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Original article

Shoot aggregation by *Tomicus piniperda* L (Col: Scolytidae) in Yunnan, southwestern China

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Summary – In *Pinus yunnanensis* forests of Yunnan, southwestern China, ten trees with evident symtoms of heavy shoot attacks by *Tomicus piniperda* were selected in two localities. Around each of these trees, five others of similar size and similar morphological and site characteristics, and as close as possible to the attacked trees, were chosen to be used as a control. For all trees, shoots were investigated for damage. No brood tree was present in the vicinity of the sampled trees (attacked or control). The percentage of the shoots damaged by *T piniperda* ranged from 64.9 to 94.3 in the attacked trees, whereas it ranged from 1.3 to 22.3 in the control trees, thus exhibiting an aggregation phenomenon during the beetle shoot-feeding period. There was no evidence of an effect of tree height and wind direction on aggregation. The percentage of damaged shoots in the control trees decreased with distance from the shoot-aggregation trees. Aggregation seemed to occur almost at the end of the shoot-feeding period, suggesting that it could play a critical role in weakening the tree, explaining the subsequent successful mass attack that always takes place in the bole of such trees and kills them. It could thus explain the very unusual nocivity of *T piniperda* in southern China.

China / *Tomicus piniperda* / *Pinus yunnanensis* / shoot attack / aggregation

Résumé – Agrégation de *Tomicus piniperda* (Col, Scolytidae) sur pousses dans le Yunnan, Chine méridionale. Dans deux localités des forêts de *Pinus yunnanensis* du Yunnan (Chine du Sud), dix arbres ont été choisis parce qu'ils étaient de toute évidence l'objet d'importantes attaques par *T piniperda* au niveau des pousses. Le plus près possible de chacun de ces arbres et dans des situations stationnelles comparables, cinq autres sujets ont été choisis, de taille et de morphologie semblables à celles des arbres lourdement attaqués, pour servir de témoins. L'importance des attaques sur pousses a été évaluée dans tous les arbres. Aucun arbre utilisé comme foyer de reproduction n'existait à proximité des arbres étudiés, qu'ils soient témoins ou attaqués. Le pourcentage de pousses endommagées varie de 64,9 à 94,3 sur les arbres attaqués, alors qu'il varie de 1,3 à 22,3 sur les arbres témoins, démontrant ainsi l'existence d'un phénomène d'agrégation pendant la période d'ali-

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mentation sur pousses. Aucun effet de la direction du vent ni de la hauteur de l'arbre n'est montré. Le pourcentage de pousses attaquées dans les arbres témoins décroît très rapidement avec la distance à l'arbre sur lequel a eu lieu l'agrégation. L'état de fraîcheur de la plupart des pousses attaquées montre que l'agrégation est sans doute intervenue vers la fin de la période de maturation sur pousses. Ceci suggère que le phénomène pourrait jouer un rôle déterminant dans l'affaiblissement des arbres, expliquant la présence et le succès des attaques massives et fatales qui ont toujours lieu immédiatement après sur le tronc de tels sujets. Il pourrait donc expliquer le caractère très anormalement nuisible de *Tomicus piniperda* en Chine méridionale.

Chine / *Tomicus piniperda* / *Pinus yunnanensis* / attaque sur pousses / agrégation

INTRODUCTION

Among the Scolytidae family, the life cycle of the genus *Tomicus* is typically characterized by the existence of a maturation period in the shoots, before the adults are able to attack the tree bole and reproduce (Ratzeburg, 1837; Eichhoff, 1881; Chararas, 1962; Bakke, 1968; Langstroem, 1983, among others). According to European studies, the shoot-attacked trees do not seem to be chosen by the young beetles, and maturation feeding generally takes place in close vicinity of the brood trees (Langstroem, 1983; Sauvard et al, 1987). These shoot attacks can weaken the host and can induce important growth losses making these beetles serious forest pests, although they never kill the trees (Langstroem, 1983; Langstroem and Hellqvist, 1990). Trunk attacks succeed on very weak or dominated trees only (Chararas, 1962; Masutti, 1969; Lieutier, 1984; Ferreira and Ferreira, 1990; Langstroem and Hellqvist, 1993), which leads us to consider the European *Tomicus* species as much less dangerous than the species belonging to the *Ips* and *Dendroctonus* genera. In the case of *Tomicus piniperda*, this failure to establish on more vigourous trees has been tentatively explained by the weakness of the association between the beetle and its phytopathogenic fungi (Lieutier, 1995).

T piniperda (L) is the most dangerous bark beetle in southwestern China and is considered to be responsible for destroying more than 0.5 million ha of Yunnan pine (*Pinus yunnanensis*) forests over the past 15 years (Ye and Dang, 1986; Ye, 1991). Local studies on this insect have dealt with several aspects such as bionomy, spatial distribution, temperature influence, mass attack on the bole and life table (Ye, 1991, 1992, 1995). Bole mass attack has been widely considered as an essential tree killing factor (Ye and Dang, 1986; Ye, 1992). Recent observations, however, have suggested that shoot feeding could cause far more serious damage in southwestern China than in Europe (Ye and Li, 1994), essentially because of the long (6–8 months) shoot-feeding period allowed by the mild winter (Ye, 1991). Moreover, shoot damage seems to be concentrated on certain trees (Ye and Li, 1994).

As part of a study aiming at defining the role of shoot attacks in Yunnan pine mortality, the present paper reports a field experiment designed to investigate the existence of shoot aggregation for *T piniperda* in Yunnan.

MATERIALS AND METHODS

The study was carried out in late March 1996, just half a month after the beginning of the trunk-attack period, in two Yunnan pine stands located in Xichong and Shaogiu (Yeman County), 10 km from each other and 80 km west of Kunming (24°45' N, 102°01' E; 1900–2000 m above sea level). These stands (about 30 years old) were planted in poor soils of mountain slopes, to limit soil erosion. Ten trees (five per stand) with evident symptoms of heavy shoot attacks and selected as 'experimental trees' (= E trees) were felt down and all shoots were checked for an estimation of damage (percentage of shoots bored by *T piniperda*). As close as possible to and all around each of these trees, five other trees of similar size and similar morphological characteristics were chosen as 'control trees' (= C trees), without taking into consideration their shoot damage level. They were not felt but about half of their branches were randomly cut to estimate shoot damage. All the inspected shoots were of the previous year.

The dimensions of all trees were measured, as well as the distances between the C trees and their corresponding E trees, which ranged from 2 to 11 m. The position of each C tree relative to its E tree was also noted with regards to the direction of the dominant wind: upwind = C tree before E tree; downwind = C tree behind E tree; sidewind = C tree beside E tree. No brood tree was present in the vicinity (300 m investigated) of the sampled trees (E or C). The E trees were randomly distributed in each locality and their frequency was estimated at 7% in Xichong and 10% in Shaogiu.

All statistical analyses were performed with SAS software (SAS Institute Inc, Cary, NC, USA). Confidence intervals were calculated at the 95% level. Comparisons between means were made with analysis of variance (GLM procedure). Differences were taken into account only when significant at the 95% level. Linear regressions were calculated.

RESULTS

Tree size characteristics

No difference concerning tree diameter and height existed between the E and the C trees in any locality (table I). Tree dimensions

Table I. Tree size characteristics and percentage of shoots attacked by *Tomicus piniperda* in each experimental tree and in the corresponding control trees.

Locality	*Height (m)*			*Diameter (cm)*			*Attacked shoots (%)*		
	Exp	*Cont*	*P1*	*Exp*	*Cont*	*P1*	*Exp*	*Cont*	*P1*
Xichong	5.8	5.4 ± 0.6	0.50	8.0	8.3 ± 1.1	0.78	64.9	9.5 ± 5.5	0.0004
Xichong	5.8	5.5 ± 0.6	0.53	11.0	9.3 ± 2.2	0.43	71.6	10.6 ± 6.6	0.0005
Xichong	3.8	3.6 ± 1.1	0.83	9.0	7.9 ± 2.8	0.68	80.2	8.7 ± 7.8	0.0005
Xichong	5.5	6.2 ± 2.2	0.72	8.0	11.3 ± 5.5	0.55	70.3	11.1 ± 4.7	0.0001
Xichong	3.8	4.2 ± 0.6	0.52	7.0	7.5 ± 2.2	0.81	70.7	18.4 ± 4.7	0.0002
Xichong (Mean)	4.9 ± 1.3	5.0 ± 1.3	0.97	8.6 ± 1.9	8.9 ± 1.9	0.80	71.4 ± 7.2	11.6 ± 4.7	0.0001
Shaogiu	4.2	4.5 ± 0.8	0.64	8.0	7.0 ± 1.9	0.61	67.9	12.6 ± 4.4	0.0002
Shaogiu	5.6	6.2 ± 1.4	0.68	12.0	12.8 ± 2.2	0.69	94.3	12.7 ± 7.8	0.0003
Shaogiu	6.0	5.5 ± 0.3	0.24	12.5	10.5 ± 1.1	0.10	83.3	7.9 ± 4.4	0.0001
Shaogiu	4.8	4.8 ± 0.8	1.00	10.0	9.3 ± 1.9	0.71	76.5	8.1 ± 7.8	0.0006
Shaogiu	4.8	4.9 ± 0.8	0.93	8.0	8.6 ± 1.4	0.67	85.0	8.3 ± 7.5	0.0003
Shaogiu (Mean)	5.1 ± 0.9	5.2 ± 0.8	0.81	10.1 ± 2.6	9.7 ± 2.7	0.75	81.4 ± 12.2	9.9 ± 3	0.0001
Comparison between localities									
P2	0.81	0.71		0.24	0.52		0.09	0.43	

Each value is given with its confidence interval at the 95% level. Exp = experimental tree (n = 1); Cont = control trees (n = 5); P1 = P value from analysis of variance between experimental and control trees. P2 = P value from analysis of variance between localities.

did not differ either between the two localities.

Shoot damage and tree status

The percentage of damaged shoots ranged from 64.9 to 94.3 in the E trees, while it ranged from 1.3 to 22.3 in the C trees. In all cases, differences between E and C trees were highly significant (table I). No difference was observed between the two localities. The frequency of the heavily attacked trees in each locality was significantly higher than what was expected from a random distribution of the attacks between the trees.

Most of the damaged shoots were fresh, but no beetles were found inside them. All E trees had recent trunk attacks, while C trees had none.

Shoot damage and tree dimensions

Since no difference between localities existed for tree dimensions and shoot damage levels, the calculations were made by combining data from the two localities. Linear correlations between shoot damage and tree height or tree diameter were very weak and never significant (table II), both for all trees and for C trees alone.

Shoot damage and wind

By combining the two localities, the mean percentage of attacked shoots in the C trees did not differ significantly according to their situation relative to their E trees with regards to wind direction. This was 12.73 ± 5.02 (n = 6) for the upwind trees, 13.02 ± 5.94 (n = 6) for the downwind trees and 10.11 ± 1.80 (n = 38) for the sidewind trees. All these values differed significantly from that of the E trees (76.38 ± 6.63; n = 10).

Shoot damage in the C trees and distance from the E trees

Calculations were made for the two localities combined. The percentage of damaged shoots in the C trees decreased linearly with increasing distance from the E trees (fig 1). The corresponding equation was:

$$S = -1.4\,D + 16.5$$

where S = percentage of attacked shoots, D = distance (m) from the E tree. The correlation coefficient was – 0.47 (P = 0.0006).

DISCUSSION

The results clearly demonstrate that tree dimensions and wind direction cannot explain the huge differences observed in the percentage of shoots damaged by *T piniperda* between the E and the C trees. No breeding material was present in the vicinity of the studied trees, which could have also explained the concentration of shoot attacks in some trees. In addition, the high percentage of heavily attacked trees

Table II. Linear correlation coefficients between tree dimensions and percentage of attacked shoots, and corresponding P values.

	Height		*Diameter*	
All trees	0.03	P = 0.82	0.02	P = 0.86
C trees alone	0.06	P = 0.70	0.10	P = 0.49

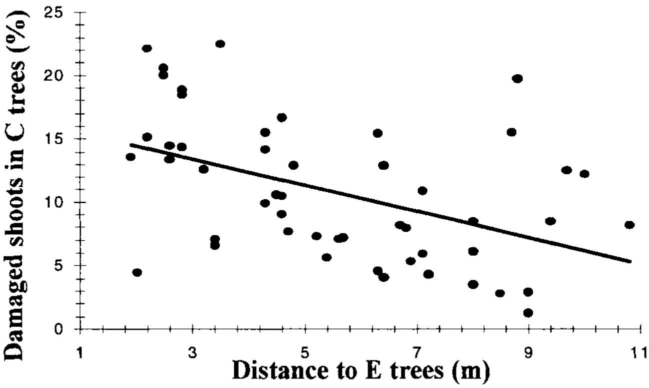

Fig 1. Linear regression between percentage of damaged shoots in the control (C) trees and distance from the experimental (E) trees.

in the stands cannot be due only to chance. The results thus demonstrate that a beetle aggregation occurred during the shoot-feeding period. Shoot feeding in Yunnan forests starts as early as June (Ye, 1991). No insect was present inside the shoots during the observations, but most of the damaged shoots were fresh and few were dried. This suggests that most of the attacks were recent and, thus, that shoot aggregation would take place at the end of the maturation period.

Aggregation of *T piniperda* during trunk attack has been observed in all pine forests where this insect develops (Chararas, 1962; Bakke, 1968; Langstroem, 1986; Ye and Dang, 1986, among others). It is due to tree terpenes escaping through the wounds caused by the first attacking insects (Schroeder, 1987). However, this is the first time that experimental indications of a possible shoot aggregation are given, thus concurring with the observations of Ye and Li (1994). It is logical to suppose that the phenomenon resulted from a directional attraction process at a distance to the preferred trees. The underlying mechanism is unknown but visual cues or host chemistry may be involved. Indeed, shoot quality and microclimatic conditions similar to those offered by the E trees very likely existed everywhere in the studied localities. Furthermore, the decrease in the percentage of attacked shoots as the distance from the E trees increased (fig 1) is in agreement with the by-effects of an attraction process to the E trees, which is corroborated by the lack of difference in shoot damage, according to the position of the C trees around the E trees. The low level of shoot damage in the C trees located at a very short distance from the E trees suggests that the attraction is very effective. This finding contrasts with all findings in Europe (Langstroem, 1983; Sauvard et al, 1987).

In *Pinus yunnanensis*, according to Ye and Li (1995), trunk attack begins in the crown and then extends down to the rest of the bole. It is not possible that shoot aggregation resulted from bole attraction at the crown level by causing insects to land on the shoots instead of the bole. Indeed, the observations were made only half a month after the beginning of trunk attacks, and no beetle was observed in the shoots, whereas many were present in the trunk. On the contrary, the localisation of the first bole attacks at the crown level suggests that trunk attacks resulted directly from shoot aggregation on the same trees, thus leading us to consider shoot aggregation as the first phase of mass attacks on the bole. Mass attraction of beetles to the shoots leads first to the presence of a considerable quantity of beetles on the same tree just before trunk attack. Simultaneously, heavy shoot damage certainly results in a dramatic weakening of the tree, disturbing its natural resistance mechanisms. In Yunnan, shoot attack would thus prepare and greatly facilitate the success of bole attacks. It would thus play an essential role in the tree killing process and in the dieback of the forest, possibly explaining the very unusual nocivity of *T piniperda* and its considerable damage in southern China, in contrast to other regions in the world.

The factors responsible for beetle mass attraction to the shoots need to be investigated. As mass aggregation in the trunk has been observed everywhere in various pine species, it can be considered as a genetically determined character present in all pine shoot beetle populations. It is associated with sexual maturity. Otherwise, all populations need a shoot maturation to become sexually mature and to respond to attractants. It is thus possible that, in Yunnan, *T piniperda* is able to respond to attractants and to aggregate before being sexually mature. This delay could be caused by the climatic particularities of Yunnan. Temperatures are favourable for flight all year round and no cold period exists between shoot maturation and trunk attack (Ye, 1991). It is also possible, however, that shoot aggregation results from beetles that are sexually mature but unable to find a suitable breeding material owing to the lack of sufficiently weakened living trees or fresh logs in the stands. Early shoot attacks by mature beetles have been suggested as a way to avoid starvation during the search for breeding material (Langstroem, 1983). The Yunnan populations of *T piniperda* may also differ genetically from the other populations.

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