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BRIEF REPORT

Seasonal prevalence of the invasive rusty-spotted longhorn beetle, *Apriona swainsoni* (Coleoptera: Cerambycidae), adults in Fukushima Prefecture, Japan

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Abstract
Invasive longhorn beetles are serious pests of tree stands worldwide. The rusty-spotted longhorn beetle, *Apriona swainsoni* (Hope) (Coleoptera: Cerambycidae: Lamiinae), is native to continental Asia, where it is a significant pest of legume trees. Its invasion into non-native ranges and damage to the local legume tree, *Maackia amurensis*, were first reported from Fukushima Prefecture, Japan, in 2021. This study investigated the biology of *A. swainsoni* in relation to adult emergence in Japan. Preliminary observations confirmed that *A. swainsoni* larvae create planned emergence holes on the host surface in late May. By exploiting these planned emergence holes, the adult emergence period was investigated in a field promenade of *M. amurensis* during the summer of 2022 and 2023. The researchers plugged the holes and recorded plug removal, resulting in the observation of 60 and 227 putative emergence events in respective years, with the majority occurring in early to mid-July. Further, during the summer of 2022, a periodic field survey of adult emergence was conducted, obtaining eight adults. Furthermore, a supplementary survey using infested logs maintained in a field cage demonstrated that the emergence period does not differ between sexes and the male-to-female ratio is one:one. Our results suggest that control efforts to suppress *A. swainsoni* adults in the field, such as insecticide spraying, should be prioritized in the relatively short, peak emergence period. This work indicates that the plug survey is useful for detecting the emergence period.

Keywords Alien species · Emergence · Exit hole · Life history · Wood boring pest

Introduction

Invasive longhorn beetles are significant pests of tree stands worldwide, leading to ecological and economic damage by causing tree mortality in forests, agricultural lands, and urban areas (Haack et al. 2010; Iwata 2018; Sarto i Monteys et al. 2021). The rusty-spotted longhorn beetle, *Apriona swainsoni* (Hope) (Coleoptera: Cerambycidae: Lamiinae), is native to India, China, the Korean Peninsula, Myanmar, Thailand, Vietnam, Laos, and Cambodia (Haack 2017a; Liu et al. 2006). It has long been a serious pest of the Chinese scholar tree, *Styphnolobium japonicum* (Fabales: Fabaceae), in China (Haack 2017a; Liu et al. 2006). While its distribution had been limited to its native range until recently, its invasion into non-native range was first reported from Koriyama City, Fukushima Prefecture, Japan, in 2021 (Anzai 2021). Subsequent surveys have revealed that *A. swainsoni* has already become established in 18 municipalities (Nagahata 2022), with a specimen record dating back to 2014 in Sukagawa City, suggesting its presence in Fukushima before 2014 (Mtow et al. 2022). Within the introduced range, *A. swainsoni* primarily infests *Maackia amurensis* (Fabales: Fabaceae) trees and, secondarily and less commonly, *S. japonicum* trees, leading to severe damages in residential areas, streets, and forested regions (Nagahata 2022). In response to the invasion, Koriyama City took measures to address the spread by felling 222 infested *M. amurensis* trees from its jurisdictional promenades in 2022. Furthermore, Fukushima Prefecture removed all *M. amurensis* trees under its jurisdiction, regardless of infestation status. However, a subsequent survey confirmed additional 1037 infested trees

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in the prefecture. The situation calls for continued efforts to control the spread of *A. swainsoni* and to protect the affected tree species and ecosystems in the region as well as the whole country. Thus, the Japanese government has recently decided to designate *A. swainsoni* as an invasive alien species to be controlled in its Invasive Alien Species Act (Ministry of the Environment 2023).

To prevent the further spread of *A. swainsoni*, understanding its ecology is necessary. However, available information is limited, as studies on *A. swainsoni* have just been initiated in Japan and there have been no other invaded countries. Thus far, females have been observed to lay eggs on *M. amurensis* trunks at night, taking approximately 40 min per oviposition sequence (Anzai 2021; Nagahata 2022). Additionally, Saito and Ono (2023) felled 21 infested *M. amurensis* trees around a building in Koriyama City and reported adult emergence periods from the logs and some morphological information.

In the native range of China, the biology of *A. swainsoni* is known as follows: Adult emergence starts in early June and peaks in mid- to late June in Shandong, Henan, and Anhui Provinces, although the period may somewhat differ among regions (Duan 2001; Li 2016; Wang 2003; Xiao 1992). The adult life span is 65–80 days and their body length ranges from 28 to 33 mm in males to 33 to 39 mm in females (Xiao 1992). *Apriona swainsoni*'s host plants include *S. japonicum*, *Butea monosperma* (Fabales: Fabaceae), *Caesalpinia decapetala* (Fabales: Fabaceae), *Dalbergia hupeana* (Fabales: Fabaceae), *Ligustrum lucidum* (Lamiales: Oleaceae), *Paulownia tomentosa* (Lamiales: Paulowniaceae), *Salix* spp. (Malpighiales: Salicaceae), *Tectaria subtriphylla* (Polypodiales: Tectariaceae), *Robinia pseudoacacia* (Fabales: Fabaceae), and *Tectona grandis* (Lamiales: Lamiaceae) (Haack 2017a; Liu and Tang 2002; Liu et al. 2006; Xiao 1992), with *S. japonicum* being the most susceptible (Liu and Tang 2002). After emergence, the adults move upward to the canopy, where they feed on the twigs for 5–10 days to achieve sexual maturation and then mate during the daytime (Duan 2001; Li 2016). Females begin oviposition 1–3 days after mating, typically laying eggs at nighttime on host trunks and branches with a diameter greater than 7 cm (Duan 2001; Wang 2003; Xiao 1992). Hatched larvae follows a 2-year life cycle. In Shandong Province, pupation begins in early May and peaks in mid-May, and just before that, mature larvae bore tunnels toward the outer side of the tree and even opened holes in the bark to eventually exit the tree (Xiao 1992). This behavior is unusual as a Lamiinae species (Haack et al. 2017b; Nakamura 2019), and the holes are hereafter referred to as "planned emergence holes."

The goal of this research was to gather ecological information on *A. swainsoni* adult emergence in Japan. To achieve that goal, the following investigations were conducted: (1) Exploiting *A. swainsoni*'s habit to form planned emergence holes, the adult emergence time of *M. amurensis* was studied in a field promenade in summer 2022 and 2023. Planned emergence holes were plugged and the subsequent plug removal was recorded. Furthermore, visual search of adults was conducted in 2022. (2) In addition, adult emergence from infested logs was monitored in a field cage. (3) Body length of *A. swainsoni* individuals taken in the wild or rescued from logs in Japan was measured for comparison with native Chinese populations.

Materials and methods

Adult emergence survey in tree stand

The adult emergence period was investigated on a promenade in Sukagawa City, Fukushima Prefecture (37.301°N, 140.374°E), where 59 *M. amurensis* trees were planted, and 43 of them were clearly infested by *A. swainsoni* (identified by frass excretion) (Online Resource 1). In this survey, the emergence hole served as an index for adult emergence. On June 23, 2022, a total of 64 holes were found on the trunks of the 43 infested trees, and these holes were plugged with floral foam (Matsumura Kogei Co., Ltd., Osaka, Japan) cut into cylindrical shapes of 0.9 cm in diameter and 10 cm in length. A preliminary survey confirmed that *A. swainsoni* larvae create planned emergence holes in Japan (Online Resources 2, 3) and we aimed to count adult emergence by exploiting the plug removal by adults emerging from the planned emergence holes. However, it should be noted that the plugged holes might have included both planned emergence holes created by larvae and old emergence holes that were already used by previously emerged adults. The trunks of all 59 trees were inspected once a week from July 2 to August 27, 2022 to observe the falling off of the plugs and any opening of new holes. The inspections were primarily conducted at 11 a.m. for approximately 90 min, but sometimes at 3 p.m., depending on the weather conditions.

Furthermore, a visual search of adult *A. swainsoni* was conducted on the same promenade. The surveys were conducted once a week from June 20 to August 29, 2022, on different dates from the plug surveys. The detected adults were captured, and their sex was recorded. Males and females were distinguished by abdominal tip morphology (Online Resource 1). The surveys were carried out between 6 p.m. and 9 p.m., when females start laying eggs on the trunks and are relatively easy to detect (Nagahata 2022).

The plug surveys were repeated in 2023 using the same 59 trees. In the previous year, it was found that planned emergence holes are rough circles, whereas emergence holes are almost complete circles (Online Resource 2). Using this knowledge, old emergence holes were identified and marked on May 12, 2023. Next, a survey was conducted on June 1, wherein 165 newly created, planned emergence holes were found and plugged. Weekly inspections of the plug fall-off and new hole openings were continued until August 11.

Adult emergence in a field cage

In the control program of *A. swainsoni* in Koriyama City, Fukushima Prefecture, infested *M. amurensis* trees on several promenades were felled between March and May 2022. Twenty-four logs of approximately 1 m long and 20–25 cm diameter were transferred to the Forestry and Forest Products Research Institute in Tsukuba City, Ibaraki Prefecture (36.008°N, 140.129°E) on May 26, 2022, and maintained in a sunny field cage made of metal mesh (2 m × 2 m × 2 m). The logs were checked for adult emergence every day from June to August 2022. Emerged adults were removed from the cage, and the number and sex were recorded.

Body length measurement

Body length of adult *A. swainsoni* individuals was measured using a digital caliper (Shinwa Measuring Co., Ltd., Niigata, Japan). The measurements included 41 field-collected individuals (20 males and 21 females) and 57 individuals retrieved from felled logs, as described in the last section (27 males and 30 females). The field-collected individuals were gathered in July and August 2022 from seven sites in Fukushima Prefecture: Tamura-machi, Koriyama City (16 males and 14 females), Asaka-machi, Koriyama City (one female), Otsuki-machi, Koriyama City (one female), Shonindan, Sukagawa City (one female), Osato, Ten-ei Village (four males and two females), Matsumoto, Ten-ei Village (one female), Terauchi, Yabuki Town, Nishishirakawa County (one female). To investigate if body length differed between males and females, Welch's t-test was conducted for field- and log-collected individuals separately.

Results

Adult emergence survey in tree stand

In 2022, a total of 60 emergence traces were detected from July 3 to August 13. Twenty-five of the 64 floral foam plugs fell off, and emergence holes became exposed (Fig. 1). Additionally, 35 emergence holes were detected in locations where there had been no holes and thus no plugs at the beginning. These events occurred mostly from early to middle July, with 51 events (85% of the total emergence traces) between July 3 and July 23. Seven emergence traces (12%) were detected in early August. The emergence of two adults (one male and one female) was directly observed on two trees on July 9 from the locations where the plugs had been applied (Online Resource 2: female). On that day, the survey was initiated at 3:00 pm, and one of the individuals was detected at 4:00 pm. The other one was detected at 8:46 p.m. during a continuous observation. Emerging adults rotated their bodies and carved and expanded the exit holes slowly. Then, the individuals moved back and forth, exited from the holes, and soon started to climb up the trunks. Their bodies were wet, possibly due to the sap. Other than the two emerging individuals, only six *A. swainsoni* adults (one male and five females) were detected on tree trunks and branches by the visual surveys (Fig. 2).

In 2023, a total of 227 emergence traces were detected from June 16 to July 21. These events occurred mostly from early to middle July (Fig. 1). In contrast to 2022, no trace of emergence was detected in August. Most of the initially applied floral foam plugs fell off (157 out of 165).

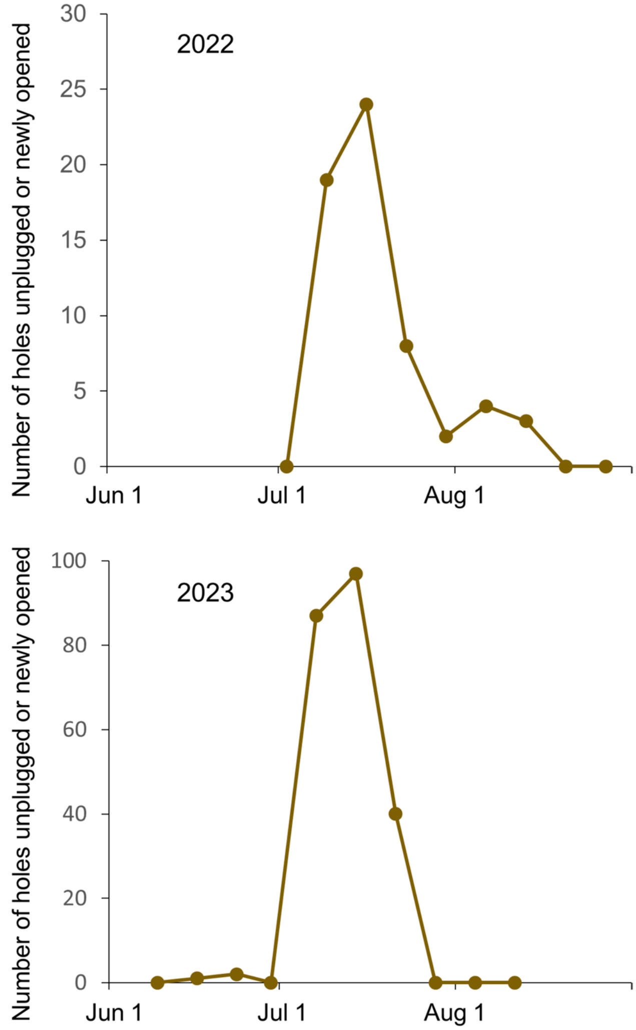


Fig. 1 Number of putative *Apriona swainsoni* emergence holes from which floral foam plugs were removed. Results of field surveys in a promenade of Sukagawa City, Fukushima Prefecture, in 2022 and 2023 are shown

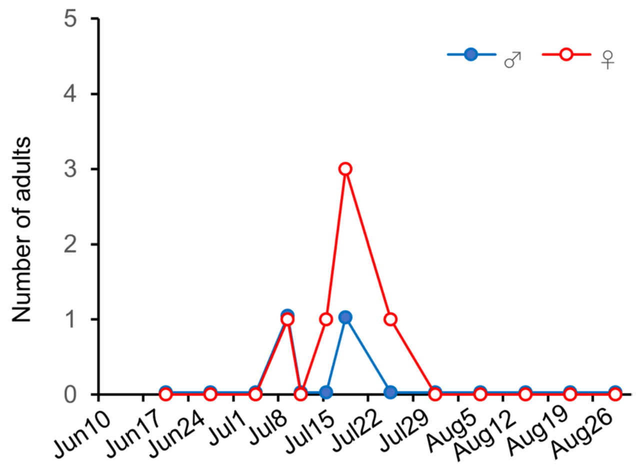


Fig. 2 Number of *Apriona swainsoni* adults detected by visual search in 2022

Additionally, 70 emergence holes were detected in locations where there had been no holes at the beginning.

In both 2022 and 2023, there were no observed organisms other than *A. swainsoni* that removed the plugs. However, ants were sometimes observed entering or coming out of the holes. In that case, they only made small entrance holes in the plugs and did not remove the entire plugs.

Adult emergence in a field cage

Adult emergence from *M. amurensis* logs was confirmed from July 4 to July 18, 2022. In total, 67 individuals—34 males and 33 females—emerged. There was no noticeable difference in the emergence period between the sexes (Fig. 3). For example, both sexes emerged on the first day of adult emergence (July 4). Additionally, the peak emergence dates of July 11–13 were common between sexes. Furthermore, the last emergence dates were almost the same: July 17 for males and July 18 for females.

Body length measurement

Body length was significantly larger in females than in males for both field-collected and log-collected individuals (Welch's t-test, t (39) = −5.5079, $p < 0.001$ and t (55) = −7.78, $p < 0.001$, respectively) (Table 1).

Discussion

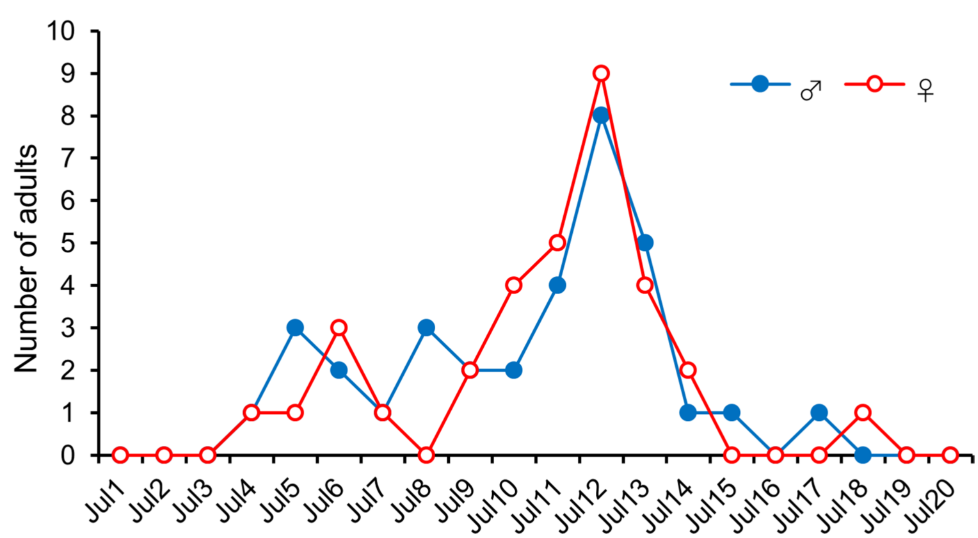
In the field survey, the emergence of *A. swainsoni* adults was assessed by monitoring the fall-off of floral foam plugs from the holes on *M. amurensis* trunks. While it could not be confirmed if all the falling off was caused by *A. swainsoni*, two instances of adult emergence from the plugged holes were directly observed. In addition, there were no observed organisms other than *A. swainsoni* that removed the plugs. Moreover, the observed pattern of plug fall-off, namely, a steep peak in early to mid-July, coincided with those of adult visual search and field cage survey (Figs. 1–3). Therefore,

Table 1 Body length of the sample individuals of *Apriona swainsoni* in Japan

Population	Sex	*n*	Mean ± SD (mm)[a]	Range (mm)
Field-collected	Male	20	31.3 ± 1.5	27.0–33.8
	Female	21	34.8 ± 2.5	27.0–38.7
Log-collected	Male	27	32.9 ± 1.2	30.5–34.9
	Female	30	36.4 ± 2.2	31.1–40.1

[a] Females were significantly larger than males in both field- and log-collected populations (Welch's t-test: $p < 0.001$, respectively)

Fig. 3 Number of *Apriona swainsoni* adults emerged from *Maackia amurensis* logs in a field cage



it is likely that the fall-off of plugs was caused mainly by *A. swainsoni*'s emergence. Only a few individuals were found by visual search, probably due to the intensive catching by collectors (Fig. 2). Therefore, the plug survey may be a more practical method to evaluate the adult emergence of *A. swainsoni* than visual search of adults.

When attempting to evaluate adult emergence by plug survey in future, the following findings should be considered. First, the opening of emergence holes was detected in many unmarked positions. There may have been multiple larvae that opened planned emergence holes after the initial plugging. Furthermore, some planned emergence holes might have been small and overlooked during the initial plugging. Second, there were many holes that remained plugged in 2022. Most of them may have been old emergence holes from which adults exited in previous years, and the exclusion of old emergence holes effectively reduced such invalid holes in the 2023 survey.

Third, plug survey could not distinguish between male and female emergence. However, results of the field cage survey suggest that the emergence period does not differ between sexes and the male-to-female ratio is approximately one:one. In the field, males have rarely been collected (Anzai 2021; Nagahata 2022). Males may be located in the tree canopies and are difficult to find compared to females, which oviposit on lower trunks. Plug survey is better than visual search of adults, as it can detect male and female emergence events equally.

In the field of Sukagawa City, the emergence of *A. swainsoni* was concentrated in early to middle July (Fig. 1) and the results were consistent between 2022 and 2023. However, some differences were also observed between the two years, possibly due to variations in the temperature. Additionally, Saito and Ono (2023) investigated adult emergence from *M. amurensis* logs kept in a field cage within a shaded forestation and found that the majority of emergence occurred from middle July to middle August in 2022. The difference in the emergence period from our study may be attributed to variations in local temperatures (sunny promenade versus shaded forestation) or host condition (standing tree versus felled log). Furthermore, the emergence periods in both Sukagawa and Koriyama were approximately 2 weeks later than those observed in Shandong and the southern provinces of China (peaking at mid- to late June; Duan 2001; Li 2016; Wang 2003; Xiao 1992). This difference in timing might be due to variations in climate and/or host tree species between Fukushima and China. For example, Fukushima (Sukagawa) has a similar latitude to Shandong. It also has a slightly lower temperature than Shandong (13.4 °C vs. 14.9 °C; mean annual temperature of 1991–2020) (Japan Meteorological Agency 2023). The cooler climate of Fukushima may slow down the development of *A. swainsoni* larvae and pupae, resulting in the later emergence of adults than in the native range. Further studies are needed to clarify the effects of environmental factors on *A. swainsoni*'s emergence period. In China, adults of *A. swainsoni* have a lifespan of up to 65–80 days (Duan 2001; Wang 2003; Xiao 1992). In Fukushima, many female adults were observed laying eggs on *M. amurensis* until September (Nagahata 2022), suggesting that they also live for a considerable period, similar to their counterparts in China.

In the native population of *A. swainsoni* in China, body length is 31.98 ± 2.86 mm for males and 36.76 ± 2.57 mm for females (Duan 2001). This study shows that the invasive population in Japan is of a similar size. Saito and Ono (2023) also reported similar measurements for 48 individuals collected from a single facility in Koriyama City. These results suggest that *M. amurensis* is an equally suitable host for *A. swainsoni* development as its hosts in the native range.

In summary, *A. swainsoni* in the introduced area of Fukushima creates planned emergence holes and adults exit from there around early to mid-July. Our results suggest that control efforts to suppress *A. swainsoni* adults in the field, such as insecticide spraying, should be prioritized in the relatively short, peak emergence period. This work showed that the plug survey developed during this study is useful for detecting this emergence period. Further research is required to investigate adult reproductive behaviors and larval life histories to gain a comprehensive understanding of the entire biology of *A. swainsoni* in the introduced area.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s13355-023-00859-0.

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Data availability Raw data are available from the corresponding author on reasonable request.

Declarations

Conflict of interests The authors have no relevant financial or non-financial interests to disclose.

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