Hindawi Publishing Corporation
Psyche
Volume 2012, Article ID 185312, 6 pages
doi:10.1155/2012/185312

Research Article

Coexistence and Competition between *Tomicus yunnanensis* and *T. minor* (Coleoptera: Scolytinae) in Yunnan Pine

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Received 6 October 2011; Accepted 12 December 2011

Academic Editor: Qing-He Zhang

Competition and cooperation between bark beetles, *Tomicus yunnanensis* Kirkendall and Faccoli and *Tomicus minor* (Hartig) (Coleoptera: Scolytinae) were examined when they coexisted together in living Yunnan pine trees (*Pinus yunnanensis* Franchet) in Yunnan province in Southwest China. *T. yunnanensis* bark beetles were observed to initiate dispersal from pine shoots to trunks in November, while the majority of *T. minor* begins to transfer in December. *T. yunnanensis* mainly attacks the top and middle parts of the trunk, whereas *T. minor* mainly resides in the lower and middle parts of the trunk. The patterns of attack densities of these two species were similar, but with *T. yunnanensis* colonizing the upper section of the trunk and *T. minor* the lower trunk. The highest attack density of *T. Yunnanensis* was 297 egg galleries/m^2, and the highest attack density of *T. minor* was 305 egg galleries/m^2. Although there was significant overlap for the same bark areas, the two species generally colonize different areas of the tree, which reduces the intensity of competition for the relatively thin layer of phloem-cambium tissues where the beetles feed and reside.

1. Introduction

A new species of pine bark beetle, *Tomicus yunnanensis* Kirkendall and Faccoli (Coleoptera: Scolytinae), was recently discovered, and which formerly had been confused with *Tomicus piniperda* (L.) [1]. *T. yunnanensis* is an important forest pest since it has caused extensive mortality of Yunnan pines, *Pinus yunnanensis* Franchet, in the southwest of China [2–5]. More than 200,000 ha of Yunnan pine forests were killed by the bark beetle by 2005 [4–6]. In addition to Yunnan pines, *T. yunnanensis* also feeds on Simao pines, *P. kesiya var. langbianensis,* and Gaoshan pines, *P. densata*, as well as some other pine species [4, 5].

T. yunnanensis is frequently joined by *T. minor* (Hartig) in attack of Yunnan pine trees in the southwest of China, Yunnan province [2, 7]. In most of the cases, the two species live in the same area and feed on the same host trees [5, 7]. Several studies have reported that there is a general competition between *T. minor* and *T. yunnanensis* [2, 5, 7–10]. However, the specific mechanisms and the extent of the competition are unclear. An investigation on the cooperation and competition between these two bark beetle species to obtain food may indicate new approaches of integrated control of pest bark beetles, especially *T. yunnanensis* and *T. minor* which are very difficult to control and monitor [11–14]. Thus, the goals of the present studies were to investigate the changes in distribution on the host tree of the beetles during the autumn dispersal from shoots to trunks and to determine the mutual influence of the two *Tomicus* species on each other's attack distribution and reproduction within the tree. Additional knowledge about the two pest bark beetle species' attack distributions and densities, colonization sequences, migratory movements, and competitive interactions

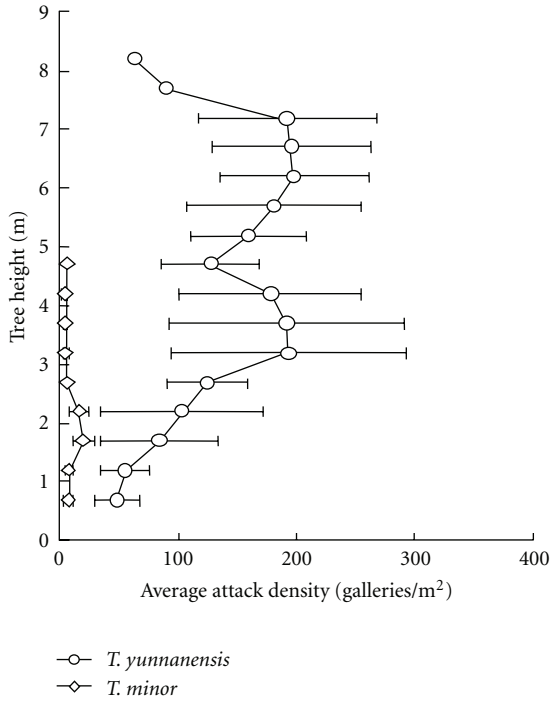

Figure 1: Average attack (egg gallery) density (±SE) and distribution of *T. yunnanensis* and *T. minor* along the trunks of Yunnan pines in November, 2005 (Qujing, Yunnan province, China).

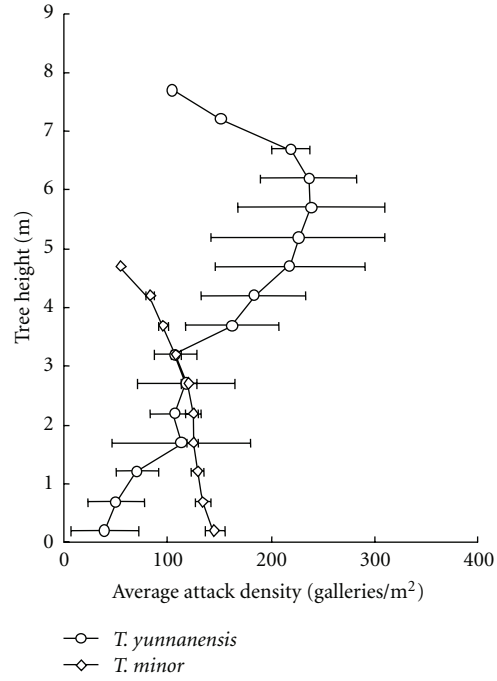

Figure 2: Average attack (egg gallery) density (±SE) and distribution of *T. yunnanensis* and *T. minor* along the trunks of Yunnan pines in December, 2005 (Qujing, Yunnan province, China).

may provide insights into more efficient management practices.

2. Materials and Methods

2.1. Study Site Conditions. A series of field studies were conducted from November to March in 2005-2006 in a 300 ha plantation of Yunnan pines, located in the mountain near Qujing city in Yunnan province (25°14′ N, 103°50′ E, and 1700–1800 m above sea level). Some broad-leaved trees were scattered inside the plantation. Most of the Yunnan pines were infested with both *T. yunnanensis* and *T. minor*. The trees were 30–45 years old and ranged from 10 to 15 m in height and 10 to 15 cm in diameter.

2.2. Experimental Design. Beginning in November 2005, two to three Yunnan pines were selected at random and cut down every week through March, or approximately 44 trees in total. Every shoot was carefully examined, and any bark beetles that were found were collected and distinguished by species with a binocular microscope. In addition, one to two pine trunks that had been colonized by *T. yunnanensis* or *T. minor* were selected and cut down every week, or approximately 17 trees. The tree trunks were divided into 0.5 m long logs, and each log was carefully peeled of bark to reveal egg galleries. The entire trunk was cut into two sections (upper section and lower section) from the middle; and the number and length of all egg galleries over the surface of each log were recorded. The bark beetles within galleries were also collected and distinguished with a binocular microscope. The heights and diameters of all the cut trees were measured.

2.3. Data Presentation and Analyses. Data are presented as mean ± standard error (±SE). The correlations between *T. yunnanensis* and *T. minor* were calculated with bivariate methods. These analyses were conducted using SPSS 11.5 (SPSS Inc., Chicago, IL, USA).

3. Results

3.1. Egg Gallery Distribution in Trunks. Most *T. yunnanensis* began to move from shoots to trunks in November (Figure 1), and most *T. minor* began in December (Figure 2). In November, there were fewer *T. minor* egg galleries compared with *T. yunnanensis*, and all of the *T. minor* egg galleries were distributed in the lower half of the tree's trunk (Figure 1). *T. yunnanensis* egg galleries were distributed over the entire trunk in some trees, but with different densities in different sections. The highest density of *T. yunnanensis* was in the upper half of the tree trunks and was about 198 galleries/m^2, while the highest density of *T. minor* was only about 19 galleries/m^2.

In December, the attack density of *T. yunnanensis* and *T. minor* was in both higher than in the previous month, with *T. minor* increasing significantly (Figure 2). However, in the lower section of the trunks, the attack density of *T. yunnanensis* decreased a little compared to earlier. *T. minor* was still mostly distributed in the lower section of the trunk.

In January, the attack density (egg galleries) of *T. yunnanensis* remained highest in the upper section of the trunks

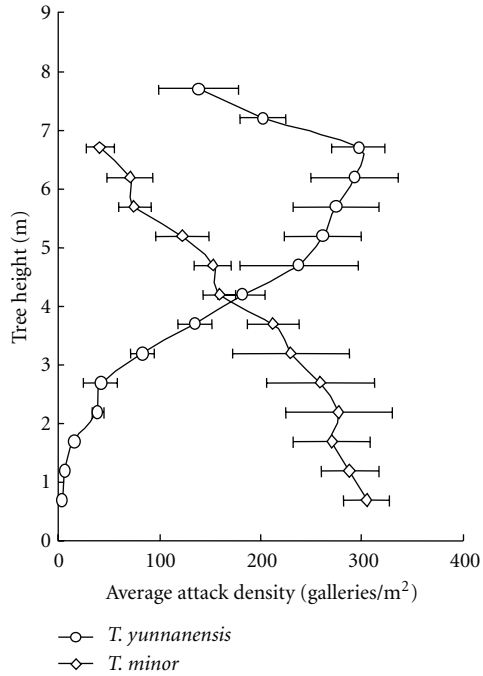

Figure 3: Average attack (egg gallery) density (±SE) and distribution of *T. yunnanensis* and *T. minor* along the trunks of Yunnan pines in January, 2006 (Qujing, Yunnan province, China).

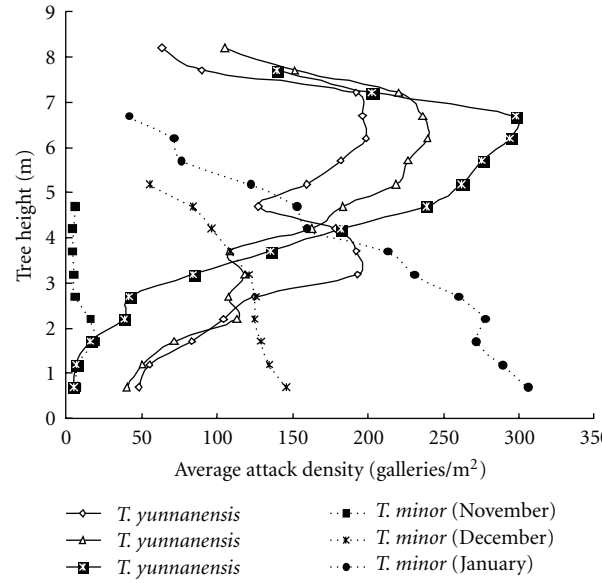

Figure 4: Progression of average attack (egg gallery) density and distribution of *T. yunnanensis* and *T. minor* along the trunks of Yunnan pines from November to January, 2005-2006 (Qujing, Yunnan province, China).

and also remained low in the lower section of the trunk (Figure 3). The highest gallery density of *T. yunnanensis* was about 297 galleries/m^2. The attack density of *T. minor* increased further, especially in the lower section of the trunks; and the egg galleries of *T. minor* were now distributed nearly over all areas of the trunks (Figure 4). The highest attack density of *T. minor* was about 305 galleries/m^2.

The measurements of egg gallery lengths show that in November these lengths for *T. yunnanensis* and *T. minor* were relatively short (Figure 5); *T. yunnanensis* egg galleries were about 3.6–4.9 cm long, while *T. minor*'s egg galleries were about 3.2–4.3 cm long. In December, the egg gallery length increased, especially for *T. minor* (Figure 6). The egg galleries of *T. minor* were about 5.9–6.2 cm long, and *T. yunnanensis* egg galleries were about 4.6–6.0 cm long. In January, egg gallery length continued to increase (Figure 7), *T. minor* egg galleries lengthened to about 8.2–8.9 cm, and *T. yunnanensis* went up to about 5.2–6.6 cm long (Figure 8).

3.2. Bark Beetle Distribution in Tree Crowns. About 11 *T. yunnanensis* were found in shoots per tree in November, and this number decreased to about nine by January, but the differences were not significant. Fewer *T. minor* (about four) were found per tree in November, and the number appeared to increase to five in December and then returned to four in January, but these differences were not significant.

3.3. Relationship between T. yunnanensis and T. minor. The two bark beetle species had different relationships in different parts of the tree during the November to January period

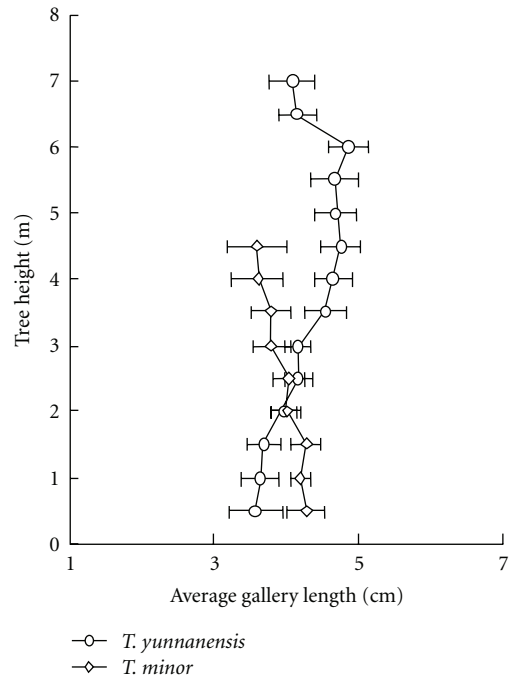

Figure 5: Average egg gallery length (±SE) of *T. yunnanensis* and *T. minor* along the trunks of Yunnan pines in November, 2005 (Qujing, Yunnan province, China).

(Figures 4 and 8). In November, there was no significant correlation between the two bark beetle species either with respect to trunks or to shoots (Table 1). In December, the two bark beetle species in shoots had no significant correlation either, but there was a significant negative correlation ($P \leq 0.01$) between *T. yunnanensis* and *T. minor*

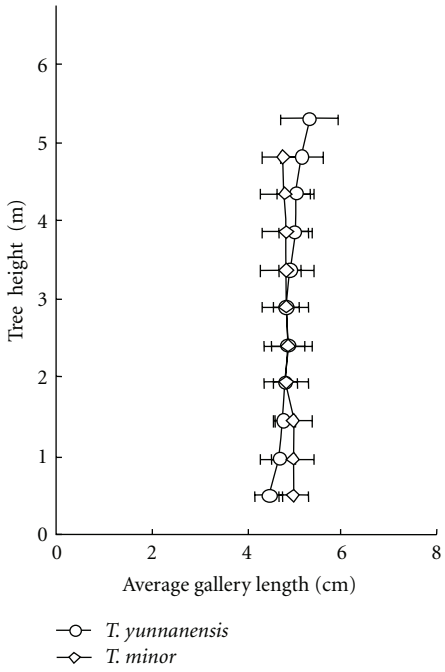

Figure 6: Average egg gallery length (±SE) of *T. yunnanensis* and *T. minor* along the trunks of Yunnan pines in December, 2005 (Qujing, Yunnan province, China).

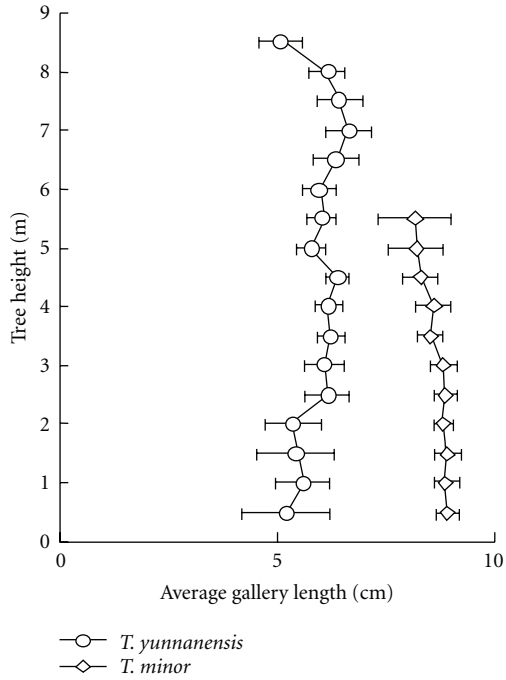

Figure 7: Average egg gallery length (±SE) of *T. yunnanensis* and *T. minor* along the trunks Yunnan pines in January, 2006 (Qujing, Yunnan province, China).

in trunks (Table 1). In January, the two bark beetle species had significant negative correlations in shoots and in trunks (Table 1).

4. Discussion

The appearance of bark beetle galleries show that most *T. yunnanensis* begin to transfer from shoots to trunks in November, a little earlier than *T. minor*. Most of *T. minor* begin to move in December. This result is consistent with earlier reports [15, 16]. The transferring period lasts from November to January, or even longer, and there is no clear peak in transferring time. In Yunnan province, the weather is much drier than other times in winter from November to April. When winter approaches, the weather has little rainfall and the soil becomes dry. Some trees are weakened because of the shortage of water. These weak trees are the first choice for bark beetles to attack and feed on. As dry weather conditions persist, more and more trees are weakened and become suitable for bark beetles to colonize. At the study site, the colonized trees were cut down when they were found. However, as the colonized trees were cut down, newly colonized trees could always be found until February. When *T. minor* begins to transfer from shoots to trunks, and the density of *T. minor* increases in the lower trunk, the newly colonizing *T. yunnanensis* will no longer feed on lower sections, indicating the latter species is avoiding competition with *T. minor* (Figure 4). Thus, the colonized trees cut down later were found to have fewer *T. yunnanensis* in their lower sections. Similarly, *T. minor* were found mainly in the lower trunk in areas with less *T. yunnanensis*, thus both species

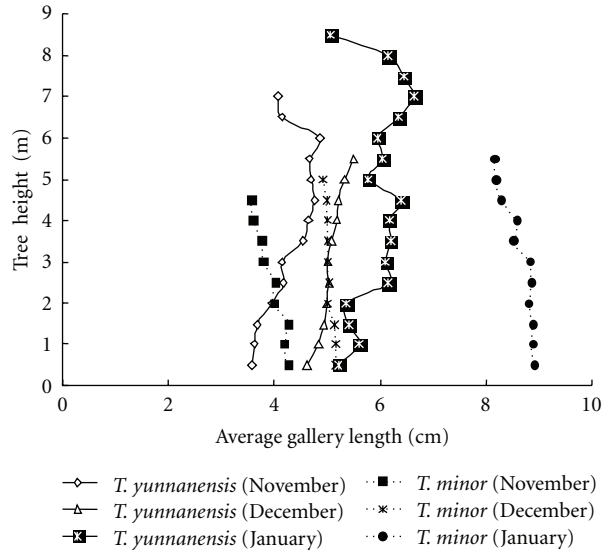

Figure 8: Progression of average egg gallery length of *T. yunnanensis* and *T. minor* along the trunks of Yunnan pines from November to January, 2005-2006 (Qujing, Yunnan province, China).

appear to be avoiding competition by selecting areas of the host with lower densities of the opposite species (Figure 4).

The egg gallery length of *T. yunnanensis* and *T. minor* not only increased during the three-month period, but also changed with the height of the trunks (Figures 5–8). The egg gallery length of *T. yunnanensis* increased, and the egg gallery

Table 1: The correlation between *T. yunnanensis* and *T. minor* in trunks and shoots of Yunnan pines.

	Bark beetles in trunks		Bark beetles in shoots	
Month	Pearson correlation	Sig. (2 tailed)	Pearson correlation	Sig. (2 tailed)
11	−0.491	0.179	−0.126	0.729
12	−0.956	$1.52E-05^{**}$	0.169	0.642
1	−0.981	$3.5E-09^{**}$	0.768	0.009^{**}

** Correlation significant at the 0.01 level (2-tailed).

length of *T. minor* decreased with the height of the trunks in different months.

We found that there are mainly two ways for *T. yunnanensis* and *T. minor* to transfer from shoots to trunks. If the host trees were already weakened, the beetles would feed on the host tree trunks directly; if the host trees were initially more healthy, beetles would feed together on the shoots of the tree to weaken it and then transfer to the trunks of these trees. These insects use this strategy to weaken the tree's defensive ability and allow better survival of the individual bark beetles.

The relationship between *T. yunnanensis* and *T. minor* changed with time and location on the tree. When the time for transferring came, *T. yunnanensis* would feed on the top of the host tree's trunk to make their host weaker or to kill it. Occasionally we found live trees with a dead top that had been killed by *T. yunnanensis*; this indicates that host trees generally have a strong resistance and were not easy to kill [17, 18], but when *T. minor* joined in to feed on the lower section of the host trunk, the resistance of the tree was further weakened which often led to its death. It is well known that the egg galleries of *T. minor* are perpendicular to the trunk length [19]. This would probably cut more transporting tissues and might be more harmful to trees than *T. yunnanensis* which have galleries aligned with the trunk. In November, the attack density was relatively low in trunks, especially for *T. minor*, so the relationship between the two bark beetle species was predominately cooperation. With more and more bark beetles transferring to trunks; however, the competition between the two species intensified, and the cooperation between them diminished. However, they could coexist very well since both species had a separate colonization location on the trunk to avoid competition as much as possible. In fact, we scarcely found two egg galleries of different families joined together, no matter whether the galleries were from the same or the other species, as has been observed in other species [12, 13, 20, 21]. When two egg galleries almost touched, bark beetles would not proceed ahead, and in most of the cases, *T. yunnanensis* would change the egg gallery direction or abandon their egg gallery, thus making some egg galleries of *T. yunnanensis* not straight or with deviations. *T. minor* also would stop when closely approaching another egg gallery and often turned and excavated in the opposite direction, because there are only two directions for *T. minor* to bore their egg galleries perpendicular to the grain of the trunk.

In the tree crowns, the behavioral relationship between the two species was more complicated. It was not uncommon that two or three bark beetles tunneled in one shoot. But in most cases, the beetles were of the same species and usually consisted of one male and one female, or one male and two females. This suggests that there was competition between *T. yunnanensis* and *T. minor* in shoots. At the beginning of the transferring period, their relationships were dominated by competition in shoots; but with more and more bark beetles transferring from shoots to trunks, their relationship changed. In other words, the competitive relationship between the beetles changed as they transferred from branches to trunks. Thus, the competitive relationship between *T. yunnanensis* and *T. minor* occurs during their entire life cycle but alters in intensity and type with the life phase and location on the host tree. Knowledge about the movement from shoots to trunks (transferring) and trunk colonization process, as well as competition between the two species, will be useful in designing control strategies that take advantage of the vulnerability of the beetles and maximize resistance of the tree.

Acknowledgment

The authors thank the Forest Pest Control Station of Qujing City, Yunnan province for logistical support and field assistance. This study was funded by the Importing International Advanced Agricultural Science and Technology Research (2002-38) and International Technological Cooperation Research (2006DFA31790).

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