Research paper

How Fecund is *Lymantria xylina* Swinhoe (Lepidoptera: Lymantriidae) in Taiwan?

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【Summary】

The casuarina moth *Lymantria xylina* is one of the most damaging pests in the casuarina windbreaks of Taiwan proper and on surrounding islands. This study aimed mainly to understand the fecundity of the casuarina moth, geographical variations in fecundity and in measurements of the egg mass, and the impact of egg parasitoids on the fecundity of this species. In total, 360 egg masses were collected from 12 casuarina plantations along the west coast of Taiwan and on Penghu Island. The number of eggs laid by the female casuarina moth varied from 180 to 1544 per egg mass, with an average of 592.5 ± 213.8. The mean number of eggs per mass varied significantly among sites. The average length of egg masses was 36.2 ± 10.3 mm, and the average width of egg masses was 9.3 ± 1.8 mm. The size of egg masses also varied significantly between sites. The longer the egg mass was, the wider the egg mass was, and the greater number of eggs there were per mass. However, longer egg masses were narrower, while shorter egg masses were wider. Egg masses on larger branches had more eggs. About 1/3 (122/360) of the collected egg masses were attacked by the egg parasitoid, *Ooencyrtus kuvanae* (Hymenoptera: Encyrtidae). A total of 855 egg parasitoids emerged from these 122 parasitized egg masses. The average number of egg parasitoids emerging per mass was 7.1 ± 6.0. No significant difference in the number of egg parasitoids was found among sites on which more than 10 parasitized egg masses were found. The low rate (0.4%) of egg parasitization by *O. kuvanae* in this study is discussed. However, the real impact of *O. kuvanae* on the fecundity of casuarina moth and the potential usefulness of *O. kuvanae* to control the casuarina moth in Taiwan require further evaluation.

Key words: casuarina moth, *Lymantria xylina*, egg mass, fecundity, *Ooencyrtus kuvanae*.

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研究報告

臺灣的黑角舞蛾(鱗翅目:毒蛾科)繁殖力有多高?

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摘　要

黑角舞蛾是臺灣本島及其周圍小島為害木麻黃防風林最嚴重的昆蟲之一。本研究之目的在於瞭解黑角舞蛾繁殖力及其卵塊測量值之地理變異，以及卵寄生蜂對黑角舞蛾繁殖力的影響。本研究在臺灣本島西海岸及澎湖等12個防風林總計採集360個黑角舞蛾的卵塊。卵塊之含卵數自180至1,544粒不等，平均為592.5 ± 213.8粒。十二個地點間的卵塊含卵數有顯著差異。卵塊平均長度為36.2 ± 10.3 mm，平均寬度為9.3 ± 1.8 mm。十二個地點的卵塊大小也有顯著差異。卵塊愈長、愈寬，其中所含的卵數愈多；但是愈長的卵塊愈窄，而愈短的卵塊則愈寬。卵塊附著其上的枝條愈粗，卵塊中的卵粒愈多。大約1/3(122/360)的卵塊受到大蛾卵跳小蜂（膜翅目：跳小蜂科）的寄生。這122個被寄生的卵塊總計羽化855隻大蛾卵跳小蜂。每卵塊平均羽化7.1 ± 6.0隻卵跳小蜂（範圍1-33）。從被寄生卵塊超過10個的6個地點來看，各地卵塊羽化的大蛾卵跳小蜂平均數量並無顯著差異。本文討論了大蛾卵跳小蜂的寄生率0.4%偏低的可能原因。然而，大蛾卵跳小蜂對黑角舞蛾繁殖力的實際影響為何，以及將之作為生物防治之用的潛力如何，仍有待進一步加以評量。

關鍵詞：黑角舞蛾、卵塊、繁殖力、大蛾卵跳小蜂。

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INTRODUCTION

Since its first introduction in 1897, casuarina has been planted extensively in Taiwan. By 1959, casuarina plantations made up 83.8% of coastal windbreaks in Taiwan (Chen et al. 1998). Even today, casuarina plantations still dominate the coastal windbreaks of Taiwan, although statistics on the present extent of casuarina windbreaks are not available (Chen et al. 1998).

Among many insect pests of casuarina in Taiwan, the long-horned beetle *Anoplophora macularia* (Coleoptera: Cerambicidae) and casuarina moth *Lymantria xylina* (Lepidoptera: Lymantriidae) are the 2 most serious ones (Kan 1958, Ou 1984). Sonan (1936) was the first to report outbreaks of the casuarina moth in Taiwan. More recent damage by the casuarina moth were recorded by Chang and Weng (1985) and Chao et al. (1996). Chao et al. (1996) also reported that casuarina moths feed on at least 63 species of woody plants in Taiwan. Casuarina moth has also been considered the main pest of casuarina plantations in Guangdong and Fujian Provinces of China (Hsiao 1992). Despite the importance of the casuarina moth, we know little of the population dynamics of this species.

In order to understand the population dynamics of a given species, it is important to obtain data on its fecundity. The fecundity of casuarina moth has not been studied. Mated females of casuarina moth deposit an egg mass after mating usually in May and June in Taiwan. The egg mass of casuarina moth is covered with brownish hairs from the body of the female moth. Therefore it is necessary to collect egg masses and dehair them in order to determine the number of eggs per mass.

In this study, egg masses of the casuarina moth were collected from casuarina plantations at different sites to reveal geographical variations in fecundity. In addition, we determined if length and width of the egg mass could be used to predict fecundity. Correlations between the diameter of branches on which egg masses were placed and each of the egg mass measurements were tested to understand their relationship. Finally, we measured percent parasitism by egg parasitoids on the casuarina moth.

MATERIALS AND METHODS

Thirty egg masses were collected from casuarina plantations at each of the following 12 sites (Fig. 1): Peitou of Taipei City (台北市北投), Kuanyin, Neihai, and Chuwei of Taoyuan County (桃園縣觀音、內海、竹圍), Taichung Harbor of Taichung County (台中縣台中港), Hsinchi and Chuanghsing of Chunghwa County (彰化縣新吉、全興), Shihu of Yunlin County (雲林縣四湖), Aoku and Tungshih of Chiayi County (嘉義縣鰲鼓、東石), Chiukuaitso of Tainan County (台南縣九塊厝), and Penghu Island (澎湖). Egg masses from Peitou, Shihu, and Penghu were collected during a period from June 8 to 28, 1995. The remaining egg masses were collected from September 20 to 22, 1995 (Table 1). Coordinates of each site were recorded using a Global Positioning System (GPS, Trimble Navigation, USA) and then plotted on a map (Fig. 1) generated from ArcView GIS (Geographical Information System) vers. 3.02.

Length and width of the egg masses, and width of the branch on which the egg mass was placed were measured. Measured egg masses were then individually placed into sealed polyethylene bags (120 × 8.5 × 0.04 mm) so that the timing and number of egg parasitoids emerging from each egg mass could be recorded.

After cessation of parasitoid emergence, each egg mass was pressed lightly using our fingers and spread in a petri dish. Dirt and hairs of the egg mass were vacuumed through a sieve (no. 30, mesh size 0.6 mm) that covered the top of the petri dish. The number of eggs in each egg mass was counted after the cleaning process.

Statistical analyses such as ANOVA and subsequent Duncan's Multiple Range Test and correlations of paired variables were performed using CoStat statistical software (CoHort2 Software, Berkeley, CA, USA.).

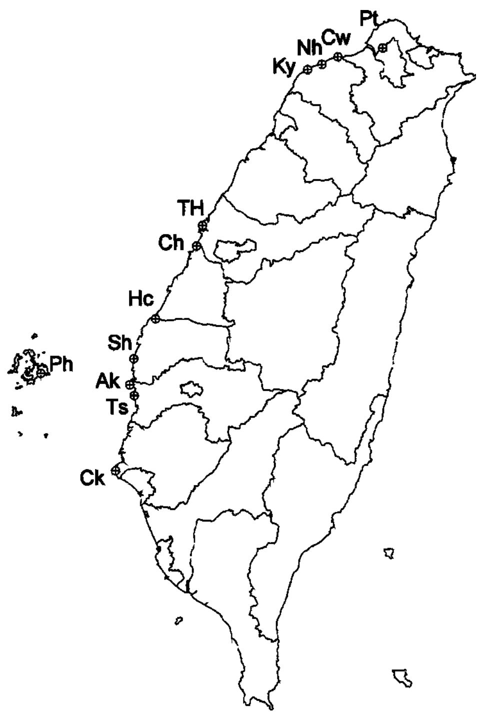

Fig. 1. Twelve casurina plantations where 360 egg masses of casuarina moth *Lymantria xylina* were collected (30 egg masses from each site). Pt: Peitou (Taipei City); Ky: Kuanyin (Taoyuan Co.); Nh: Neihai (Taoyuan Co.); Cw: Chuwei (Taoyuan Co.); TH: Taichung Harbor (Taichung Co.); Hs: Hsinchi (Chuanhwa Co.); Ch: Chuanghsing (Chunghwa Co.); Sh: Shihu (Yunlin Co.); Ak: Aoku (Chiayi Co.); Ts: Tungshih (Chiayi Co.); Chiukuaitso (Tainan Co.); Ph: Penghu Island.

RESULTS

A. Egg mass measurements

Egg masses of the casuarina moth vary greatly in size and shape, though in general, egg masses are roughly oval in shape. Table 1 lists the average length, width, and number of eggs of 30 egg masses collected from each of the 12 sites. The number of eggs laid by a female casuarina moth varied from 180 to 1544 per egg mass, with an average of 592.5 ± 213.8 (Table 1). There was a significant difference in the mean number of eggs per mass among sites (ANOVA, $F = 11.42$, $p = 0.000$). Table 1 shows that the average number of eggs per egg mass was lowest in Hsinchi of Chunghwa County (410.8 eggs per egg mass) and highest in Neihai of Taoyuan County (777.4 eggs per egg mass). In addition, egg masses collected north of Chuanghsing had more eggs per mass than those collected south of Chuanghsing (Table 1), with the exception of Chiukuaitso.

The average length of egg masses was 36.2 ± 10.3 mm (Table 1, range 16.0 to 93.0 mm), and the average width of the egg masses was 9.3 ± 1.8 mm (Table 1, range 2.9 to 14.7 mm). The size of egg masses varied significantly among sites (for length of the egg mass: ANOVA, $F = 7.1$, $p = 0.000$; for width of the egg mass: ANOVA, $F = 5.8$, $p = 0.000$). The longer the egg mass was, the greater number of eggs per mass ($r = 0.62$, $p < 0.000$, Table 2). Similarly, the wider the egg mass was, the greater number of eggs per mass ($r = 0.48$, $p < 0.000$, Table 2). However, longer egg masses were narrower, and shorter egg masses were wider ($r = -0.11$, $p = 0.03$, Table 2).

Table 1. Mean length, width, and egg number of 360 egg masses of casuarina moth (*Lymantria xylina*) and mean diameter of branches (Br. diam.) on which these egg masses were placed. Percentage of egg masses parasitized and the number of parasitioids emerging are also included. Thirty egg masses were collected from casuarina plantations at each of the following 12 localities in 1995. See Fig. 1 for details of localities

Locality (Date of collection)	Length (mm)	Width (mm)	Egg number (range)	Br. diam. (mm)	Egg masses parasitized (%)
Peitou (June 13)	39.8^{a}	8.6^{c}	706.6^{abc} (353-1095)	3.0^{c}	0 (0/30)
Chuwei (Sept. 22)	38.8^{ab}	9.7^{ab}	617.8^{cd} (354-924)	4.6^{ab}	3.3 (1/30)
Neihai (Sept. 22)	40.3^{a}	10.4^{a}	777.4^{a} (363-1298)	4.8^{ab}	90.0 (27/30)
Kuanyin (Sept. 22)	38.0^{abc}	9.5^{abc}	607.4^{cd} (316-888)	4.0^{b}	33.3 (10/30)
Taichung Harbor (Sept. 21)	41.5^{a}	8.6^{c}	596.4^{de} (214-1544)	3.1^{c}	70.0 (21/30)
Chuanghsing (Sept. 21)	41.5^{a}	10.4^{a}	729.1^{ab} (357-1227)	4.6^{ab}	76.7 (23/30)
Hsinchi (Sept. 21)	28.5^{d}	9.2^{bc}	410.8^{f} (209-753)	4.2^{b}	53.3 (16/30)
Shihu (June 8)	29.2^{d}	8.6^{c}	414.3^{f} (180-792)	4.5^{ab}	0 (0/30)
Aoku (Sept. 20)	33.1^{cd}	9.4^{bc}	543.2^{de} (281-829)	4.4^{ab}	6.7 (2/30)
Tungshih (Sept. 20)	37.4^{abc}	8.9^{bc}	583.3^{de} (299-963)	3.9^{b}	73.3 (22/30)
Chiukuaitso (Sept. 20)	32.9^{cd}	10.3^{a}	629.9^{bcd} (261-1057)	5.2^{a}	0 (0/30)
Penghu (June 27-28)	33.7^{bcd}	8.5^{c}	494.2^{ef} (267-772)	4.4^{ab}	0 (0/30)
$\overline{X} \pm SD$	36.2 ± 10.3	9.3 ± 1.8	592.5 ± 213.8	4.2 ± 1.6	33.8 (122/360)

Means followed by different letters within columns are significantly different (Duncan's Multiple Range Test, $p < 0.05$).

Table 2. Correlations of paired variables relevant to measurements of 360 egg masses of casuarina moth (*Lymantria xylina*) collected from 12 sites of Taiwan in 1995. Branch diameter is the diameter of the branch on which the egg mass was placed

	Egg number	Length	Width	Branch diameter
Egg number	—	0.62[3)]	0.48[3)]	0.19[3)]
Length		—	− 0.11[1)]	− 0.15[2)]
Width			—	0.72[3)]
Branch diameter				—

[1)] $p < 0.01$.
[2)] $p < 0.001$.
[3)] $p < 0.0001$.

Table 3. Mean number of the egg parasitoid, *Ooencyrtus kuvanae*, emerging from parasitized egg masses of casuarina moth (*Lymantria xylina*) collected from 8 cauarina plantations along the west coast of Taiwan in 1995

Site	Mean no. of egg parasitoids emerging per mass	No. of egg mass
Chuwei	-	1
Neihai	$8.6^{a} \pm 7.8$	27
Kuanyin	$3.9^{c} \pm 4.3$	10
Taichung Harbor	$4.9^{bc} \pm 3.4$	21
Chuanghsing	$8.6^{a} \pm 6.7$	23
Hsinchi	$7.0^{abc} \pm 5.2$	16
Aoku	-	2
Tungshih	$7.5^{ab} \pm 5.0$	22
Total	7.1 ± 6.0	122

Means followed by different letters within columns are significantly different (Duncan's Multiple Range Test, $p < 0.05$).

B. Branch diameter

The mean diameter of branches on which egg masses were deposited was 4.2 ± 1.6 mm (Table 1, range 1.5 to 10.2 mm). Branch diameter was positively correlated with the number of eggs per mass ($r = 0.19$, $p < 0.000$, Table 2) and egg mass width ($r = 0.72$, $p <$ 0.000, Table 2), and negatively correlated with egg mass length ($r = - 0.15$, $p = 0.003$, Table 2).

C. Egg parasitoids

About 1/3 (122/360) of the collected egg masses were attacked by egg parasitoids (Table 1). These egg parasitoids of casuarina moth, identified by the late Dr. Liang-Yi Chou of the Department of Applied Zoology, Taiwan Agricultural Research Institute, were *Ooencyrtus kuvanae* (Hymenoptera: Encyrtidae). More than 2/3 (68.8%) of the parasitized egg masses came from north of Chuanghsing (Table 1). A total of 855 egg parasitoids emerged from 122 parasitized egg masses (Table 3). The average number of egg parasitoids emerging per mass was 7.1 ± 6.0 (Table 3, range 1 to 33, $n = 122$). Only 0.4% of the total 213,304 eggs in the 360 egg masses were parasitized. There was no significant difference in mean number of egg parasitoids among sites where more than 10 parasitized egg masses were found (ANOVA, $F = 1.86$, $p = 0.11$).

No *O. kuvanae* was found emerging from those egg masses collected in June (from Peitou, Shihu, and Penghu). All emerging *O. kuvanae* came from egg masses collected in September (see Table 1), and the emergence period was from September 26 to October 9. An additional 10 egg masses collected in December at Peitou, Taipei City were all parasitized by *O. kuvanae* (with an average of 12.5 ± 7.6 wasps per egg mass) and 80% of parasitoids emerged during the period from December 12 to 22.

DISCUSSION

Eggs of the casuarina moth are oviposited in several layers and are laid in masses. The egg mass is covered with brown hairs from the body of the female moth. The covering of egg masses of the gypsy moth *Lymantria dispar*, a close relative of the casuarina moth, not only protects the eggs from excessive evaporation, but also renders the egg mass unattractive to some birds (Cooper and Smith 1995). We presume that the covering used by the casuarina moth has a similar function.

An egg mass of gypsy moth may have 100 to 1,000 eggs in US (Cooper and Smith 1995) and 400 to 1,500 eggs in China (Hsiao 1992). Li et al. (1981) stated that the number of eggs per egg mass of the casuarina moth in Fujian Province of China averaged 1019 ± 36 (range 354 to 1517, n = 108). Chang and Weng (1985) reported that the number of eggs per egg mass of casuarina moth in Taiwan ranged from < 100 to < 700, with a mode of 100 to 200. Our data show that few egg masses contained fewer than 200 eggs (see the lower range of egg number in Table 1). The current study used a larger sample size and revealed a greater variation that may more accurately reflect the situation of the real world.

The majority of egg masses of casuarina moth are roughly oval in shape. However, egg masses vary greatly in size. The actual size of egg masses of gypsy moth is a vital statistic for assessing gypsy moth populations. Larger egg masses (more than 500 eggs per mass) indicate a healthy, increasing population, whereas smaller egg masses are characteristics of a decreasing population. The number of eggs per mass can be estimated in the field by measuring the length of the egg mass (Moore and Jones 1987). Our results show that both the length and the width of the egg mass are positively correlated with the number of eggs per mass (Table 2). In other words, width, and especially length, of the egg mass can be used as an indicator of the fecundity and hence the population trend of the casuarina moth.

The length of the egg mass, width of the egg mass, and egg number per mass also correlated significantly with the diameter of the branch on which the egg mass was placed (Table 2). It is interesting to note that the larger the branch on which the mass was placed, the wider the egg mass (r = 0.72, Table 2) and the greater number of eggs per egg mass (r = 0.19, Table 2), but the shorter the egg mass (r = −0.15, Table 2). It seems that on larger branches, egg masses tend to be wider and shorter, while on smaller branches, egg masses tend to be narrower and longer (see Table 2). The oviposition behavior of casuarina moth has not been studied. It would be interesting to test the hypothesis that more-fecund females prefer larger branches for egg laying.

We also found that egg masses of the casuarina moth in Taiwan did have a significant geographical variation in terms of the number of eggs per mass. Our samples showed that, in general, egg masses collected north of Chuanghsing had a higher number of eggs (Table 1, except for Chiukuaitso). This trend may be due to differences in density or differences in the size of branches collected from study sites. The size of egg masses of gypsy moth is affected by population density and food supply experienced by the parental generation (Gerardi and Grimm 1979). In high-density infestations of gypsy moth, most egg masses are located on tree trunks and branches. In low-density populations of gypsy moth, most egg masses are found on the forest floor or on man-made objects. Trees at the edge of a forested stand may have more egg masses than trees at the center of the stand (Nealis and Erb 1993). Unfortunately, neither the location of egg masses nor the population density of casuarina moth was included in this study to understand the causality of variations of egg masses. These patterns seem worthy of thorough investigation in the future.

There are at least 15 natural enemies of the casuarina moth in Taiwan (Chao et al. in preparation). The egg parasitoid *O. kuvanae* is one of the 2 natural enemies that specifically attack eggs of the casuarina moth. About 1/3 of the sampled egg masses were parasitized, and more than 2/3 of the parasitized egg masses were collected from sites north of Chuanghsing (Table 1). The percentage of egg parasitism by *O. kuvanae* is related to the size of the mass, with smaller masses containing more eggs that can be reached by the ovipositors of the parasitoids (Dowden 1961, Leonard 1974). We did not compare the size of egg masses with the percent parasitism of casuarina moth. This deserves further study.

We found that the egg parasitoids did not cause high mortality of the casuarina moth. The fact that only a small portion (0.4%) of eggs were attacked by parasitoids indicates that only eggs of the top layer of the egg mass were subject to attack. The removal of egg masses during sampling also made study of repeated parasitization impossible. Alternatively, the population density of *O. kuvanae* was not high enough to have a strong impact on the mortality of eggs of casuarina moth.

Ooencrytus kuvanae that lives on eggs of gypsy moth produce several generations per year in the US (Dowden 1961, Hitchcock 1972) and 6-7 generations per year in warmer areas of South China, with a generation span of 21-35 days (Yan et al. 1995). Therefore, *O. kuvanae* in subtropical Taiwan could also be multivoltine and be able to parasitize the eggs of casuarina moth repeatedly. The sketchy information we have (1 emergence occurred from late-September to mid-October and another one from mid- to late-December) supports the idea that *O. kuvanae* in Taiwan is multivoltine. Finally, no *O. kuvanae* was found emerging from egg masses collected in June, regardless of geographical location. Therefore, egg masses of the current year may be first attacked (oviposited) by *O. kuvanae* some time in July.

Primarily as an egg parasitoid of the gypsy moth, *O. kuvanae* may play an important role as a biological control agent of this notorious pest species (Brown 1984). In fact, the application of *O. kuvanae* to control gypsy moth on different continents has been proposed (e.g., Bellinger et al. 1988, Yao and Yan 1994). In addition, *O. kuvanae* has been recorded as a hyperparasitoid of 2 parasitoids of *L. dispar* and as an egg parasitoid of at least 14 species of moth, including moths of the Lasiocampidae, Lymantriidae, and Saturniidae (Huang and Noyes 1994). Like that of the gypsy moth, the egg stage of the casuarina moth lasts about 9 months and is vulnerable to parasitization by *O. kuvanae*. The real impact on *O. kuvanae* to the fecundity of casuarina moth and the potential usefulness of *O. kuvanae* to control casuarina moth in Taiwan require further evaluation.

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