The lure was replaced by a virgin female of *S. maroccana* enclosed in a small cage. The traps were buried in the ground (sand), with only the cover and the female being on the surface. The count of attracted males was carried out every half hour during the period of activity of the males, between 16:30 and 21:30.

RESULTS

1) IDENTIFICATION OF LARVAE responsible for attacks on the roots of cork oaks

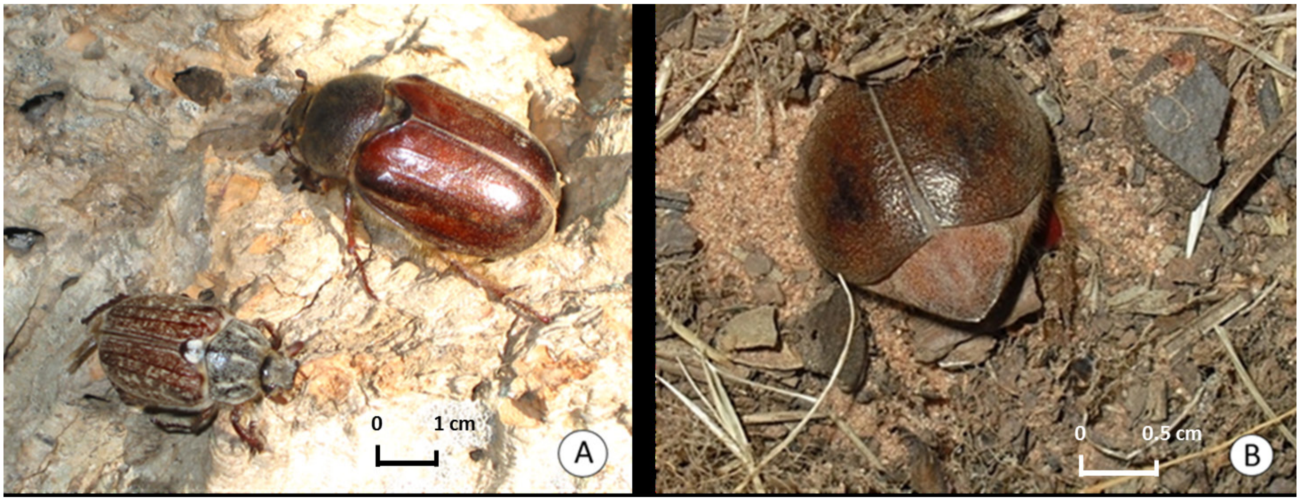
A very high proportion (95 to 98%) of the damage on the cork oak roots was due to larvae of *Sphodroxia maroccana* Ley, 1923 (Melolonthidae: Melolonthini), an endemic Moroccan species reported only from the Mamora Forest (Ghaioule *et al*. 2007).

2) Biology and ecology of *Sphodroxia maroccana*

Sexual dimorphism in this species is substantial, with males smaller (19 - 25 mm) than females (31.6 - 35 mm) (see Montreuil *et al*. 2004) (Figure 2A). Adults are mostly active in June and July. Males are active from mid-afternoon (16:30) until night (21:00), with a peak of activity between 18:30 and 19:30 (Figure 3). They fly in a zigzag pattern near the ground in search of females that remain half buried at the entry of a short burrow from where they emit a sex pheromone (Ghaioule *et al*. 2007) (Figure 2B). In nature, mating is very fast, with strong competition among males which form clusters of three to five males around each female.

The male life span ranges from 8 to 19 days (mean 13 ± 2.9 days) and is a little longer for females (10 to 21 days, 15 ± 3.4 days on average). Most of the life cycle occurs in the soil. Immediately after mating, 60 to 120 eggs (82 ± 16) are laid at the interface between dry and moist sand. The duration of egg development depends on soil temperature (22 ± 0.5 days at 28°C; 23,2 ±1,6 at 23°C) (Fegrouche 2014). The second larval stage is reached 7 months later, a period which corresponds to the end of the wet season in March. The total larval development needs three years for males and five years for females (Lumaret *et al*. 2005). In their final instar (L3), the larvae of *S. maroccana* reach 3-4 cm in length (males) and 6-7 cm (females), with a highly sclerotized head capsule (10 mm x 9.7 mm for largest larvae).

After hatching, the larvae gradually disperse in the soil in search of young plant roots. They perform both horizontal



Figures 2A, B. (A) Female (above) and male (below) of *Sphodroxia maroccana*; (B) Body orientation of the female when emitting sex pheromone.

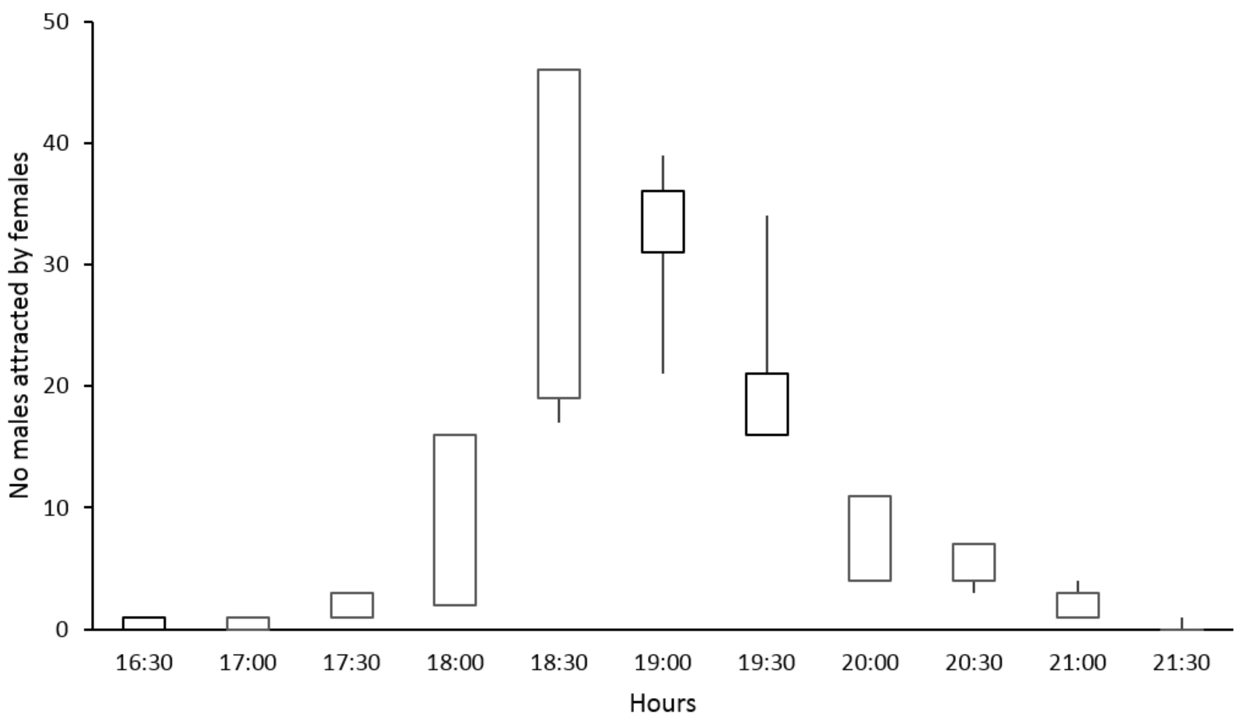


Figure 3. Activity of males of *Sphodroxia maroccana* attracted by virgin females used as baits (4 females).

and vertical movements whose speed and distance depend on soil moisture conditions. Larvae move in the soil so that they stay at the interface between dry and moist sand, depending on rainfall events and drought (Fegrouche *et al*. 2012a). Over a three-month period, a mature larva can move approximately 5 meters in the soil if soil moisture conditions are suitable, as opposed to only 40 cm in dry soil (Fegrouche *et al*. 2012a). That explains why the damage observed on seedlings mostly occurred either in winter or spring, due to rainfall which encouraged larvae towards the surface where they reach the root level of seedlings, or in summer following a substantial watering by foresters.

3) Causes of mortality of cork oak seedlings

The seedlings of several blocks of 500 planting holes were monitored monthly to identify the cause of damage when symptoms were apparent (Lumaret *et al*. 2005). The causes of mortality were diverse: (i) summer drought, in spite of watering in summer (7-10 litres per planting hole per month); (ii) during the hoeing of weeds by forest workers, with the accidental severing of seedlings; and (iii) attacks on roots by *S. maroccana* larvae. The cumulative annual

Table 1. Causes of mortality of seedlings in two regeneration plots (BV10 and BV11) in canton B of the Mamora Forest, Morocco (June 2000 - June 2001). Mortality due to white grubs was distinguished from that due to drought and hoeing.

Regeneration plots	Initial no. of seedlings	Causes of mortality	Number of dead seedlings	% mortality	Total annual mortality (%)
BV10_NE	1640	White grubs	582	35.5	50.6
		summer drought + hoeing	247	15.1	
BV10_SW	1903	White grubs	820	43.1	68.0
		summer drought + hoeing	473	24.9	
BV11_NE	2003	White grubs	477	23.8	41.3
		summer drought + hoeing	351	17.5	
BV11_SW	1593	White grubs	492	30.9	45.9
		summer drought + hoeing	239	15.0	

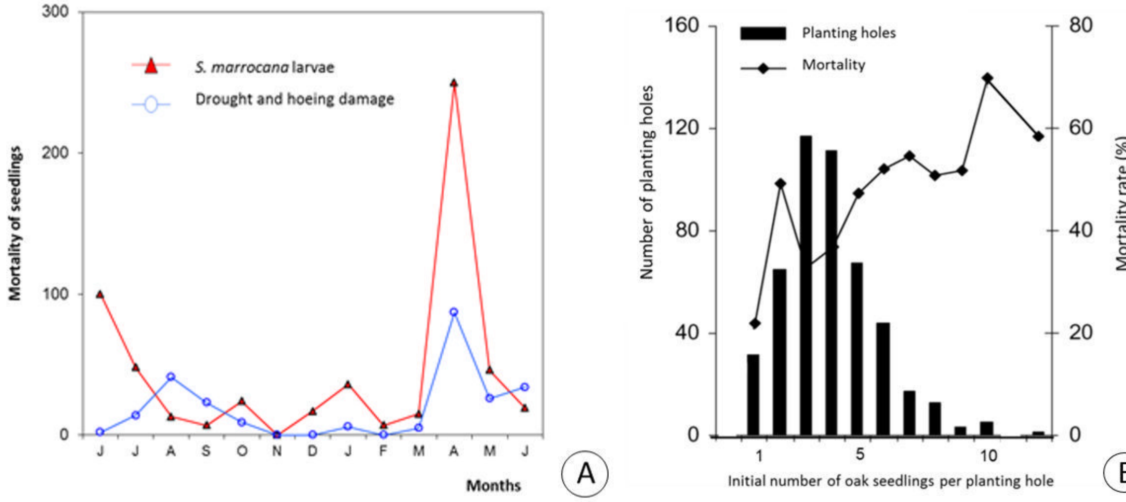
mortality in the period June 2000 to June 2001 ranged from 41% to 68% across the regeneration plots and blocks (Table 1). The larvae contributed from 24% to 43% of the total mortality of seedlings during the first year. The damage due to larvae mainly occurred during the wettest period of the year (spring), although watering in summer occasionally caused larvae to rise from a deeper level in the soil (mainly observed in June). In summer, under normal conditions, the larvae remain far below in the moistest zone, and their root feeding activity is considerably reduced. Damage due to forest workers was substantial during the hoeing of weeds in spring (April-May) (Figure 4A).

Damage due to attacks on the roots of young oak trees by *S. maroccana* caused their deaths for at least the first 4 years after planting, until the young trees were of sufficient size and robustness to withstand attacks (Ghaioule *et al*. 2007; Ghailoule *et al*. 2013). The larvae are polyphagous and therefore not specialized on the roots of oak trees. The high mortality of oak seedlings can be explained by the high density of larvae in some regeneration plots in the cantons of the Mamora Forest and the accidental severing of seedlings by forestry workers while they eliminated weeds manually from the planting holes, especially during the first year after planting. Even though they compete for water with seedlings, weeds provide the advantage of reducing the severity of attacks on the roots of oak seedlings through the sharing of root damage and contribute to the slowing of the dispersal of larvae in the soil. To compensate for the mortality of seedlings, foresters increased the number of seedlings in the planting holes. The results were inconclusive, with the oak seedling mortality tending to increase with the number of seedlings per planting hole, with the larvae tending to stay longer, as long as suitable roots were available (Ghaioule *et al*. 2007) (Figures 4B, and 5A-B).

4) Variations in larval density of *S. maroccana* between cantons

From the data obtained between the winters of 2007-2008 and 2014-2015 by collecting all larvae along the strips surveyed across all cantons, the larval density of *S. maroccana* was mapped annually to predict the risk of damage during each planting campaign from December to March, and to determine the most appropriate protective measures. The densities were measured in all the cantons to reflect both the increasing W-E gradient of aridity, and the changes in soil depth. Soil depth is crucial because, in the Mamora Forest, the total capacity for water retention depends on the depth of the clay layer under the sand (Figure 6). Larval densities were counted for several consecutive years to account for inter-annual fluctuations in *S. maroccana* populations, depending in part on rainfall and soil water reserves (Ghaioule *et al*. 2007; Fegrouche *et al*. 2012b). The objective was to establish a robust predictive model for all geographic and climatic circumstances, in order to prepare planting campaigns in an optimal manner.

Results from surveyed strips were used to calculate the larval density per hectare, with extrapolations to the adjoining plots with similar pedo-climatic characteristics. Larval density was always higher in the northern parts of cantons A, B and C (sub-humid bio-climate), regardless of the year (Figure 7). The larval density was lower in districts D and E that experience a more arid bioclimate, unless the increased depth of the sandy horizon compensated for the aridity, with sand depth important for the total amount of water storage in the soil, e.g. in the northern part of district D where the soil depth is greater than 3 meters (Figure 6). Conversely, the shallow soil in the southern part of canton A prevents the development of large populations of *S. maroccana*, despite favorable bioclimatic conditions (Figure 7). For a given canton, inter-annual differences in larval density were independent from rainfall fluctuations (Table 2).



Figures 4A, B.- (A) Monthly mortality of oak seedlings in canton B (plot BV10_NE) (from Lumaret *et al.* 2005); (B) Mortality of cork oak seedlings in relation to their initial number in planting holes (block BV10-SW) (from Ghaioule *et al*. 2007).

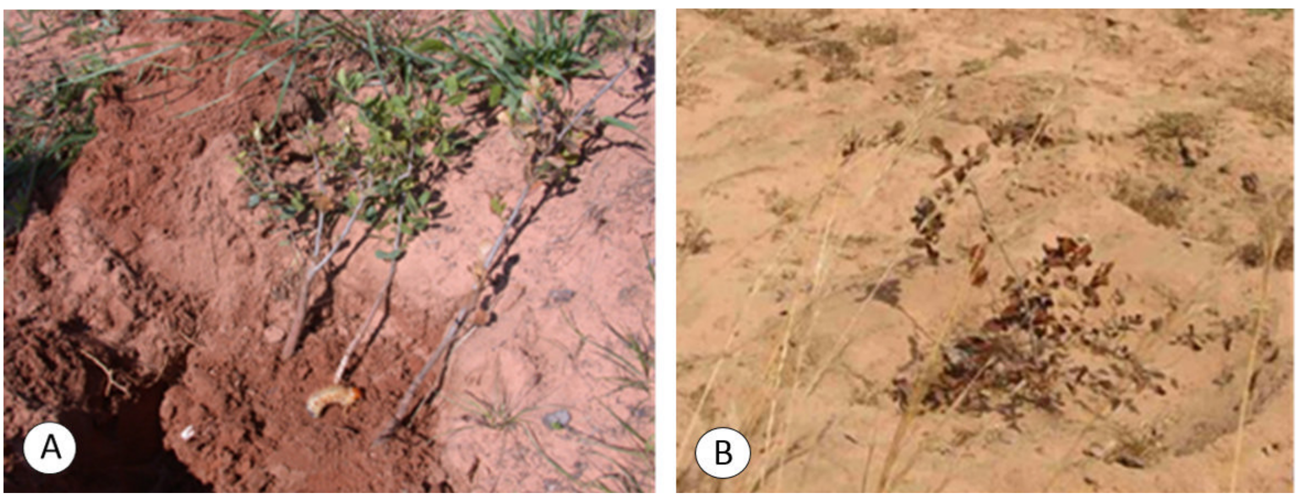


Figure 5AB. (A) Presence of *Sphodroxia maroccana* larvae at the root level; (B) Death of seedlings following an attack on roots.

Table 2.- Annual rainfall for the 2006-2015 period (weather station of Rabat-Salé).

Year	Annual rainfall (mm)
2006	505.19
2007	514.88
2008	848.86
2009	651.51
2010	951.75
2011	424.43
2012	-
2013	402.85
2014	576.31
2015	243.28

- missing data

DISCUSSION

The protection of cork oak seedlings must combine a necessary change in planting methods and a rational use of chemical control

1) Changes in planting methods

Sphodroxia maroccana is an endemic species that is only present in the Mamora Forest of Morocco. In the absence of significant human disturbance, its presence is always at a low level and no damage has been reported on the spontaneous regeneration of the cork oak (e.g. in the hunting reserve of Ain Johra). It therefore appears that this polyphagous species only damages oak seedlings when trophic resources were reduced through overgrazing or after the elimination of forbs in the regeneration plots regarded by foresters as competing for water (458 species reported, with a clear dominance of therophytes (50.5%) (Aafi *et al*. 2005). The proper management of regeneration plots,

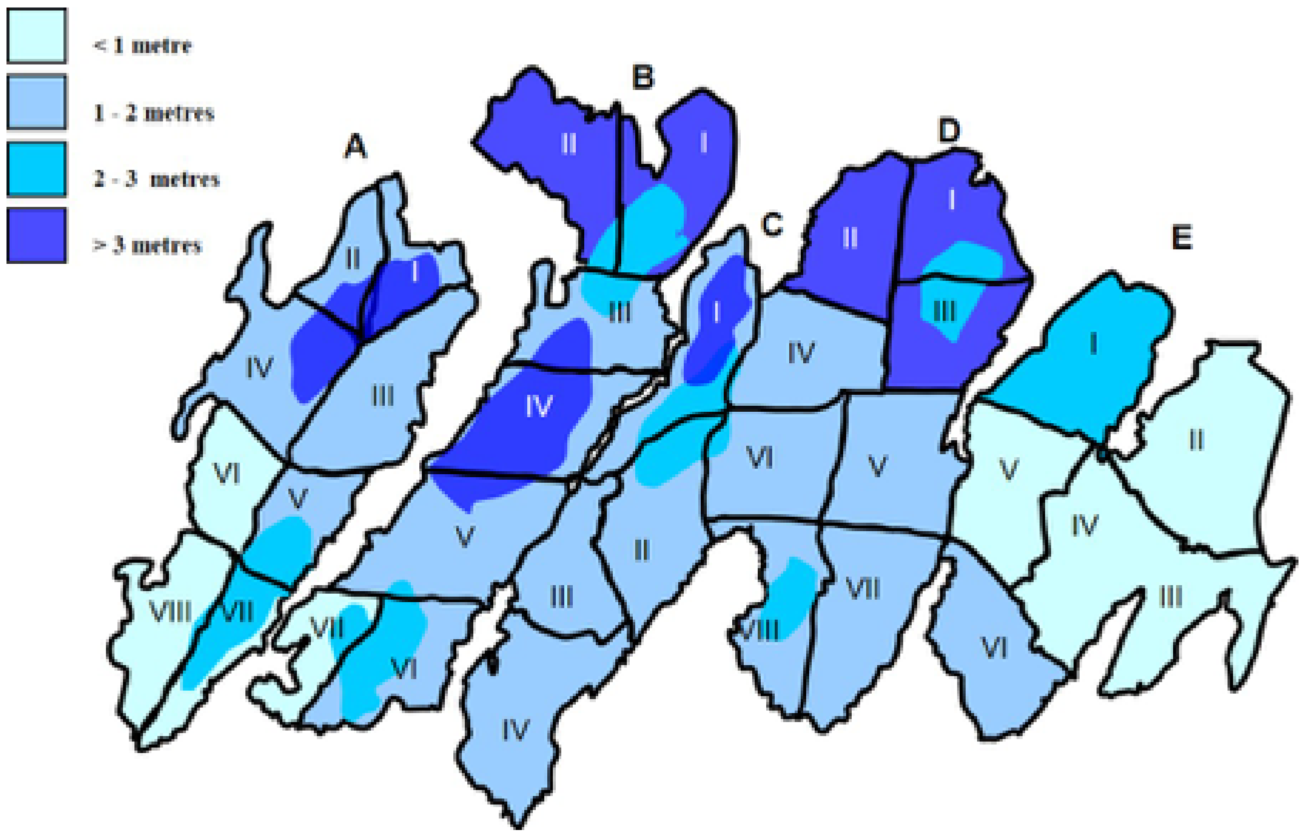


Figure 6. Differences in soil depth (Mamora Forest, cantons A to E).

before and after planting, requires a detailed knowledge of the potential risks, estimated from the analysis of larval density maps. The complete elimination of weeds in all plots by full plowing before planting, which created bare soil over several hectares, followed by the use of routine manual hoeing after planting, increased the frequency and intensity of attacks; the larvae used the only resource available in the plots, namely the roots of oak seedlings, resulting in high mortality in the first year and beyond (Figure 8A). This technique had another drawback in that it alters the micro-climatic conditions of the plots which become more arid, whatever the canton, due to very high soil temperatures and low humidity. During the summer, at the surface of such plots, air vortices are very common, carrying away the sand and organic matter, which can either expose or bury seedlings, depending on the local circumstances.

Our long term studies helped to change the planting technique. These are now mostly done in non-fully plowed plots. The plantations are designed in strips, with a plowed, planted row alternating with an undisturbed vegetated strip. This strategy maintains an alternative food source that results in the larvae tending to move less in the soil and to mainly attack the roots of other plants (Figure 8B). Furthermore, the success of plantations also depends largely on keeping sheep and cattle and human activity away from the new plantings. This is critical to the success of the replanting program, given they contributed substantially to the origin of the problem. Planted plots were surrounded by fences to prevent livestock entry, but they are only kept for a few years, which probably only postpones the grazing problem.

2) Strategic chemical control of larvae

In the most vulnerable plots i.e. those with high densities of larvae in the northern parts of cantons A, B and C, as evidenced from the larval distribution maps (Figure 7), chemical protection of seedlings at planting time is still necessary. Preventive treatments were carried out using insecticides applied in the form of granules. The use of carbosulfan was abandoned by foresters in 2011, despite its use at the correct label rate greatly reducing root damage. During a field test, the mortality of seedlings under carbosulfan protection, with the granules buried in contact with the roots was 8.3% against 73.5% for the controls (untreated seedlings) (Ghaioule *et al*. 2010). However, several cases of granule misuse have been observed in the Mamora Forest, with some workers casting granules over the soil surface, or arranging them in a circle around the seedlings. In both cases, this practice was completely ineffective because white grubs do not move at the soil surface (Fegrouche *et al*. 2012a). As a consequence, the mortality of many non-target beetles was observed at the soil surface (mostly darkling beetles) and granules could be consumed by granivorous birds (Fegrouche *et al*. 2014). These bad practices are not compatible with the conservation

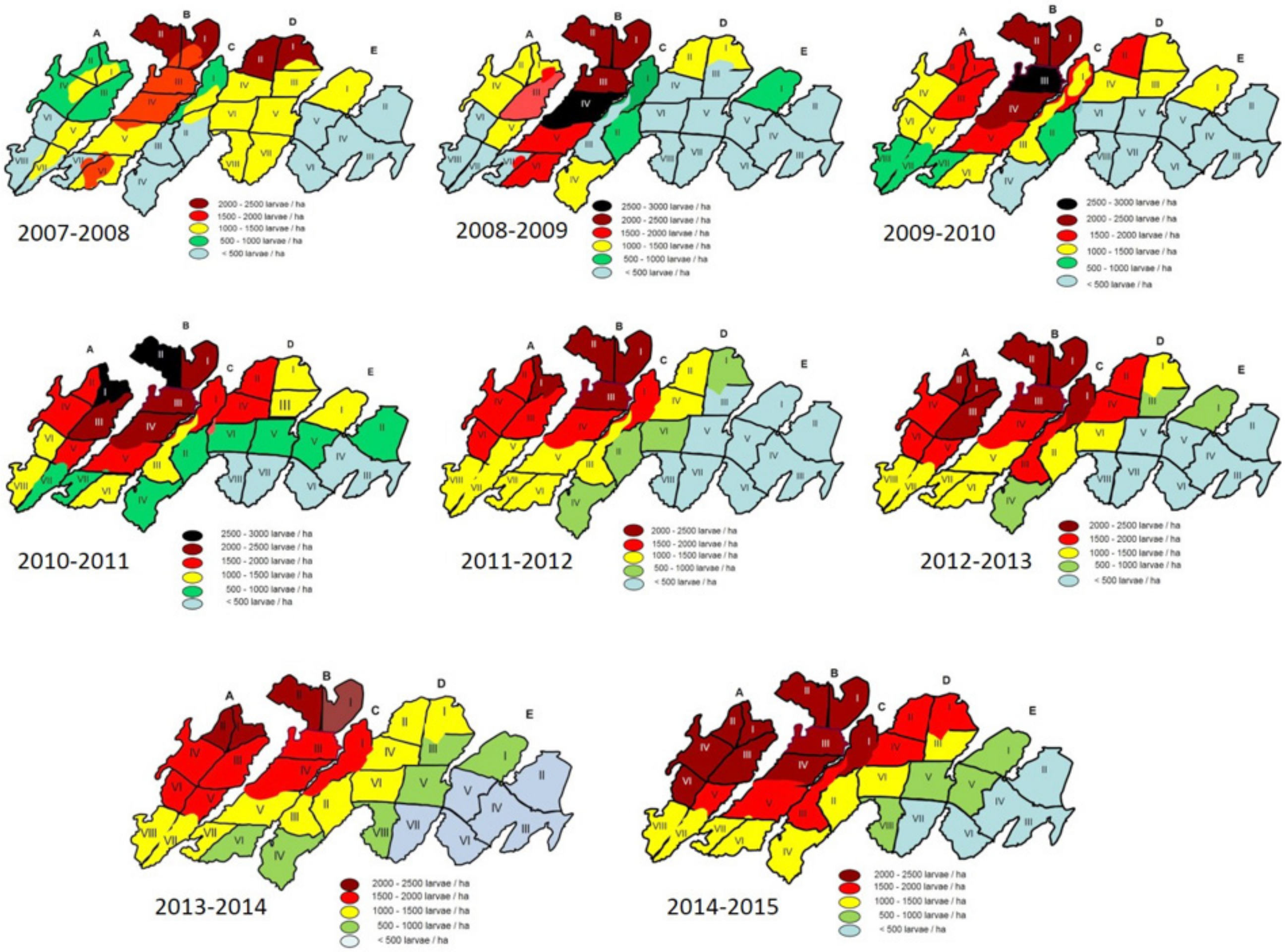


Figure 7. Annual variations in the larval density of *S. maroccana* in cantons A-E of the Mamora Forest (2007- 2008 to 2014-2015).

Figure 8 AB. (A) A fully plowed plot (old technique) before the planting of *Quercus suber* in the Marmora Forest; (B) Planting site preparation (new technique) by plowing alternating strips.

of the environment and the organisms that provide vital ecological services. Because of the environmental risks related to its toxicity, carbosulfan was banned in Europe in 2008 and in Morocco in 2011 (Fegrouche *et al*. 2014). Other pesticides are currently being used in the plots at risk, for example chlorpyrifos-ethyl, although its toxicity is likely to limit its use due to the risks to human health attached to the active substance (Rauh *et al*. 2012; EFSA 2014).

CONCLUSIONS

We report the case of an endemic species, initially discreet, which has become a local pest in the Marmora Forest of Morocco due to anthropogenic disturbance. Originally, *S. maroccana* was probably well controlled (see Ain Johra reserve ecological conditions, Figure 1B). The degradation of the environment through anthropogenic processes (Figure 1A) suddenly provided this species with a disproportionately large amount of oak seedling roots as a food resource when the cork oak forest regeneration program started. The challenge for forest technicians was to control this endemic species without complete eradication. Control has been achieved mainly through the use of pesticides but alternative methods are being tested, for example: (i) strip planting in alternate rows that keeps the herbaceous vegetation intact and (ii) the restriction of chemical treatments to 'at risk' areas where larval densities are highest. The forest regeneration program requires a greater support from the local population to minimize pressure on the replanted plots, including grazing and trampling by wandering livestock and wood cutting, and better training and supervision of forestry supervisors and workers, in order to minimize the risks associated with pesticide use. The project managers also require a better knowledge of *S. maroccana* biology to maximize the success of plantings, with the choice of the best strategy for planting based on risk assessment. Based on the information provided by the larval density maps and anticipating the risks according to rainfall, in many plots the use of pesticides is not necessary for the success of plantings, provided the seedlings are sufficiently watered in summer, but not in excess, to discourage movement of the larvae. Managing such a regeneration program is complex but the solutions provided by 15 years of research should contribute to its success.

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