Distribution and attack behaviour of the red turpentine beetle, *Dendroctonus valens,* recently introduced to China

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ABSTRACT: The red turpentine beetle, *Dendroctonus valens* LeConte (Coleoptera: Scolytidae), was found for the first time in China in Yangcheng and Xinshui counties, Shanxi province in 1998, and in Hebei province in 1999. The beetle mostly attacks the oil pine *Pinus tabulaeformis* Carriére. By 2003 the beetle was found in 85 counties of three provinces in north China and the area of infested pine forests covered more than 700,000 ha. The elevation above sea level of forests infested is more than 800 m. The beetles most frequently attack trees on hilltops and at the forest edge, fewer attacks occur in the centre of the stand. This correlates with the damage done to the trees by wind or man. Weak and dying trees are more vulnerable to attack than healthy ones. The most attractive breeding sites are fresh stumps. The population density of the beetles is higher in the forests on northern slopes than on southern slopes. Most of the bores in the trunk are less than 0.5 m above ground; the galleries are found also on roots.

Keywords: bark beetles; outbreak; *Pinus tabulaeformis*; forest pest; host location; distribution

The red turpentine beetle (*Dendroctonus valens* LeConte) naturally occurs in the United States, Canada and Mexico (Wood 1982). It is the largest and most widely distributed bark beetle in North America. It belongs to a group of beetles that characteristically tunnel between the bark and the xylem. In its native area, the red turpentine beetle is a common pest of forest, shade, and park trees of pole size or larger. In North America it has been recorded on at least 40 species of domestic and foreign conifers. The insect usually attacks trees of reduced vigour or those infested by other bark beetles, but it can also attack apparently healthy trees. Despite the abundance and wide distribution of this beetle, outbreaks have not been extensive or severe (Schwerdtfeger 1959; Richard, Smith 1971).

In China, the red turpentine beetle was found for the first time in Yangcheng and Xinshui counties, Shanxi province in 1998, to which it was probably imported from North America with pine logs used in the local coalmines in the 80's (Yin 2000). The species had never been recorded in China before. Its pest status was recognized in 1998, when the beetle was also recorded in Hebei and Henan provinces (Yushuang et al. 2000). One year later the beetle was found in Shaanxi province and in 2002 it was reported in Gansu province. So far the insect has been found mainly in *Pinus tabulaeformis* Carriére forests at higher elevations of the Taihang Mountain Range, where it caused severe damage. The outbreaks were abrupt and struck in all infested localities. In order to obtain more detailed data for

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the control, we investigated the patterns of distribution of the red turpentine beetles in forest stands and studied the outbreak characteristics in Hebei province, China.

MATERIAL AND METHODS

The bores of beetles were searched for and counted on randomly selected pine trees of varying age in pine forests characterized by different orographical characteristics (elevation, compass orientation of the slopes, etc.). The differences in numbers of attacked trees and/or numbers of bores on attacked trees were statistically evaluated (ANOVA). Field investigations were done in pine forests in Neiqiu, Xingyu, Lincheng and Xingtai counties, Hebei province.

The life stages of the red turpentine beetle are easy to recognize. The eggs are shiny white, ovoid, and a little over 1 mm long. The larva is grub-like, legless and white, except for the brown head capsule and a small brown area at the hind end. It attains a length of 10 to 12 mm when fully grown. Larvae share a common brood chamber. The exarate pupa is slightly shorter than the larva and still white. The wings, legs and antennae of the pharate adult are free but closely attached to the body. The stout callow adults that emerge from pupae are 6 to 10 mm long and light brown (Yin 2000). The flight of adults has two peaks during one season in Hebei province.

RESULTS

Characteristics of attack

Distribution and hosts. After the first discovery in 1998 (Yushuang et al. 2000) the red turpentine beetle has been found in the Taihang Mountain area in more than 40 counties belonging to Shanxi, Hebei and Henan province. The elevation of most forests infested by the beetle ranges from 800 to 1,500 meters. Serious damage was done mainly to the oil pines, *P. tabulaeformis*. The total area of oil pine forests infested in 2002 was more than 700,000 ha and more than 6 million trees died in the three provinces by then. Attacks on other genera of conifers, namely the white bark pine, *Pinus bungeana* Zuccarini, and Huashan pine, *Pinus armandii* Franch, have occasionally occurred in Hebei province. Tree mortality was mostly observed in *P. tabulaeformis*. Since 2002 the population density of the beetle has been declining and currently the beetle causes serious problems only in small areas.

Description of attack. Attacks by the red turpentine beetle are concentrated in the basal section of the tree trunk (90% of the holes were 50 cm or less) but occasional holes may be observed 2 or more meters above the ground or on roots. Indicators of an attack are a pitch tube on the surface of the bark, fine wood particles (frass) either in bark crevices or on the ground at the base of the tree, or pitch pellets on

Table 1. Classification scale of the vigour grades (health status) of the oil pine trees

Vigour grade	Health status	Characteristics
I	healthy	Needles green, no dying twigs, the growth was more than 10 cm during the previous year
II	weak	With a few dying twigs (less than 20%), the growth was less than 10 cm during the previous year
III	very weak	With many dying twigs (20 to 70%), the growth was less than 5 cm during the previous year
IV	dying	With only few live needles, more than 70% of twigs were dead
V	dead	No green needles
VI	stumps	Fresh cut stump after thinning

Table 2. Attacks by the red turpentine beetle on pine trees of different vigour grade

Vigour grade	Number of investigated trees	Number of attacked trees	Percentage of attacked trees	Difference (p = 0.05)
I	150	24	16.0	A
II	223	69	30.9	BC
III	140	27	19.3	A
IV	55	14	25.5	AB
V	35	8	22.9	AB
VI	22	11	50.0	C

Table 3. Populations of the red turpentine beetle on oil pine trees of different vigour grades

Vigour grade	Number of investigated trees	Number of beetle attacks per tree			ANOVA		
		range	mean	s. d.	F	difference*	
I	5	0–2	1.00	0.71	140.78 ($p < 0.01$)	D	f
II	5	5–12	9.00	2.92		D	e
III	6	18–26	22.67	3.05		C	d
IV	4	23–36	30.25	5.17		C	c
V	7	47–61	52.86	5.50		B	b
VI	9	57–79	66.44	8.17		A	a

*For Table 3–8: No significant difference at $p < 0.01$ and $p < 0.05$ between the grades indicated with the same capital or small letter, respectively

Table 4. Attacks of oil pine trees of different age

Tree age (years)	Numbers of surveyed trees	Percentage of attacked trees			ANOVA		
		range	mean	s. d.	F	difference*	
< 30	84	6.7–10.0	8.33	0.017	21.26 ($p < 0.01$)	A	a
30–40	350	17.5–23.0	22.28	0.044		B	b
40–50	85	18.4–19.2	18.82	0.004		B	b

the ground. The resin that flows from the wood, the insect's frass and bark borings are mixed and pushed outside the entrance hole by the boring beetle. The mixture either adheres to the bark surface, forming a pitch tube, or falls onto the ground in pitch pellets of various sizes. The pitch tubes are white or light yellow and protrude 3–5 cm. The tubes can be up to 8 cm broad. The galleries made between the bark and wood are generally vertical and partially packed with granular, pitchy borings or frass. The symptoms of dying attract other conspecifics to the attacked tree. The needles of the dying tree fade and turn yellow. Such fading of the needles is often associated with attacks by other insects, primarily other species of bark beetles.

Factors affecting the attack

The effect of the health condition of trees. The pine trees were classified into six grades according to their health status (growth vigour) (Table 1). After inspecting 625 trees in Neiqiu county we found 153 (24%) trees infested with the red turpentine beetle. Freshly cut stumps were attacked most frequently. Another most frequently infested target was the base of weak and dying trees. The least attacked were healthy trees (Table 2). The population density of the red turpentine beetle on individual attacked trees showed a similar pattern; the infestation increased progressively with the increasing degree of weakness of the host trees (Table 3).

The effect of the age of pine trees. The effect of age of the trees on infestation by the beetle was investigated in Xingtai county in 2001. In 18 forest stands 519 trees were surveyed. The results showed that the beetles mainly attacked trees more than 30 years old (Table 4).

The effect of elevation. The occurrence of outbreaks in areas of different elevation was surveyed in Hebei province in 2000 and 2001. It appeared that outbreaks occurred only in forests at an elevation of more than 850 meters above sea level (Table 5).

Distribution of infested trees within the forest stand. In 2001 the distribution of the infested trees was investigated in 19 forest stands in different locations in the Taihang Mountains in Hebei province. Most infested trees were found in forests along the roads, less on the top of hillsides and only a few attacks were recorded in the centre of the forest (Table 6).

The effect of the compass orientation of a hillside. The survey was conducted in 18 mountain locations of Neiqiu, Xyngiu and Lincheng counties. The locations were categorized according to their compass orientation as (1) hilltop, (2) south or west slopes, (3) north-west slopes, and (4) north or north-east slopes; and the numbers of attacked pine trees recorded in each. Most attacks occurred in hilltop forests, less in the forest stands on the hillsides facing north or northeast and the pine trees on the south- or west-facing slopes were significantly less infested (Table 7).

Table 5. Outbreaks of the red turpentine beetle in areas of different elevation

Elevation (m)	Numbers of surveyed trees	Percentage of infected trees			ANOVA		
		range	mean	s. d.	*F*	difference*	
< 850	52	0.00–0.00	0.00	0.000	136.22 ($p < 0.01$)	A	a
851–1,000	257	13.8–21.5	17.50	3.207		B	b
> 1,001 (with the highest of 1,350 m)	240	25.5~31.4	28.75	2.864		C	c

Table 6. Distribution of infected trees within the forest

Location of the tree	Number of surveyed trees	Percentage of infested trees			ANOVA		
		range	mean	s. d.	*F*	difference*	
Inside the forest	373	16.2–20.9	18.8	2.35	132.49 ($p < 0.01$)	A	a
At the edge of forest	48	29.3–36.4	33.3	3.64		B	b
On the hilltop	27	46.8–49.6	48.1	1.41		C	c
Along the road	49	55.8–59.7	57.1	2.24		D	d

The effects of trunk diameters at breast height (dbh). The relationship between the numbers of attacks and the size of the oil pine trees was investigated on 779 trees in five forest stands of comparable exposition in Hebei province. No significant differences in the infestation rate between oil pine trees with dbh ranging from 7.5 to more than 20 cm were found (Table 8). Occasionally the trees with as small dbh as 3 cm were also infested.

DISCUSSION

The present study is an attempt to characterize ecological requirements and colonization behaviour of adults of the red turpentine beetle (*D. valens*), which was introduced to China most probably with construction wood from North America about two decades ago (Yin 2000). The introduced species encountered rather specific ecological conditions in the new territory, namely poor diversity of suitable host trees. A dominant tree in the range of its current occurrence is a pine species (*P. tabulaeformis*) that was propagated in the mountains of North China several decades ago mainly to prevent soil erosion from the hills deforested during previous centuries. The outbreak of the red turpentine beetle may have been facilitated by several coincidental circumstances:

Table 7. The numbers of attacked pine trees on hillsides of different compass orientation

Sites	Orientation of the hillside	Number of surveyed trees	Percentage of infested trees			ANOVA		
			range	mean	s. d.	*F*	difference*	
Neiqiu Xingyu	Top of a hill	157	35.2–40.3	38.8	2.44	287.94 ($p < 0.01$)	A	a
Lincheng	South or west	44	5.2–8.2	6.8	1.29		D	d
	North-west	217	10.9–13.6	12.4	1.11		C	c
	North or north-east	148	18.4–23.2	20.9	2.04		B	b
	Top of a hill	27	38.9–43.2	41.2	1.88		A	a

Table 8. Attacks on oil pine trees with different dbh

dbh (cm)	Number of surveyed trees	Percentage of infested trees			ANOVA		
		range	mean	s. d.	*F*	difference*	
< 10**	175	20.9–21.8	21.8	0.93	0.739 (NS)	A	a
11–20	353	21.4–23.5	23.2	1.74		A	a
> 21	251	20.5–24.1	22.0	1.86		A	a

**The smallest dbh investigated was 7.5 cm

(a) the species was a new invader with only a few natural enemies in the newly colonized territory;
(b) there was a large area of *P. tabulaeformis* monoculture forests in the mountains of north China and the pine appeared a suitable host tree for the introduced beetle;
(c) after thinning there was a large number of fresh stumps (specially in Shanxi province) that are very suitable hibernation and breeding sites for the beetle, as shown by this study;
(d) there was a severe drought in north China in the late nineties that may have weakened the pine trees and made them susceptible to the beetles' attack.

Our detailed analysis of the beetles' behaviour under various ecological conditions revealed several factors favouring reproduction of the species. The health status of the host tree seems to be one of the most important. It is generally accepted and in various bark beetle species experimentally proven that weak tree specimens are more vulnerable to beetle attack than healthy ones, particularly at low population densities. Host searching behaviour of dispersing pioneer beetles is guided by semiochemicals released by dying trees (Paine et al. 1997). The behaviour of the red turpentine beetle is no exception. Recent investigations of the chemosensory orientation of the red turpentine beetle to host semiochemicals (Sun et al. 2004) and their inhibitors (Sun et al. 2003) revealed the importance of the host volatiles (kairomones) for orientation of the beetles during host searching. We have also observed that the beetles can successfully colonize an apparently healthy tree and under certain circumstances the tree can survive the beetles' attack. Interestingly, even trees that recovered from an initial attack were repeatedly infested; most of them survived even the second attack (Wen et al. unpubl.).

Our results also show that the trees along the roads and on hilltops are more frequently attacked than the trees inside the forest stand or on the slopes. We tentatively assume that the trees in both situations are weakened – by human activity in the former case, and strong winds in the latter. The low attack rates recorded inside forest stands may also be explained by the reluctance of the beetles to colonize trees with dense canopy. The trees on hillsides appear less vulnerable to the beetles' attack than those on hilltops. Trees were least attacked if they grew on slopes facing south or west (locations most intensely insolated). Elevation and age/size of the grown host tree within a certain range appeared to have little or no effect on the behaviour of the beetle. Understanding the conditions favouring reproduction of this pest introduced recently into its new habitat is important not only for understanding the beetles' behaviour during infestation but also for designing an efficient control strategy.

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Rozšíření lýkohuba *Dendroctonus valens* čerstvě zavlečeného do Číny a jeho chování při napadení stromů

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ABSTRAKT: Je popsáno rozšíření lýkohuba *Dendroctonus valens* na území severovýchodní Číny, kam byl nedávno zavlečen ze Severní Ameriky. Studovali jsme jeho ekologické nároky, hostitelskou specificitu a chování při kolonizaci hostitelských stromů, jimiž jsou převážně domácí borovice *Pinus tabulaeformis.*

Klíčová slova: kůrovci; kalamitní výskyt; *Pinus tabulaeformis*; lesní škůdci; lokalizace hostitelské rostliny; rozšíření

Lýkohub *Dendroctonus valens* LeConte (Coleoptera: Scolytidae) byl v Číně poprvé pozorován v roce 1998 v provincii Shanxi v oblastech Yangcheng a Xinshui, o rok později byl zjištěn v provincii Hebei. Tento druh kůrovce zde napadá porosty domácí borovice *Pinus tabulaeformis* Carr. Do roku 2003 byl zjištěn v 85 různých oblastech tří provincií severovýchodní Číny a celková výměra porostů poškozených napadením převyšuje 700 tisíc ha. V posledních dvou letech kůrovcová kalamita slábne.

Nejčastěji jsou zasaženy porosty nad 800 m nadmořské výšky. Stromy na vrcholcích kopců a na okrajích porostů, tedy na lokalitách oslabených buď větrem, nebo činností člověka, jsou lýkohuby napadány častěji než stromy uvnitř porostů. Oslabené a chřadnoucí stromy jsou náchylnější k náletu než stromy zdravé; nejčastěji byl pozorován nálet kůrovců na čerstvé pařezy. Porosty na svazích severně exponovaných jsou napadány silněji než svahy exponované jižně. Nálet na kmeny je směrován většinou do výšky 0,5 m nad zemí, časté jsou rovněž požerky pod kůrou kořenů.

Kalamitu lýkohubů zavlečených do Číny ze Severní Ameriky pravděpodobně s importovaným dřívím na výdřevu uhelných štol mohlo způsobit několik souběžně působících okolností:

(a) jedná se o invazi druhu z jiného kontinentu, který se na novém území setkal jen s nemnoha přirozenými nepřáteli;
(b) v místech introdukce (horské oblasti s důlním průmyslem) jsou velké plochy monokultur borovice *P. tabulaeformis,* které zde byly zakládány před několika desetiletími hlavně jako ochrana před erozí, a tato borovice se ukázala být pro zavlečeného kůrovce vhodnou hostitelskou dřevinou;
(c) při probírkách vznikalo velké množství čerstvých pařezů, které jsou zvlášť vhodným a atraktivním substrátem pro zakládání nových požerků;
(d) koncem devadesátých let minulého století bylo v severní Číně několik velmi suchých let, což mohlo borovice oslabit a učinit je tak méně odolné vůči útokům kůrovců.

Objasnění podmínek usnadňujících reprodukci tohoto introdukovaného škůdce v jeho novém habitatu je důležité nejen pro obecné poznání chování brouků při infestaci, ale i pro vypracování účinné strategie ochrany lesa proti němu.

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