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An Investigation of the Field Occurrence of *Philus antennatus* (Coleoptera: Vesperidae), a New Pest of Citrus in Pomelo Orchards in Taiwan

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ABSTRACT

Philus antennatus (Gyllenhaal) a long-horned beetle, has become a new pest on citrus, especially pomelo, in Madou District in Southern Taiwan. The adults are nocturnal, and the larvae feed on the roots of the pomelo tree, weakening and eventually killing the tree. This field study was carried out to investigate the seasonality of the larvae and adults of *P. antennatus* in order to develop a sustainable control for this pest. In a pomelo orchard in Madou 16 quadrats were laid out, each quadrat measuring 100 × 60 cm. Then the number of larvae and pupae from each quadrat were recorded. There were 12.6 larvae/quadrat in the Madou pomelo orchard. The adult female (0.760 ± 0.124 g) was significantly larger and 2.9 times heavier than the male (0.259 ± 0.061 g). We studied the adult emergence pattern in three orchards in Zhuanjing, Nanshih, and Beishih townships, all within Madou District, from 2004-2006. Each year the adult emergence peak was recorded to be in late May. The highest adult density was 7977 individuals in the Zhuanjing orchard (0.23 ha.) in 2004, and the lowest was 1713, in the Beishih orchard (0.46 ha.) in 2005. Understanding the fluctuations of the number of these beetles and the ecology of their larvae provides additional information to control them.

Key words: *Philus antennatus*, long-horned beetle, citrus, larvae, adult, population density

Introduction

Madou Wentan (*Citrus grandis* Osbeck cv. Matou Wentan) is a popular variety of pomelo in Taiwan. This fruit is produced in the Madou district in southern Taiwan and is harvested in early September. It is a preferred fruit for family reunions during the Chinese moon festival, a festival that usually falls during the second or third week of September. In recent years, the pomelo tree has been subjected to damage by the long-horned beetle *Philus antennatus* (Gyllenhaal) (Coleoptera: Vesperidae) (Lin *et al*., 2004, 2005). The grubs infest the roots of the Madou Wentan tree and affect its growth. Reduced fruit yield and eventually the death of the pomelo tree have been recorded where control measures were not adopted in time (Lin

et al., 2004).

P. antennatus is widely distributed in China (Fujian, Guangdong, Guanxi, Hainan, Hobei, Hong Kong, Hunan, Jiansu, Jianxi, Shanxi and Zhejiang), India and Taiwan (Yin, 1994, Lin *et al*., 2004), and infests citrus, tea, mulberry, and pine (*Pinus elliotti*, *P. taeda*, *P. masoniana*) (Chiang and Chen, 1996). The subterranean larvae feed on the fibrous roots of the host plant. It is also proven to be a pest that damages pine trees in China (Yin, 1996).

It was not until 2002 that this insect started causing economic damage to pomelo orchards in Taiwan. The outbreaks, resulting in a decline in tree vigor and a reduction of fruit yield in some orchards became obvious in Madou District in 2003 (Lin *et al*., 2004). This insect has now proven to be an endemic pest that needs to be controlled. The adult is nocturnal and emerges from the soil during the night from May to June (Lin *et al*., 2004, 2005). The adult beetles mate immediately after emerging from the soil. The females lay their eggs at night in cracks of the pomelo bark, and the larvae bore into the soil immediately after hatching. The larvae feed on the root system of the pomelo tree, thereby damaging all fibrous roots, leaving only the main root intact. This weakens, defoliates, and eventually kills the tree. The larvae develop from a 3 mm size in the first instar to a size of approximately 20 mm at maturity. A female adult can lay over 500 eggs in the cracks of bark or in soil. The eggs hatch within 7 days (Lin *et al*., 2004). As a result, a high larval population can be build up quickly, capable of severely damaging an entire orchard.

Although *P. antennatus* causes heavy economic losses, little information beyond laboratory studies is available on the biology of this insect. We conducted a field survey to determine the occurrence of *P. antennatus* in three Madou Wentan orchards during 2004-2006. The data collected in the first two years was briefly presented in Lin *et al.* (2005). The present article reports new information extracted from the analysis of that data combined with the information obtained from the data in all three years, so as to refresh the data gained from the first two years. The aim of this study was to generate more information on the ecology of this pest in order to enable the development of an effective management strategy.

Materials and Methods

Survey of larvae

A pomelo orchard of 0.2 ha was selected in Madou District in southern Taiwan. Sixteen quadrats of 100 × 60 cm each were laid out at random to survey the larvae of *P. antennatus* in February and March, 2005. The soil in each quadrat was carefully turned over in order to check for the presence of larvae. The habitat depth of each larva found was measured and noted. Some larvae were killed during the turning over process, but the ones that remained intact were put in individual numbered vials and brought to the laboratory. Larval weight, body length, and head capsule width were recorded. Those data were then plotted on a scatter plot and were then analyzed by linear regression and correlation analysis, respectively (SAS, 1999).

Survey of the adults

In 2005, *P. antennatus* adults were collected between 7 to 10 pm each day during May and June, their normal period of emergence (Lin *et al*., 2004). Female beetles mostly walked on the ground at night. Although many male beetles would fly, many were also found walking on the ground. We collected adults by hand and placed them into individual vials to bring them back to the laboratory in order to measure their body weight, width, length and sex. The data of their body weight, width, and length were analyzed for each sex using the ANOVA (Proc GLM, SAS Institute 1999).

Study of the Fluctuation in Emergence

White-light lamps of 13 W were set at a height of 50 cm above ground level. A plastic container (60 cm in dia.) half filled with water was placed under each lamp in three of the Madou Wentan orchards in order to determine the number of emerging adult beetles. Each day, the lamps were turned on at dusk and turned off the next day after sunrise. The number and sex of adult beetles collected the next morning were recorded consecutively from May 1 until June 15 during 2004, 2005 and 2006.

The location, acreage, and the number of lamps used at the three Madou Wentan

orchards were as follows: Zhuanjing orchard (TM2 173746.1380, 2563889.6977), 0.23 ha, 6 lamps; Nanshih orchard (TM2 174324.2333, 2565659.2213), 0.18 ha, 6 lamps; Beishih orchard (TM2 173329.7434, 2565577.7419), 0.46 ha, 10 lamps.

Results

Larval survey

In the first set of surveys carried out on February 23, March 10, and March 17, 2005, a total of 194 larvae including 49 injured ones were found in elliptical oval cells (Fig. 1). The depth of the larval cell, larval weight, body length, and body width on each survey date are shown in Table 1. The weight of the smallest larva was 0.073 g with a body length of 10.1 mm; the weight of the largest larva was 1.587 g with a body length of 28.9 mm. The ratio of the standard error over the mean for each measurement at all three survey dates was always less than 0.1, mostly 0.05 or less. The only exceptions were the observations made on February 23, when it was almost 0.1. This implies that the larvae found in the survey were all from the same brood.

Fig. 1. The larva of *P. antennatus* compresses the soil to form an elliptical oval cell and then lives inside this cell.

The larvae in the orchard grew well; their body length and head width were significantly correlated to their body weight, with r = 0.93 and 0.85 (n = 145), respectively (Fig. 2). Larvae were found from 2.5 cm to 45 cm below the soil surface. The inhabiting depth was not related to body size. Larger larvae did not bore deeper than smaller ones and vice versa (Fig. 3).

In 2005, in the laboratory, a few larvae pupated and emerged as adults. These larvae were collected on March 10 and March 17. The females weighted on average 1.2 g (range: 0.95-1.59), with a body length of 23.72 mm (range: 21.59-27.01) while the males weighted on average 0.61 g (range: 0.48-0.76); with an average body length of 19.5 mm (range: 17.66-21.75). The pupal stage lasted 12-18 days.

Survey of the adults and the fluctuation in emergence

Males were lighter ($F = 732.81$, $p < 0.0001$) in weight and measured approximately one third the length of the females. Adult females, besides being significantly longer ($F = 512.05$, $p < 0.0001$), were also wider ($F = 437.11$, $p < 0.0001$) than the adult males. In either sex, the individuals with a larger body length were also heavier (Fig. 4).

The peak for emergence for *P. antennatus* adults was from the middle of May until early June, varying each year depending on the level of precipitation and other undefined factors. The pattern of emergence was similar among all orchards from 2004 to 2006 (Figs. 5-7). In 2004, adults started to emerge from May 12 until June 10, and the peak emergence was recorded on May 28, 29, 30 for Zhuanjing, Nanshih, and Beishih orchards. In these orchards, 79.13, 43.99, and 56.49% of the beetles, respectively, were collected on these three days. The highest level of adult emergence was recorded in Zhuanjing orchard with 2180 females and 1630 males emerging on the three peak days. A total of 7977, 2871, and 14028 beetles were caught at Zhuanjing, Nanshih, and Beishih orchards, respectively; of which 4448, 1205, and 7101 beetles, were females respectively (Fig. 5).

In 2005 emergence commenced in early May, and peaked during the third and fourth week of May and then tapered off (Fig. 6). From a total number of 8785, 3393 and 1731 adults caught in the Zhuanjing, Nanshih, and Beishih orchards, only 5158, 876, and 318 were females respectively, resulting in a sex ratio of 1.42, 0.35, and 0.23 (♀:♂) respectively, or a combined sex ratio of 0.84 for the beetle population in those 3 orchards.

In 2006 the adult beetle emergence started

Table 1. The depth of the larval cell underground and the weight, length, and width of the larvae of *P. antennatus* found in the soil in quadrats measuring 1 × 0.6 m in a Madou Wentan orchard in 2005

	Depth (cm)	Weight (g)	Length (mm)	Head width (mm)
Feb. 23 (3, 11, 6, 15)*				
N	33	25	25	25
Mean (range)	13.5 (3-29)	0.7 (0.07-1.5)	20.4 (10.1-28.9)	8.3 (4.1-10.6)
SE/Mean	0.09	0.11	0.04	0.03
Mar. 10 (5, 10.8, 5, 18)*				
N	47	48	48	48
Mean (range)	10.2 (4-20)	0.8 (0.2-1.6)	20.7 (14.5-27.0)	8.45 (5.9-10.6)
SE/Mean	0.06	0.05	0.02	0.02
Mar. 17 (8, 14.25, 3, 31)*				
N	114	72	72	72
Mean (range)	18.3 (2.5-45)	0.8 (0.3-1.6)	20.5 (14.3-28.4)	8.2 (6.2-10.6)
SE/Mean	0.04	0.05	0.02	0.02
Total				
N	194	145	145	145
Mean (range)	15.5 (2.5-45.0)	0.8 (0.1-1.6)	20.6 (10.1-28.9)	8.3 (4.1-10.6)
SE/Mean	0.04	0.05	0.01	0.01

*: number of quadrats surveyed, mean, minimum, and maximum number of larvae found per quadrat

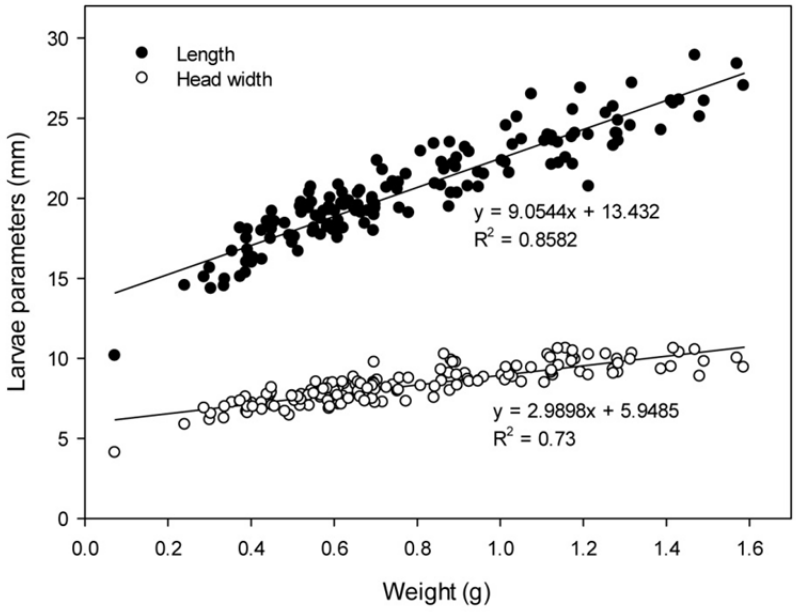

Fig. 2. Linear regression of body length and head width to body weight of the larvae found in the survey of the quadrats.

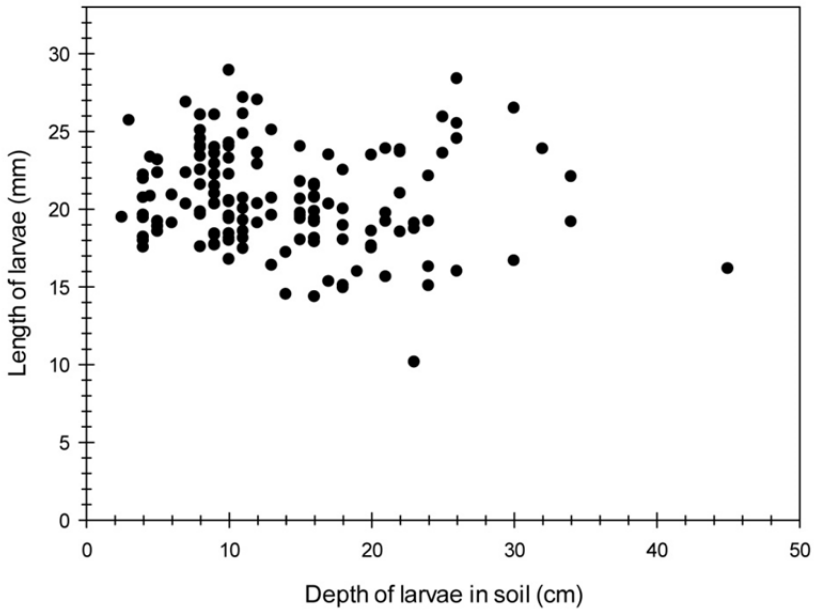

Fig. 3. The relationship between habitat depth and body length of the larvae of *P. antennatus* found in the soil in the Madou Wentan orchard.

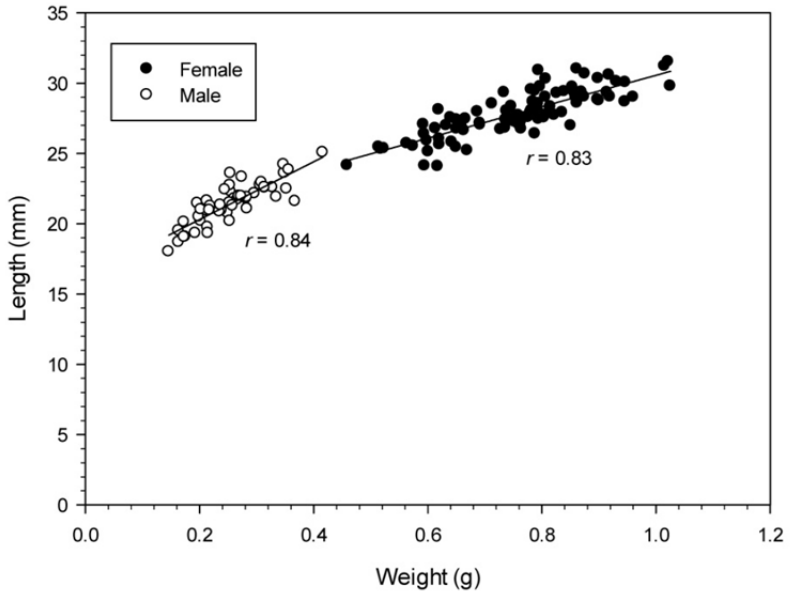

Fig. 4. The relationship between body length and weight of the adult beetle of *P. antennatus*.

on May 7 and ended on June10 (Fig. 7). There were two peak-emergence patterns, first a smaller peak was recorded on May 11 and 12 May, and a larger second peak was recorded around May 25, which was different from the single peaks observed in 2004 and 2005. On the night of May 25, 2524 beetles from three orchards (865 females and 1659 males) were caught by light traps. A total of 11028 beetles were caught during the 3-year period with a sex ratio (♀:♂) of 0.43.

Discussion

In 2005, from February 23 to March 10, the average body length and head width of the larvae extracted from the soil increased slightly and then decreased marginally from March 10 to March 17. This was suspected to be due to the fact that some larvae were preparing to pupate

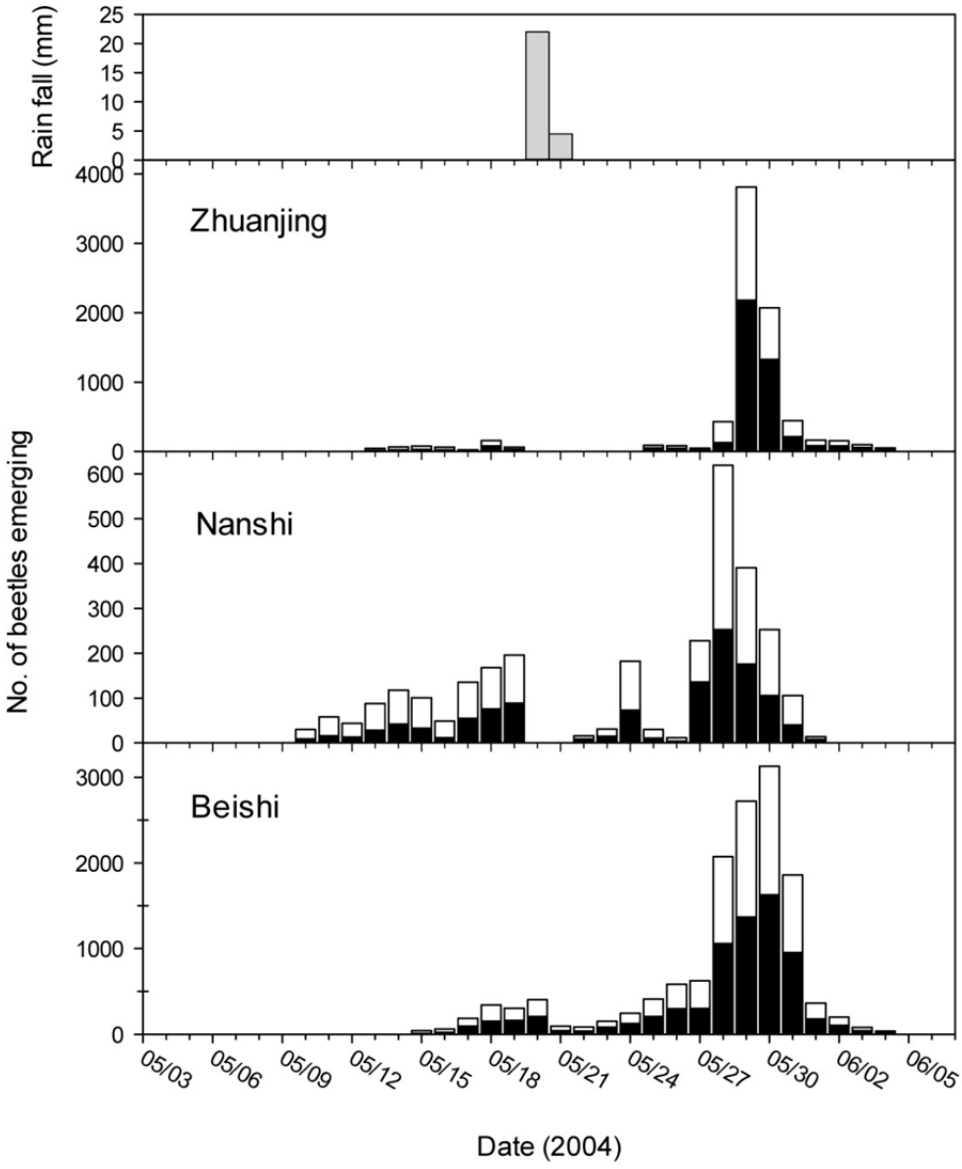

Fig. 5. The daily emergence of adult *Philus antennatus* in three Madou Wentan orchards in Madou in 2004. Black part: female, White part: male.

(a few larvae were found to be pupating after March 10).

Linsley (1959) classified the larvae of Cerambycidae into eight guilds. Özdikmen (2013) reported a root feeder *Vesperus ocularis* Mulsant & Rey, from Turkey with a biology very similar to *P. antennatus*. Adult beetles are nocturnal and they are easily attracted to light, they can lay a large number of eggs in crevices in the field, and the cylindrical larvae then live in the soil and feed on roots. Their life cycle probably lasts a few years. How long is the life cycle of *P. antennatus*? In 2005 the weight of the larvae collected showed two peaks, on February 23 and March 17 (Fig. 8). These 2 peaks could have been the result from two herds, with the 2 peaks representing the difference between both sexes. Beetle eggs are approximately 3 mm long (Lin *et al*., 2004). In this study, prior to pupation, the mature larvae averaged 23.72 and 19.5 mm in length, for female and male individuals, respectively. However, over 94% of all the larvae were more than 10 mm in length (Fig. 9). Considering that *P. antennatus* is assumed to be univoltine it is doubtful that there is more than one herd of this insect in existence.

An interesting but perplexing phenomenon is the reduction in sex ratio from 2004 to 2006. The survey of the larvae in 2005 showed more males than females as indicated by the higher

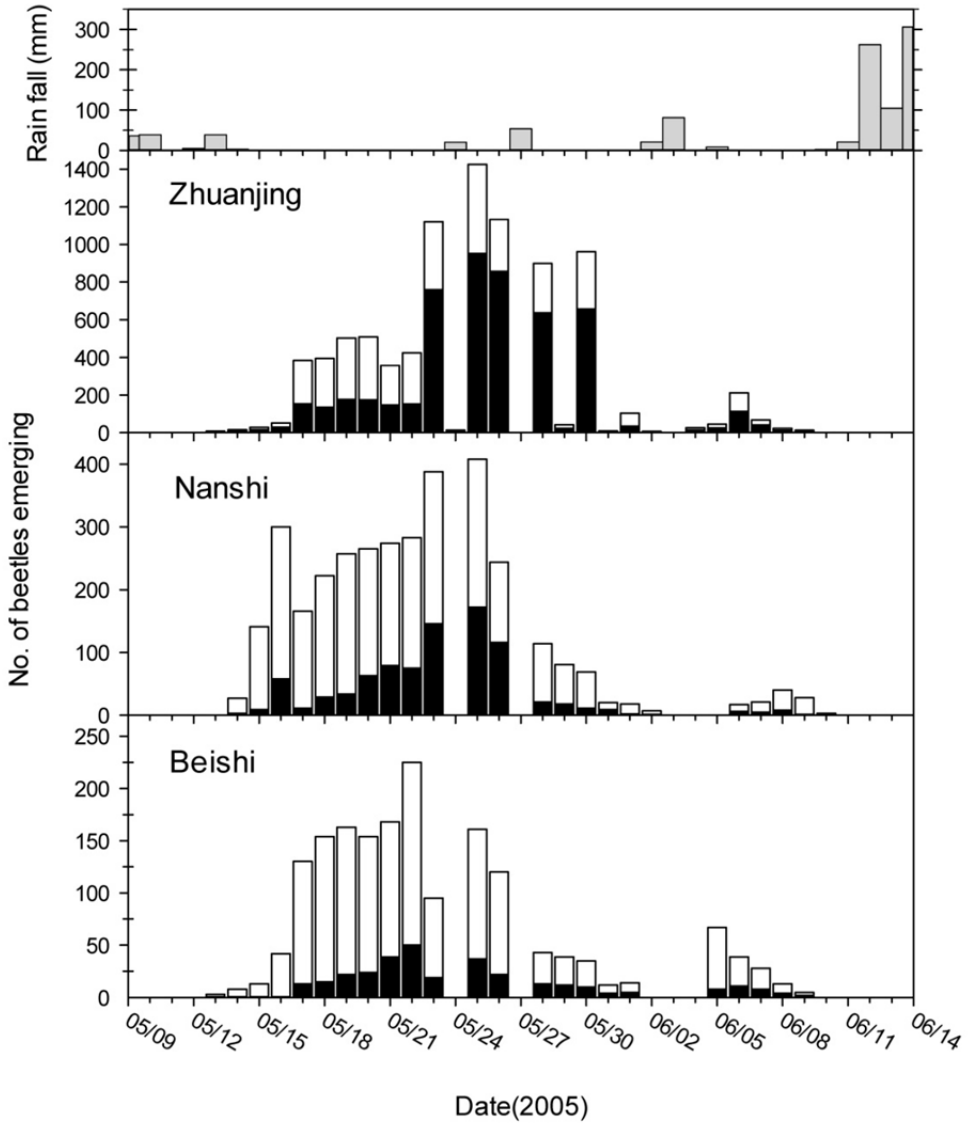

Fig. 6. The daily emergence of adult *Philus antennatus* in three Madou Wentan orchards in Madou in 2005. Black part: female, White part: male.

left peak and lower right peak (Figs. 8 and 9) on March 17 which coincided with the length and weight of pupated male and female larvae. This phenomenon is contrary to what is normally expected and requires further study.

Lin *et al*. (2004) collected 177 *P. antennatus* larvae from the root system of a single Madou Wentan tree. That works out to about 5310 larvae per 0.1 ha of orchard based on a plant density of 30 Madou Wentan trees per 0.1 ha. In this survey, an average of 12.56 larvae per quadrat (100 × 60 cm^2) were found, working out to approximately 20933 larvae per 0.1 ha; a density far greater than that of Lin *et al*. (2004). Infestations by *P. antennatus* larvae in such a high density will severely damage the root system and reduce fruit production. In the three orchards surveyed, thousands of female beetles were caught each year from 2004 to 2006. In an earlier study it was found that a single adult beetle lays an average of 509.3 eggs (Lin *et al*., 2004). The possible volume of eggs that could be laid and the resulting theoretical larval density in these 3 orchards are summarized in Table 2. The actual larval density was, however, much lower than the calculated numbers, as indicated by the number of adult beetles caught by light traps the following year. The possible reasons for this include: (1) The fecundity of female beetles under field conditions might be lower than 509.3, (2) some female beetles migrated to other orchards to oviposit, (3) a low egg hatching

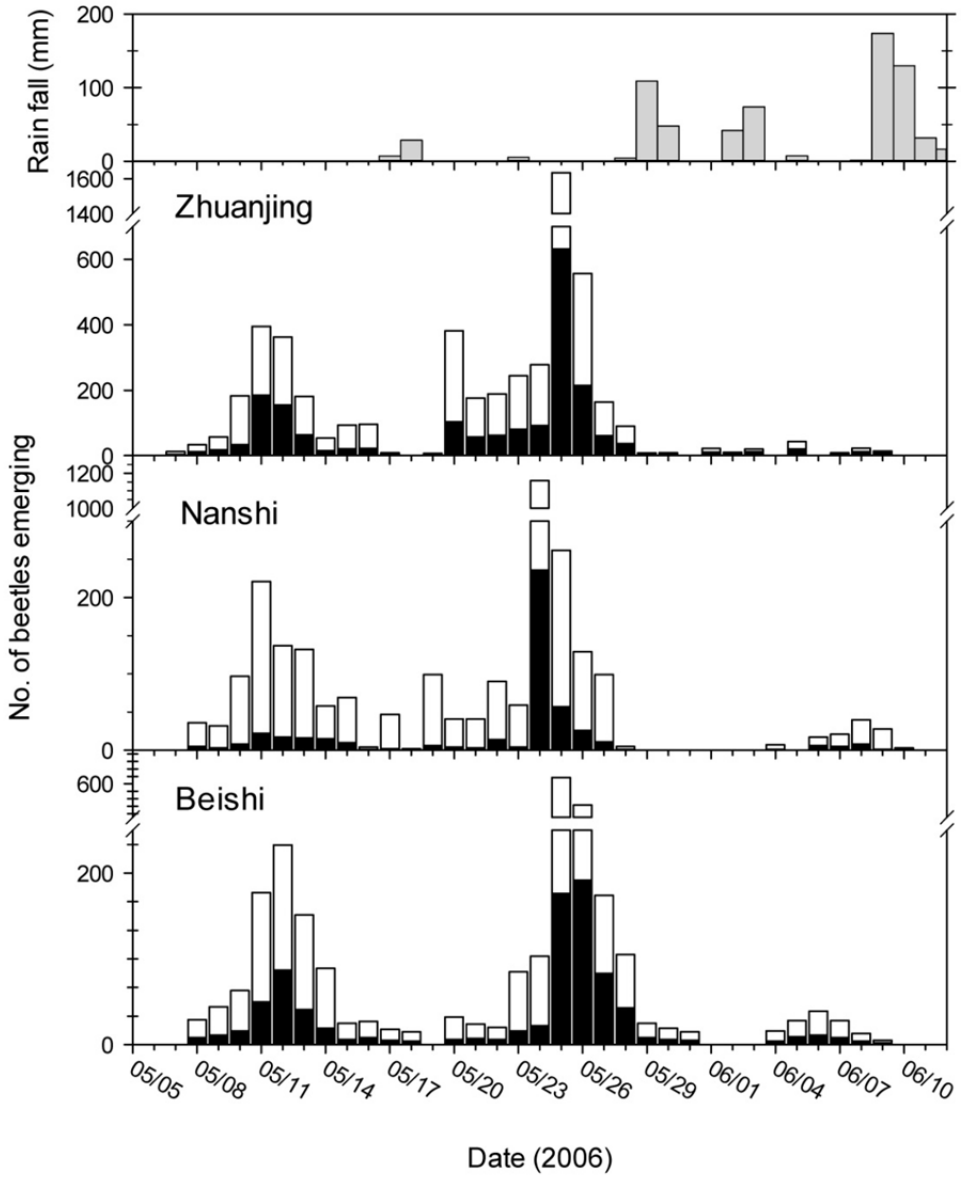

Fig. 7. The daily emergence of adult *Philus antennatus* in three Madou Wentan orchards in Madou in 2006. Black part: female, White part: male.

rate, and (4) a high larval and/or pupal mortality. It was inferred that the larvae collected belonged to the same generation. However, the size and weight of the larvae varied greatly. The larval weights varied from 0.073 to 1.587 g. It is possible that the unusually small larvae failed to pupate.

The trunk-biting, white spotted longicorn beetle, *Anoplophora macularia* (Thomson) is a major pest of citrus in Taiwan (Lee and Lo, 1996; Hwang and Ho, 1994) and eastern Asia (Linsley, 1959). This beetle usually emerges from April to July. Females bite the tree trunk and lay only 1 to 3 eggs inside. The larvae bore into the live citrus tunneling through the phloem and xylem. Only two *A. macularia* larvae per tree can weaken the citrus tree (Hwang and Ho 1994). *P. antennatus* is a new and more serious pest due to its high population density in citrus orchards.

Based on the findings of this study and other research (Lin *et al*., 2004), the biology of *P. antennatus* can be summarized as follows: Larvae start their metamorphosis from March onward. They become inactive, stiff, cylindrical in shape, thorax cuticle wrinkled up, and pupate. The pupae then molt into adult beetles approximately 3 weeks later. The adult beetle remains underground and emerges during May - June. Adults copulate soon after emergence and lay their eggs in one mass in the cracks of

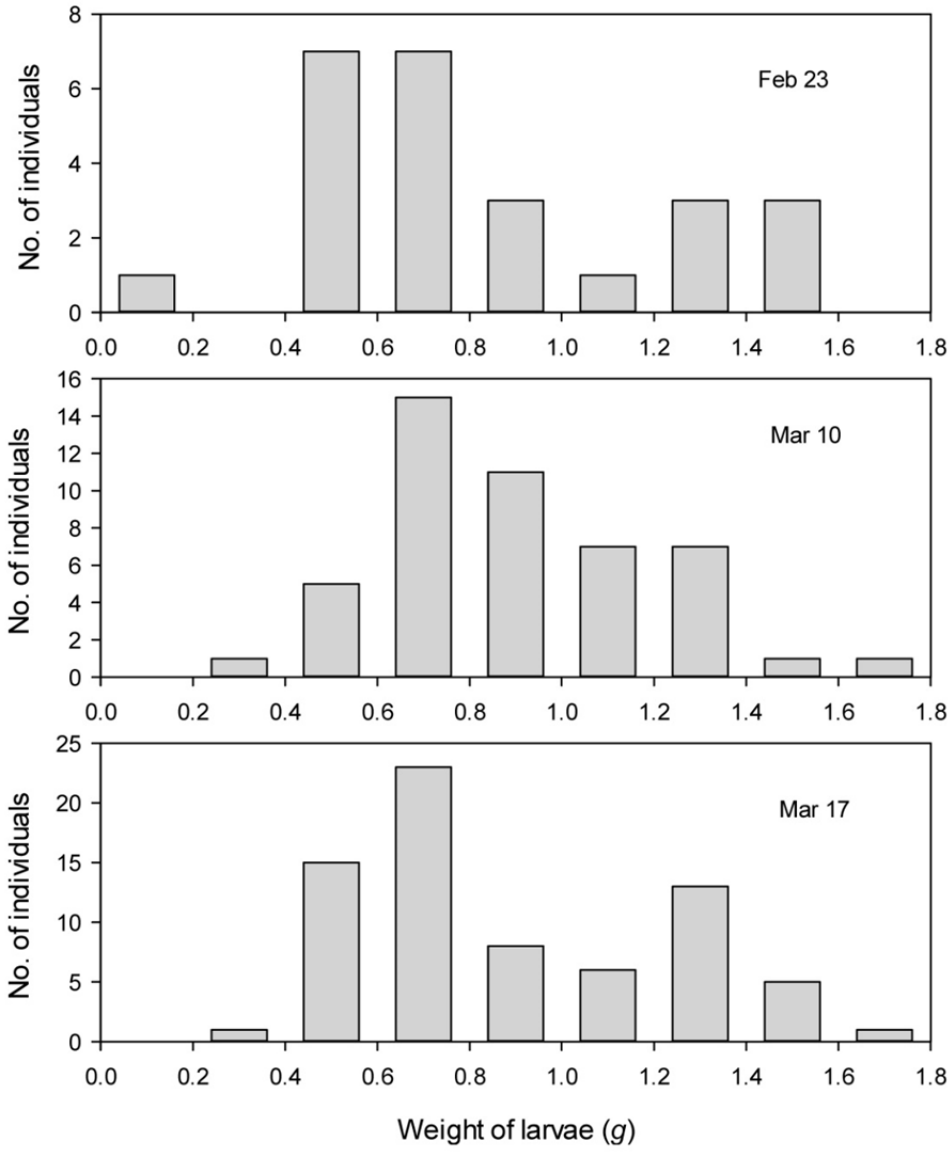

Fig. 8. Frequency distribution of the weight of the larvae found on each survey date in 2005.

the bark of a tree trunk or on a log. Eggs hatch within approximately 7 days. The larvae burrow into the soil that surrounds the root system on which they feed. They then mature and pupate in March and April of the following year. At present the stimuli causing the larvae to metamorphose, the reason for the adult beetles to remain underground after emerging from the pupa stage, and the stimulus evoking the adult beetles to emerge synchronously from the soil remain unknown and requires further study.

Due to the high larval density and the potential severity of the damage that can be caused by the larvae, there is an urgent need to develop an efficient control method for this beetle, preferably an environmental friendly, non-chemical control method. Designing a trap for luring adult females to lay their eggs is almost complete (Chang *et al*., 2015). Meanwhile a survey of effective natural enemies of this beetle is in progress. In addition, understanding the factors responsible for evoking the adult beetles to emerge from the soil might help in developing a control for this beetle.

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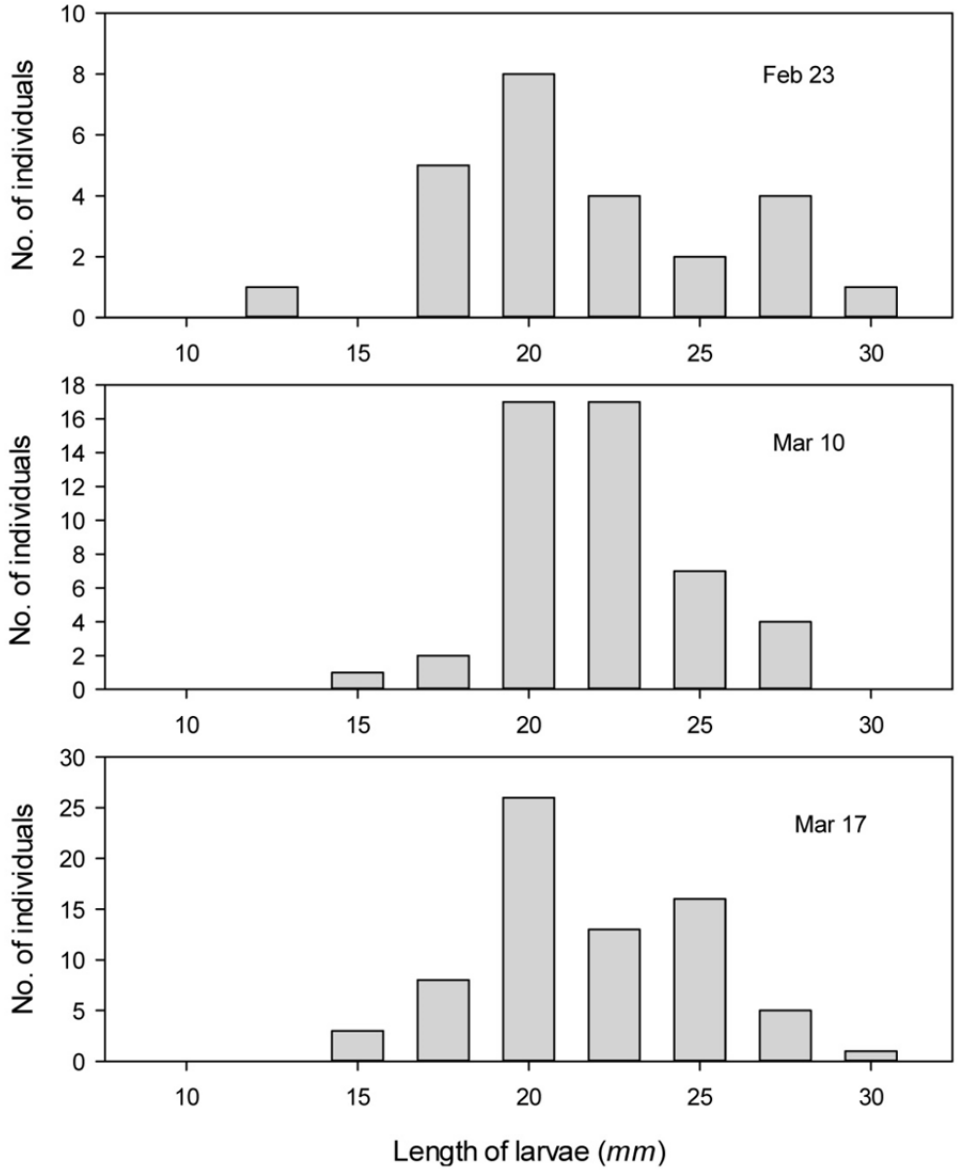

Fig. 9. Frequency distribution of the body length of the larvae found on each survey date in 2005.

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Table 2. Estimated larval density in the 3 orchards surveyed

	Zhuanjing (0.23 ha)			Nanshih (0.18 ha)			Beishih (0.46 ha)		
	2004	2005	2006	2004	2005	2006	2004	2005	2006
No. of females caught	4448	5158	1953	1205	876	480	7101	318	863
Eggs produced (theoretically)*	2265366	2626969	994663	613707	446147	244464	3616539	161957	439526
Theoretic larval density (no./m^2)	984.9	1142.2	432.5	340.9	247.9	135.8	786.2	35.2	95.5

*: The estimated eggs production was based on 509.3 eggs per female

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臺灣柑橘新害蟲-柑橘窄胸天牛（鞘翅目：舊天牛科）之田間發生研究

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摘　　要

柑橘窄胸天牛（*Philus antennatus* (Gyllenhal)）是柑橘類果樹的新害蟲，特別是在麻豆地區的柚類果樹造成嚴重的為害。成蟲夜行性，幼蟲土棲，取食柚樹的根，造成植株的生長勢衰弱甚至死亡。本研究主要是進行幼蟲及成蟲之田間調查，以利研擬後續進行防治的策略。在臺南麻豆地區一處約 0.2 公頃的文旦園進行取樣調查，共調查 16 個樣方，每個樣方為 100 × 60 cm^2，挖掘調查土中幼蟲及蛹之數量。調查結果幼蟲平均密度每樣方 12.6 隻幼蟲。雌成蟲（0.760 ± 0.124 g）體型顯著地大於雄成蟲，體重為雄成蟲（0.259 ± 0.061 g）的 2.9 倍。2004~2006 連續 3 年在麻豆區磚井里、南勢里及北勢里 3 處文旦園，進行成蟲羽化時期及數量調查，成蟲羽化的高峰期集中在每年 5 月下旬。此 3 年的結果，以 2004 年在磚井里（0.23 ha）之文旦園捕捉到 7977 隻為最高，2005 年於北勢里（0.46 ha）捕捉到 1713 隻為最低，掌握其羽化高峰期將有助於對此蟲進行防治管理。本研究顯示柑橘窄胸天牛在文旦園的發生密度極高，可造成嚴重危害，研發有效的防治方法有其必要性。

關鍵詞：柑橘窄胸天牛、天牛、柑橘、幼蟲、成蟲、族群密度