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Source: The Journal of the Lepidopterists' Society, 66(3) : 133-136

Published By: The Lepidopterists' Society

URL: https://doi.org/10.18473/lepi.v66i3.a2

Journal of the Lepidopterists' Society
66(3), 2012, 133–136

BEHAVIOR OF *LYMANTRIA LUCESCENS* (BUTLER) (EREBIDAE: LYMANTRIINAE); ESPECIALLY DURING AN OUTBREAK NEAR TOYOTA CITY, HONSHU, JAPAN

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ABSTRACT. *Lymantria (Lymantria) lucescens* (Butler) collections and observations were made at Toyota and Azumino, Honshu, Japan. Larvae are now recorded to feed on Fagaceae (*Quercus*, four species); Ulmaceae (*Ulmus* and *Zelkova*) and Moraceae (*Morus*). During the moth flight (July in Toyota), both sexes (but only 15% females) were attracted to commercial lighting and settled on lit surfaces such as storefronts. Females (wingspan av. 72 mm) carried on average 758 eggs each. Periodicity of male moths responding to either synthetic sex pheromone or to visible lights showed that flight activity peaked between 2000 and 2100 h. Three different larval parasitoids from *L. lucescens* were recovered. *L. lucescens* is discussed in light of attributes favoring its potential invasiveness.

Additional key words: Food plants, fecundity, population outbreak, flight to lighting, potential for invasion, parasitoids.

Lymantria (Lymantria) lucescens (Butler) is considered "rare" and "local" and is distributed on the Japanese islands of Honshu, Kyushu and Hokkaido and in Korea (Inoue 1957; Nam & Kim 1981; Sato 1987, Pogue & Schaefer 2007). In 1997, I targeted *L. lucescens* for an on-going systematic study of sex pheromone communication systems. That effort culminated in the 2000 field season in Toyota City, Aichi Prefecture, Japan (Gries et al. 2002). This season coincided with an apparent rare occurrence—an outbreak of *L. lucescens*. Given this unusual opportunity, I assessed female fecundity, apparent dispersal potential and flight distance, recorded food plants, recovered natural enemies and noted overall behavior. At Azumino (then known as Toyoshina), Nagano Prefecture, I encountered *L. lucescens* as well, and independently, in Ueda, in the same prefecture, Nishio (2000) (cited in error as "Noritaki, 2000" in Pogue & Schaefer 2007) recorded another outbreak location similar to what I experienced. Nishio and I both witnessed localized outbreaks of this usually scarce moth. In concluding, I briefly discuss the behavior of this moth especially with regard to its potential for invasion into new habitats.

METHODS

Late stage larvae of *L. lucescens* were collected from *Quercus* spp. in a forest fragment in the suburban community of Mifune (N 35.14°, E 137.19°) in the outskirts of Toyota City. With assistance from Ban Tanaka (Toyota City) and Yasutomo Higashiura (Tokyo Univ. Pharmacy & Life Sciences, Tochachi), we collected larvae from various oak species, noting the species involved. All larvae within our reach were collected using 4 m pruning pole clippers. We tallied each species captured at the conclusion of our collecting. While other species were released, the collected *L. lucescens* caterpillars were reared on fresh *Quercus* sp. leaves until pupation. Pupae were isolated for eventual emergence (females being used for sex pheromone analysis reported elsewhere (Gries et al. 2002)) and any natural enemies were frozen and then pinned for identification. Only a qualitative assessment of natural enemies was made.

At the time of moth flight in August, we returned for pheromone field tests. During this period, I noted the general flight of moths into Toyota center city, noted their sex, photographed some accumulated adults, and collected specimens. I preserved one series of females from a convenience storefront by placing specimens directly into Listerine® liquid mouthwash, (21.6 % ethanol, Warner-Lambert Co, Morris Plains, NJ) as a temporary preservative. Subsequently, I dissected these preserved females and counted the number of ova per female.

To gain insight into the flight periodicity of *L. lucescens*, at Azumino (N 36.28°, E 137.92°), in 1997 and at several subsequent visits, I recorded the time of arrival at various light sources. At Mifune, I recorded male moth arrival at pheromone traps and at all-night convenience store-front lights. At first light, I revisited several well lit locations and noted and collected from the nightly accumulation of moths.

RESULTS AND DISCUSSION

On May 27–28, 2000, late stage larvae (Fig. 1) were collected in Mifune on *Quercus variabilis* Blume, *Q. serrata* Thunb. ex. Murray, and *Q. glauca* Thunb. A total of 326 *L. lucescens*, 181 *L. dispar japonica* (Motschulsky) and 29 *L. mathura* Moore larvae were collected on the mentioned *Quercus* spp. Often all three moth species were taken from the very same *Quercus* spp. foliage indicating that these moths were all competitors. We previously recorded three *Quercus* spp. as food trees (Gries et al. 2002). On 3 June 2000, at Azumino, I collected *L. lucescens*, *L. dispar*, and *L. mathura* larvae, all on *Quercus acutissima* Carruthers, again competing for the same food source. Nishi (2000) reported further that late instars, in addition to feeding on *Quercus* spp., also fed on *Ulmus davidiana* Planchon, *Ulmus parvifolia* Jacquin, *Zelkova serrata* (Thunb.) Makino (all Ulmaceae), and *Morus bombycis* Koidz. (Moraceae). The known food plants recorded to date appear in plant families Fagaceae (*Quercus*, four species), Ulmaceae (*Ulmus* and *Zelkova*), and Moraceae (*Morus*).

In rearing the collected *L. lucescens* larvae, *Meteorus* sp. (Hymenoptera: Braconidae), *Glyptapanteles liparidis* (Bouche) (Hym.: Braconidae), and *Exorista* sp. (Diptera: Tachinidae) were recovered.

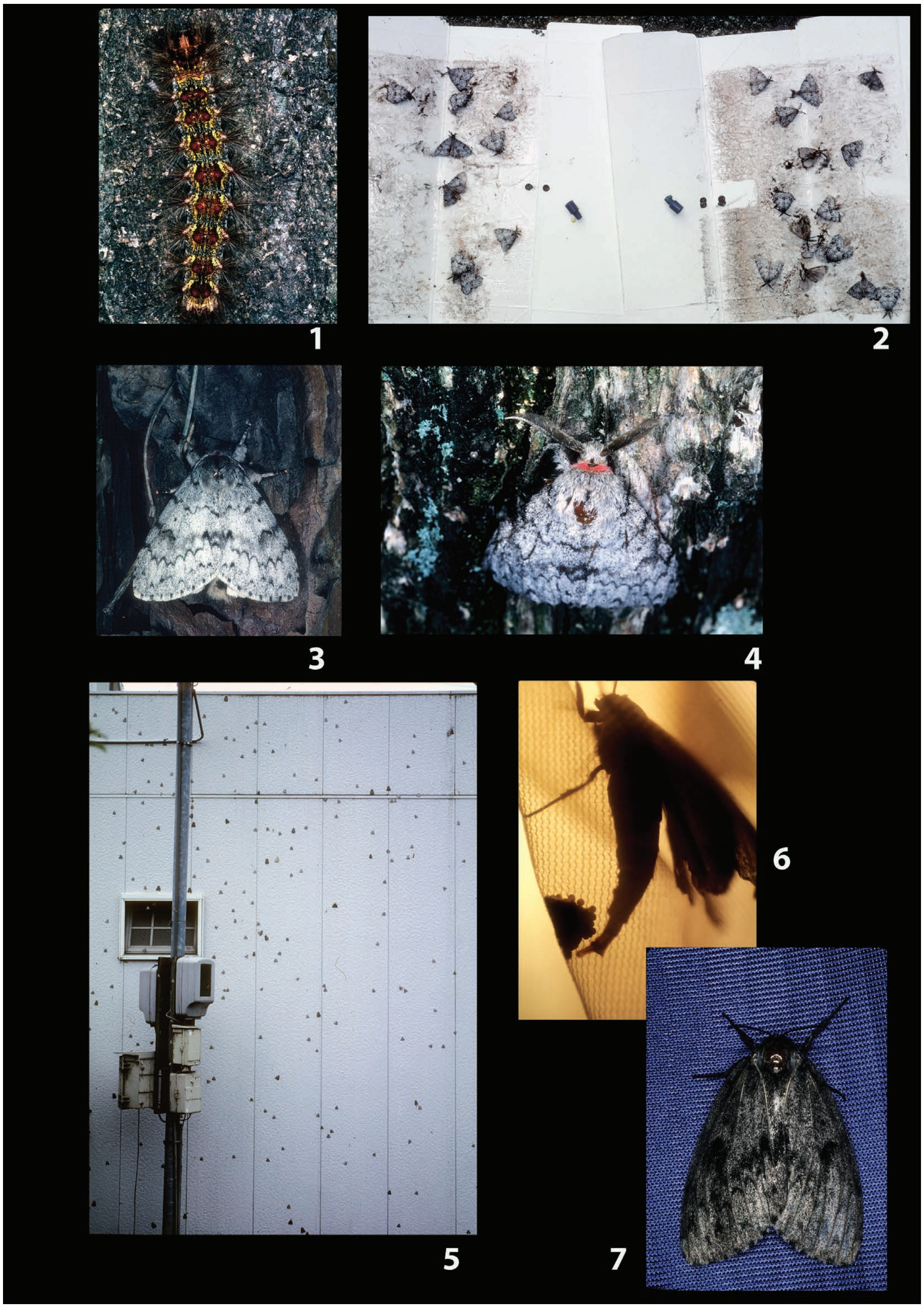
Our main accomplishment concerning *L. lucescens* was the identification of the sex pheromone (Gries et al. 2002). This followed earlier hints of male attraction to a blend we earlier found best for *L. monacha* (L.) (Schaefer & Kishida 1999). This "blend" included the sex pheromone of *L. lucescens* as one of three components, explaining the earlier male captures, however minimal. Availability of the *L. lucescens* sex pheromone has made it possible to survey for this moth or to conduct behavioral studies. Baited Delta-like sticky traps were highly specific and most effective (Fig. 2).

Adult *L. lucescens* males (Figs. 3 and 4) at Azumino responded to blacklight in the early evening hours (Table 1), similar to the time of response to synthetic sex pheromone (Gries et al. 2002), and similar to the arrival of males at convenience store lights (Fig. 5) in Mifune (Table 1). All evidence suggests that males fly during the early evening hours, whether they are responding to synthetic sex pheromone or to lights (either UV, white light, or commercial lighting) (Table 1). During the week (10–17 July 2000), repeated observations at lights near downtown Toyota revealed ca. 85% males vs. 15% females at outdoor lighting at overnight job site lights at the Toyota Stadium (then under construction), on the attractive Yahagi River bridge spanning the river leading from center city to the stadium, and at all-night convenience store lighting (Fig. 5). It remains unknown if this skewed ratio of the sexes was a reflection of the emerging adult sex ratio or whether it might reflect sex differential behavior.

All observations confirmed that moths (fewer females) appeared within center city nightly. Although it was never entirely clear just how far they had traveled, it was apparent they moved some distance to reach center city. Forested areas outside Toyota were < 2 km from center city. However, it was not possible to pinpoint just where the outbreak population had originated. On the night of 12–13 July, assessment of the composition of the moth flight showed that *L. lucescens* predominated (85% males in sample of 182), but that a few specimens of both *L. d. japonica* and *L. mathura* (both sexes) were also in flight. Elsewhere in the Toyota vicinity, we successfully pheromone trapped these latter

TABLE 1. Nocturnal periodicity of *Lymantria lucescens* male flight, based on both attraction to lights and to synthetic sex pheromone baited sticky traps, Honshu, Japan. End = termination of surveillance; Next AM = numbers found when checking the scene soon after dawn the following day. 15 July data also grafted in Gries et al. (2002).

Location:	Mifune	Mifune	Toyota City	Azumino	Azumino
Date:	15 Jul 2000	16 Jul 2000	16 Jul 2000	27 Aug 1997	31 Aug 2000
Method:	Phero. Trap, N=5	Phero. Trap, N=5	Storefront lights	Hg Vap. Light	UV Light
Elevation:	48 m	48 m	48 m	567 m	567 m
Time:					
1900	0	0	0	0	0
1930		0	0	2	1
2000	6	1	18	4	3
2030		15	33	1	4
2100	50	15	28	0	0
2130		5	8	1	0
2200	4	1	13	0	0
2230		4	7	0	0
2300	4	2	5	0	0
2330		2	11	end	0
2400	0	3	end		1
0030		4			0
0100	0	end			end
0130	end				
Next AM	1	12			0
Total:	65	64	123	8	9



FIGS. 1-7: *Lymantria lucescens* Butler, life stages except as noted. **1.** Late stage caterpillar **2.** Males captured in two sticky traps, at Mifune, near Toyota city, on 14 July 2000 after two nights of exposure. Synthetic lure was dispensed by the two respective rubber septa shown near image center. **3 & 4.** Males with latter showing pinkish-red setal collar on pronotum just behind the head. **5.** External wall of a convenience store showing accumulated moths, on the early morning of 13 July 2000. *L. lucescens* predominated but occasional *L. mathura* and *L. dispar japonica* were also present. Total moth count in view was 192 with 81% of these male *L. lucescens*, Toyota city, Aichi Prefecture, Japan. **6 & 7.** Females, with former showing tapered abdomen and telescoping ovipositor used to insert eggs in cracks or under bark scales on tree boles (illustration ex Pogue & Schaefer (2007)). All photos by Paul W. Schaefer.

two species. All three species were coincident in their flight periods although the peak periods for *L. d. japonica* and *L. mathura* appeared to precede that of *L. lucescens*.

Efforts to clarify the periodicity of male moth flight were consistent and illustrated that most flight activity occurred between sunset and 2100 h. (Table 1). Regardless of the method used (i.e. attraction to Hg light, UV light, pheromone baited traps, or arrival at lights of existing storefronts), male activity peaked 2000–2100 h, precisely the same hours reported by Nishio (2000). In all our previous work on sex pheromones (citing two relevant cases (Gries et al. 1999; Schaefer et al. 1999)), we based nocturnal periodicity upon the arrival of males at synthetic sex pheromone baited traps at forests in complete darkness. Here we have evidence that attraction of male *L. lucescens* to both lighting and to a sex pheromone lure coincides.

Fecundity measurements of females (wingspread av. 72.0 mm, S.D. = 3.92) (Figs. 6 and 7) collected at a convenience store at 0445 h on 15 July 2000 averaged 758.0 eggs each (S.D.= 183.5, Max. = 1096, N= 18) when arriving at store lights. It was not clear from my data just when normal mating occurred, however, Nishio (2000) reported mating and oviposition occurred 2000–2100 h. At the time these collections were made, I noted that when disturbed, females would usually raise their wings up over their back, curl their abdomens upward and feign death by remaining motionless for a minute or more. Some others, upon being disturbed, would fly but flew for only a very short, quick flight before promptly re-landing.

Inoue (1957, 1959) had indicated that the *L. lucescens* moth flight is July and/or August. My experiences corroborate this flight period while further illustrating that at the two sites visited (Toyota and Azumino), the respective moth flight periods differed by more than one month's time, likely due to the higher elevation at Azumino (cooler temperatures and slower moth development) than at Toyota (see Table 1). Weather, geography, elevation, and population density (outbreak) are all factors impacting the timing of moth flight.

When compared morphologically to *L. d. japonica*, females of *L. lucescens* possess a very long, tapered ovipositor (i.e. insertion type) (Fig. 6, also in Pogue & Schaefer (2007)), used to insert eggs *en masse* into holes, under bark scales or cracks in tree trunks. Nishio (2000) illustrated one such egg mass. *L. mathura* and *L. lucescens* are similar in this regard, but both species are very unlike that of sympatric *L. d. japonica*, which possess a non-telescoping ovipositor and lay their eggs on the surface of a suitable substrate, often that of a tree bole. With the observed female flight propensity, dispersal capability, egg laying behavior, and larval food plant acceptance, *L. lucescens* possesses attributes that could easily result in eggs being deposited on ship superstructures or on containerized cargo in well-lit seaports or other holding yards. *L. lucescens* might in this way easily invade and establish in oak forests on new continents. One should now be alert to another potentially invasive species and another threat to temperate deciduous habitats (especially oak forests) most anywhere outside Japan and Korea, as first suggested by Pogue & Schaefer (2007).

ACKNOWLEDGEMENTS

I thank Yasutomo Higashiura and Ban Tanaka for larval collection assistance and arrangements that introduced me to the Toyota vicinity moth population. Thanks also to Yasunori Kishida with whom I first went black-lighting for these moths on the hills above Azumino, and to Tadao Gotoh for assistance and for translation of the biological note by N. Nishio. Thanks to my wife Jane Schaefer for improving the photos and to the journal editor and two anonymous reviewers for suggested improvements in an earlier manuscript draft.

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Submitted for publicaton 24 March 2011; revised and accepted 14 January 2012.