Development and survivorship of the Japanese giant weevil, *Sipalinus gigas* (Fabricius) (Coleoptera: Rhynchophoridae), in cut pine bolts

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Abstract

Cut pine bolts were exposed to allow a field population of *Sipalinus gigas* to oviposit and the colonized insects in the bolts were examined periodically up to 29 mo after oviposition. The estimated survival rate of the immatures in the bolts decreased throughout the first and second season, and reached almost zero before the second overwintering. Predation was thought to be one of the major mortality factors of immature *S. gigas*. The increase of larval size and formation of a pupal chamber indicated that larval growth of *S. gigas* was completed within 4–5 mo after oviposition. The occurrence of pupae, callow adults and emerged adults suggested that *S. gigas* have bimodal adult emergence, namely they emerge in autumn of the year when they were laid as eggs as well as in the autumn of the following year. Although a small number of live larvae were found just before the second overwintering, they were less likely to grow into adults in the third season because of the high mortality of immatures in the second and third seasons.

Key words: *Sipalinus gigas*, developmental time, adult emergence, survivorship

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INTRODUCTION

The Japanese giant weevil, *Sipalinus gigas* (Fabricius), is one of the most important wood pests in Japan (Inoue, 1953; Morimoto, 1984). Its potential damage has caused growing concern in relation to lumber production using the field drying method (Makino and Yoshida, 1993) and the occurrence of huge amounts of fallen trees in coniferous plantations caused by recent typhoon attacks (Kubozono, 1993, 1995). Despite its wide prevalence, the life history of *S. gigas* has not been clarified in detail. Kumamoto Regional Forest Office (1932) described that the eggs laid in April to July grew into adults in October of the following year. On the other hand, Furuta (1972) observed that most individuals considered to have been laid as eggs in the spring emerged by autumn of the same year. Nakamura et al. (2000) investigated the developmental stages of *S. gigas* in cut pine bolts set in a forest stand at different times and showed that adult emergence occurred in the autumn of the year following oviposition as well as the current year. They also suggested that some individuals need three years or longer to become adults. However, the number of insects they examined was not suffi-

cient to fully clarify the life cycle of *S. gigas*. In addition, they did not investigate the development of immature *S. gigas* after the second overwintering.

In this study, we attempted to collect as many *S. gigas* colonizing cut pine bolts as possible by exposing a large number of bolts to a weevil field population at the peak time of oviposition, which was shown to be mid-June through July by Nakamura et al. (2000). Bolts were examined periodically for live and dead *S. gigas* including immatures and adults to trace development and survivorship of the insects. The examination was conducted up to 29 mo after oviposition to investigate the developmental status of *S. gigas* after the second overwintering.

MATERIALS AND METHODS

Study stand. The study stand was the same as that described by Nakamura et al. (2000). It was a 31-year-old plantation (in 1995) of the Japanese red pine, *Pinus densiflora* Sieb. et Zucc. located on the southeastern foothills of Mt. Kuju, Oita Prefecture, at ca. 800 m above sea level.

Setting of pine bolts. Fresh cut bolts of *P. densi-*

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flora were used in the experiment. These bolts were obtained from pine trees growing in a *P. densiflora* forest in Kusu Town, Oita Prefecture. The bolts were 30–40 cm in length, 4.8–13.3 cm in diameter and used within 7 d after logging. In 1995, 30 cut bolts were set on the forest floor of the study stand on 16 June and left for 28 d to allow *S. gigas* females in the field to deposit eggs. In 1996, two batches of 50 bolts were set on 14 June and 12 July, respectively, and exposed to allow the weevil to oviposit for 28 d. Then the bolts were put in nylon net bags to trap the emerged adults, and placed in field cages (180×100 cm, 25 cm high; with 16 mesh wire netting) to prevent additional oviposition by *S. gigas*. The nylon net bag often became tattered by cerambycids emerging from the bolts or possibly by small mammals invading the cages from the ground. Therefore we put the bolts into a 16-mesh wire netting bag in April just after the first overwintering when they had frass excreted by developing *S. gigas* larva on the bark. Two black beer baited bottle traps were set in each field cage to check the invasion of *S. gigas* adults from the outside.

For the bolts set in 1995, we took six bolts out of the cages on 17 August, 16 October, 15 December in 1995, and on 25 April and 11 November in 1996. For the ones set in 1996, 10 bolts were taken from each of the two batches on 11 November in 1996, 5 May, 20 November in 1997, and on 18 May and 2 November in 1998. Hereafter, when the bolts are referred to in terms of the time elapsed after oviposition by *S. gigas*, the bolts are presumed to carry eggs laid in June for 1995 bolts, and July for 1996 bolts.

Collection of emerged adults. For the bolts set in 1996 and examined in May or November in 1998, we investigated the occurrence of emerged adults in the net bags on 16 March 1998 to discriminate the trapped adults emerged in the third season from those that had emerged earlier. The bolts were taken out of the net bags and the emerged adults or their remains in the net bags were collected. The bolts were then put in the net bags again and placed in the field cages until the scheduled examination time.

Examination of the bolts. Bolts left in the field cages as above were taken for examination to Kyushu Research Center, Forestry and Forest Products Research Institute in Kumamoto City. The net

bags were removed and checked for emerged adults of *S. gigas* or their remains. The bolts were debarked and all holes that appeared were marked. The holes made by Cerambycids or *Hylobitelus* sp. weevils, which were easily discriminated by the shape of the tunnels, were excluded from further examination. Holes were measured for their diameter and examined for the contents by carefully dissecting the bolts. When a live or dead larva was collected, head capsule width was measured with a calipers. In some cases, the head capsule had been fragmented by a predator or was destroyed when we dissected the bolts and the width could not be determined.

The number of *S. gigas* colonized in a bolt was estimated as the total of the number of entrance holes 3 mm or larger in dia. except for the holes inhabited by scolytids and holes less than 3 mm in dia. with live or dead *S. gigas* larva, according to Nakamura et al. (2000). The survival rate of *S. gigas* in a bolt as of the time when examined was determined as follows: (number of live *S. gigas* found in the bolt)/(estimated number of colonized *S. gigas* in the bolt). Because an emerged adult is regarded as emigrant from the immature *S. gigas* population in a bolt, the number of emerged adults and their tunnels were not used in the calculation of survival rate in the bolts.

RESULTS

No adult *S. gigas* was caught by the black beer traps in the cages, suggesting that all immature and adult weevils in the bolts originated from eggs deposited during the exposure time in the stand.

The estimated numbers of colonized *S. gigas* in the bolts set in 1995 and 1996 were 62 and 166, respectively (Table 1). Among these, we collected a total of 68 immatures alive. We also collected 14 live and 8 dead adults emerged from the bolts and trapped in the net bags.

The estimated survival rates were higher than 70% before the first overwintering (Fig. 1). They decreased through the second season, and became almost zero just before the second overwintering. From the bolts set in 1996 and examined after the second winter, we could not find any live immatures of *S. gigas*.

Dead immatures and remnant head capsules of the larvae were collected from 16 and 43 tunnels,

Table 1. Numbers of individuals of each stage of *Sipalinus gigas* or tunnels supposed to be made by *S. gigas* in the cut pine bolts exposed to the weevil's oviposition

Year of oviposition	Emergent adult	Live immature				Dead immature				No. of tunnels with head capsule	No. of tunnels without remains ^a	Total
		Larva	Pupa	Callow adult	Subtotal	Larva	Pupa	Callow adult	Subtotal			
1995	0	30	4	0	34	3	0	1	4	8	16	62
1996	22 ^b	32	1	1	34	7	1	4	12	35	63	166
Total	22	62	5	1	68	10	1	5	16	43	79	228

^a Figures show the numbers of empty tunnels with entrance hole 3 mm or larger, which were supposed to be made by *S. gigas* (Nakamura et al., 2000).

^b Eight dead adults were included.

Fig. 1. Number of live and dead *Sipalinus gigas* collected and their survival rate in cut pine bolts examined at different times. Columns show the status or developmental stage of *S. gigas* collected from the bolts at each examination time. Circles show the estimated survival rate of immatures within the bolts. The survival rate at the oviposition times was assumed to be 100%. For the bolts set in June 1996 and examined in May–November 1998, the emerged adults trapped in the net bags containing the logs were collected in March 1998, precedent to the examination of the bolts. Patterns of the columns mean as follows: ■ live larvae, ▨ live pupae, ▩ live callow adults, □ emerged adults, □ mortality in the bolts.

respectively, while we could not find any remains in 79 tunnels with an entrance hole 3 mm or larger that were considered to have been made by *S. gigas* (Table 1). Head capsules found in the tunnels were often fragmented. Three larvae, one pupa and one callow adult appeared to have been killed by some disease. One callow adult died from false eclosion and another was found dismembered. On dissecting a bolt taken in August 1995, we observed a larva of *Trogossita japonica* Reitter in a tunnel with a killed *S. gigas* larva. The mortality factors of the other larvae and callow adults found dead were unidentified.

Most of the live insects were collected as larvae (Table 1, Fig. 1). They were found in the bolts examined in the first August through the second November (Fig. 1). When the bolts were examined 5 mo after oviposition or later, larvae were found in chambers compartmented from the rest of the tunnel with packed frass. In many cases, larvae packed frass only on the outer side of the tunnel, but some made the chamber in the middle of the tunnel packing frass on the outer and inner sides. The packing showed concave surface inside the chamber. Pupae were found in October through December of the first season (Fig. 1). One callow adult was found from a bolt set in 1996 and examined in the first November. Six live and two dead adults were collected from the net bag that contained the bolts set in 1996 and examined in the second November. We also collected six live and eight dead adults inside the net bags in March 1998, which had emerged from the bolts set in 1996.

In the bolts set in 1995, the mean diameter of the entrance holes in the first October (4 mo after oviposition) were significantly larger than those in the first August (2 mo after oviposition), while no significant differences were shown subsequently (Sheffé's test, $p < 0.05$) (Fig. 2). The mean head capsule width in the first August was smaller than that in the first December and next April (6 and 10 mo after oviposition, respectively), although the difference from that in the first October was not significant (Sheffé's test, $p > 0.05$). The same measurements were done for the bolts set in 1996 and taken out 4 through 16 mo after oviposition, in which live larvae were found. There were no significant changes in the size of entrance hole ($F = 0.39$; $df = 2, 31$; $p > 0.6$) nor head capsule width ($F = 0.18$;

Fig. 2. Temporal change of the size of entrance holes of larval tunnels and head capsule width of the larvae. Circles and triangles show the means of the entrance holes and head capsule width, respectively. Solid and open symbols indicate the data of the bolts set in 1995 and 1996, respectively. Error bars show SD.

df=2, 29; $p>0.8$) by the one-way ANOVA.

DISCUSSION

The adult emergence time of *S. gigas* has not been clarified; it has been reported to be in the current autumn (Furuta, 1972) or the following October (Kumamoto Regional Forest Office, 1932). Nakamura et al. (2000) showed that adult emergence of *S. gigas* occurred in autumn of the current year and also in the year following oviposition. The results in this study supported the bimodal emergence of *S. gigas* adults. We collected four pupae and one callow adult in October or November of the year of oviposition (Fig. 1). Those would have emerged as adults within the year if they had remained intact. Meanwhile, many individuals in the same cohorts overwintered as larvae. In 1997, in the second November examinations of the logs set in 1995, we collected eight emerged adults. In March 1998, 14 adults were collected from the net bags containing the bolts set in 1996. Those adults were considered to have emerged in late autumn in 1997, because the adult weevils were inactive until late April (Nakamura et al., 2000).

The increase of the size of entrance holes and head capsule width of the larvae seemed to reach their maximum by 4 mo after oviposition (Fig. 2). Thus we can speculate that the larval growth of *S. gigas* requires only 4–5 mo after oviposition. When the bolts were examined 5 mo after oviposition or later, most larvae were found in compartmented chambers within their tunnel. Pupae and callow

adults were also found in the chambers, indicating that pupation and eclosion took place in them.

Survivorship of the immatures in the bolts steadily decreased throughout the first and second seasons, except for the examination in October 1995 (Fig. 1). There were many empty tunnels that were supposed to have been inhabited by *S. gigas*. Head capsules of *S. gigas* were sometimes found inside. A dismembered callow adult was found in a tunnel examined in November 1997 (Fig. 1). Those tunnels may have been invaded by some predators of immature *S. gigas*. We observed a *T. japonica* (syn. *Temnochila japonica*) larvae, one of the major predators of subcortical insects in Japan (Kishi, 1970; Ueda et al., 1996), with an almost consumed body of an *S. gigas* larva at the dissection of the bolts in August 1995. Predation could be an important mortality factor of immature *S. gigas*.

Nakamura et al. (2000) noted that *S. gigas* might also emerge after the second overwintering, on the grounds that they found a small number of live immatures in the bolts that had been exposed to the weevils oviposition and examined in November of the next year of the oviposition. In this study, a live larva was found in the second November in a bolt set in 1996 (Fig. 1). However, we could not find any live immatures in the bolts examined in the third season (Fig. 1). Thus we can consider that there would be few adults emerging in the third season, because of the low survival rate of immature *S. gigas* after the second season.

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