Response of Adult Lymantriid Moths to Illumination Devices in the Russian Far East

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ABSTRACT In field studies in the Russian Far East, five types of illuminating devices were evaluated for attracting adult gypsy moth, *Lymantria dispar* (L.), pink gypsy moth, *L. mathura* Moore, and nun moth, *L. monacha* (L.). Our objective was to determine if light from commercial lamps suited to out-of-doors floodlighting could be modified to reduce their attractiveness to moths without a reduction of illumination. During 17 nights of tests, fluorescent blacklight lamps captured significantly more adults than either phosphor mercury or high-pressure sodium lamps. Captures were slightly higher for phosphor mercury than high-pressure sodium lamps but both were unattractive to all three lymantriids after the addition of filters that blocked spectral emissions <480 nm. Daily temporal periodicity, based on adult captures at lights, resulted in distinct activity patterns for the three lymantriids. Peak activity for *L. dispar* was between 2300 and 0100 hours; for *L. mathura,* 0100–0300 hours; and 0300–0500 hours for *L. monacha.* Temporal activity patterns suggest that *L. dispar* and *L. monacha* possess nonoverlapping diel rhythms, whereas *L. mathura* overlaps broadly with both *L. dispar* and *L. monacha.*

KEY WORDS *Lymantria dispar, Lymantria monacha, Lymantria mathura*

THE RECENT INTRODUCTION of the Asian strain of gypsy moth, *Lymantria dispar* L., into North America occurred because gravid females were attracted to lights in Russian Far East ports (Anonymous 1992) where they deposited eggs on ships and cargo. Egg masses subsequently were transported to the North American ports of Tacoma, WA, Portland, OR, and Vancouver, BC, where neonates hatched from these eggs and dispersed. The presence of Asian gypsy moths in the northwestern United States was verified in 1991 by catching males in pheromone traps and analyzing them with mitochondrial DNA (mtDNA) (Bogdanowicz et al. 1993). Confirmation of male Asian gypsy moths in traps resulted in the initiation of a $25-million eradication program in 1992.

The Asian gypsy moth has behavioral traits distinct from the European strain, which was introduced into the United States from France in 1869 (Forbush & Fernald 1896). Unlike the European strain, female Asian gypsy moths may fly up to 100 km (Rozkhov & Vasilyeva 1982) and feed on a broader range of hosts including conifers (Baranchikov 1988, Turova 1992). Also, egg diapause in the Asian strain is prolonged (Markov 1988). In northeastern China, females are attracted to lights where they deposit egg masses (Schaefer et al. 1984). Marked gypsy moth females have been recaptured at ultraviolet lamps 3.5 km away from their release site (Baranchikov 1988).

Two other lymantriid pests in Russian Far East port regions include the nun moth, *Lymantria monacha* (L.), and the pink gypsy moth, *Lymantria mathura* Moore. Both have habits similar to the Asian gypsy moth and, thus, the potential to be transported to North America. The nun moth has widespread outbreaks in spruce forests of Europe and Asia where trees are routinely killed by defoliation (Bejer 1988). Although both male and female nun moths are strong fliers, there is no information on the factors influencing distance of flight or the relative attraction of illumination devices. Also, little information exists concerning the pink gypsy moth which currently is found in the Russian Far East and northeastern China (Wallner et al. 1984). Observations in these areas indicate this pest is a defoliator of oak, larch, birch, and alder (W.E.W., unpublished data). As with the nun moth, there is no information available concerning flight behavior or attraction to lights.

A range of activities synchronized within the 24-h cycle of nocturnal moths is induced by the change from day to night (Dreisig 1980). After activity has been initiated, adults may be attracted to various illuminating devices by changing from ce-

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lestial orientation to a light source (Sotthibandhu & Baker 1979). Among Lepidoptera, many factors influence adult light-captures: temperature, humidity, wind (Tashiro 1961), proximity to vegetation (Nelson 1967), moon phase (Sotthibandhu & Baker 1979, Taylor 1986), height of trap above the ground (Stewart & Lam 1968), trap design (Deay et al. 1965), and, perhaps most important, wavelengths of the light source (Weis 1945, Frost 1954, Hollingsworth et al. 1968). Although gypsy moth males are readily attracted to ultraviolet light, electroretinogram responses indicate low sensitivity in the ultraviolet region, higher sensitivity from 540–590 nm, and no sensitivity in the red region (Brown & Cameron 1977). The authors also found that female moths reflected ultraviolet light, suggesting that electroretinogram responses were not reliable in predicting spectral sensitivity.

Our objective was to prevent ship infestation by ovipositing female lymantriid moths by using modified lighting in ports and on ships. We report results of studies in the Russian Far East to change the attraction of standard versus modified illuminating devices to three lymantriid species.

Materials and Methods

Phosphor-coated mercury vapor and incandescent lamps are the lighting devices currently in use at the ports. Spectral power distributions of these lamps are comparable with those produced in western Europe and North America. Although high-pressure sodium lamps are not used at the ports, they were included in this study because it is likely they will replace incandescent lamps in the future. High-pressure sodium lamps typically produce 5- to 6-fold greater efficacy (lumens per watt) and last at least 10-fold longer than incandescent lamps.

Field studies on the attraction of illuminating devices to the three test species were conducted from 23 July to 8 August 1992, in a mixed hardwood/coniferous forest in Mineralni, Primorsky Krai, Russian Far East. Counts of captures at three lamp locations were made simultaneously for 43 nights encompassing 232 h of monitoring. Two high-intensity discharge lamps were used in the experiments: MV, a phosphor coated, high-pressure mercury discharge lamp (type H38AV-100/N); and Na, a diffuse-coated, high-pressure discharge lamp (LU100/D/MED). Operation was on multitap Magnetik ballasts (types 1030-90R and 12310-90, respectively) with taps selected for use in the range of 250 V, 50 Hz. The lamps were placed in Hubbell Microliter weathertight floodlight luminaires (MIC-0100X-X5X) (Hubbell Lighting, Christiansburg, VA), 24 by 24 by 18 cm with aluminum reflectors and borosilicate cover glasses. The beam angle (full width, half maximum intensity) was 34°, and field angle (full width, tenth maximum intensity) was 100°. The beam spreads were the same with both lamps because the phosphor-coated and diffuse-coated outer lamp bulbs were the same size. The third lamp used in the experiment was a 15-W fluorescent blacklight lamp (F15T8/350BL) and served as a basis for comparing captures with various lamps and filters. All lights were mounted 2 m above the ground. The floodlight beam centerlines were positioned horizontally; the UV lamp was mounted vertically without a fixture. The various light source spectral power distributions are shown in Fig. 1. All spectral measurements were made on the spectroradiometer system (Eby 1970) built around a Perkin-Elmer model E-1 Ebert type grating monochrometer used in a double pass mode with an integrating chamber before the entrance slit.

Although attraction of moths as a function of wavelength is not well known, previous reports suggest that attraction to moths decreases as wavelength increases in the visible spectrum. The human photopic spectral luminous efficiency function (Wyszecki & Stiles 1982) peaks at 555 nm and decreases monotonically with wavelength on both sides. These data suggest that a short wavelength blocking filter with a transition wavelength near 500 nm might reduce attractancy to moths while providing adequate illumination for human activity.

Durable, heat-resistant plastic filters (Rosco, Port Chester, NY) in sheet form were cut to 26 by 26 cm and placed over the high-intensity discharge floodlights to modify the quantity of light. Two layers of a UV blocking filter (to increase UV attenuation) and one layer of a blue blocking filter were combined into a thin (0.2 mm), short wavelength-blocking filter stack with a cut-on wavelength of 50% of maximum transmittance. Nearly complete blocking occurs below ≈480 nm (Fig. 2). The maximum wavelength spectral transmittance of 0.72 (see Fig. 2, curve C) is a noticeable light loss and is caused by the air stacking of three filters because they are not in optical contact. Although the long wavelength absorption of the filters is small, each air-plastic interface has a loss of ≈4.5% because of Fresnel reflection. Reducing the number of interfaces from six to two significantly increases long wavelength transmittance. A single filter with the combined properties of the stack could raise this value to 0.90–0.92, an insignificant loss.[6]

A vertically oriented UV lamp has constant intensity for all directions in the horizontal plane. The intensity decreases above and below the horizontal as a cosine function of the angle from the horizontal. Consequently, the areal coverage of this lamp is not coincident with that of the floodlights but the UV catch can be used to verify lymantriid

[6] Reflectance at each air-plastic boundary (Fresnel reflectance) is $(n - 1)^2/(n + 2)^2$; n is the refractive index of the plastic, typically 1.50–1.55. Each boundary will have ≈4.5% reflectance. Neglecting second order effects, three filters (six boundaries) produce 6 × 4.5 = 27% reflectance while one filter (two boundaries) produces 2 × 4.5 = 9% relfectance. Because the filters have negligible internal absorption in the transmission band, the transmittance is one minus reflectance.

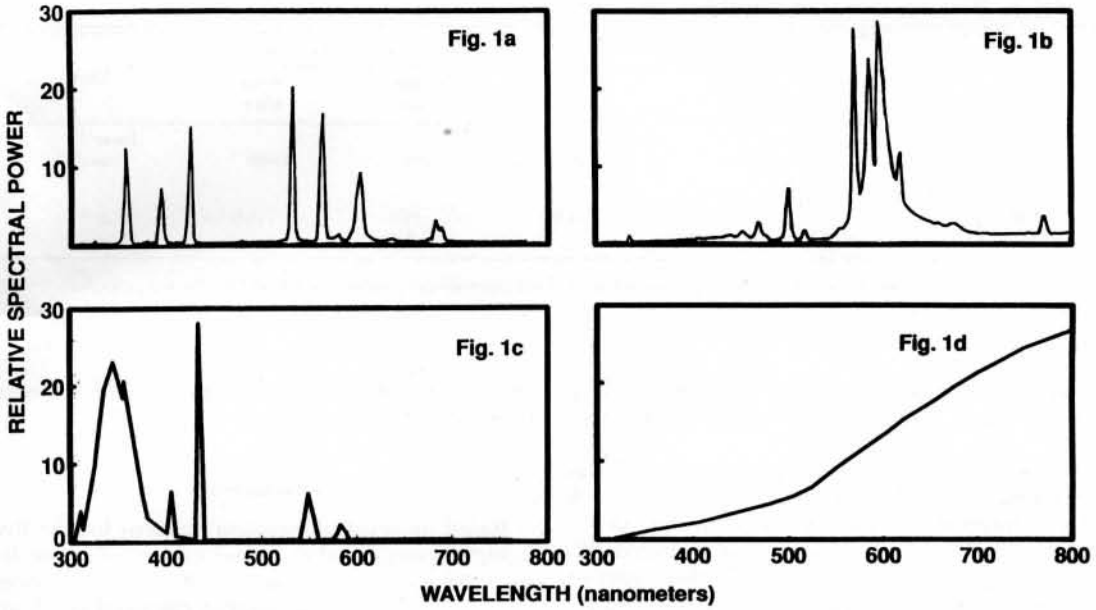

Fig. 1. Relative spectral power distributions of light sources designated in text. (a) phosphor coated, high-pressure mercury lamp; (b) diffuse coated, high-pressure sodium lamp; (c) blacklight fluorescent lamp; (d) incandescent lamp.

availability. For UV, the horizontal intensities are: luminous intensity = 8.3 $lm \cdot sr^{-1}$; radiant intensity = 0.34 $W \cdot sr^{-1}$ (U.S. Department of Commerce 1978).

All light sources were located on the walls of three buildings within a recreational area; they were positioned so as not to compete with each other. A white sheet (2 by 3 m) was suspended behind each light source to facilitate easy counting and collection of adults attracted to the light. The light sources were rotated among stations each evening; thus, a given lamp was in the same position every fourth night, eliminating location as a determining factor in adult captures. Filters were attached and removed alternately on each floodlight every 1.5 h. Each light was observed constantly from dusk (2200 hours) until trapping ceased 3.5–8.5 h later. Weather conditions (precipitation and temperatures <5°C) dictated the duration lights were deployed. The time of day, sex, and species of lymnatriid were recorded and used to calculate mean hourly capture rates. Using the number of adult captures at each light, the data were transformed using LOG ([capture + 0.2]/h) to satisfy the homogeneity of variance assumption of analysis of variance (ANOVA).

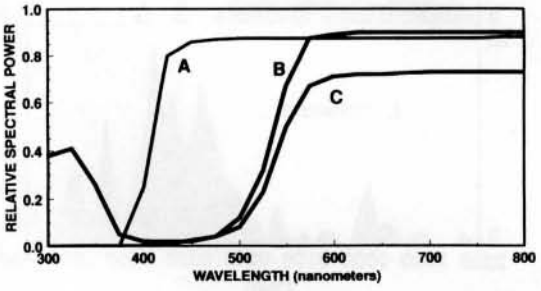

Fig. 2. Spectral transmission of absorption filters: A, ultraviolet blocking Rosco no. 311411 filter; B, blue blocking Rosco no. 15 deep straw filter; C, combination of two (A) and one (B) used with the high-intensity discharge lamps.

Results

Field constraints prevented in situ photometric measurements on the light sources. In the absence of a known spectral attractancy function, unweighted radiant power is reported in Table 1. The variation due to voltage fluctuations was estimated to be approximately ±20%. The relative spectral power and distributions of the three lamps tested and the incandescent lamps used in the ports are shown in Fig. 1a–d. Radiation output characteristics illustrate a descending level of ultraviolet and blue emission, relative to light emission (human photopic response) in progressing from the UV, to mercury vapor, to incandescent, to high-pressure sodium lamps. The addition of filters (Fig. 2) eliminated the wavelengths <480 nm of both mercury vapor and high-pressure sodium lamps.

All illuminating devices attracted adults of the three *Lymantria* spp. (Fig. 3) and patterns of attraction by lamps were comparable. The UV light captured the most adults and the unfiltered mercury vapor and high-pressure sodium lamps captured more adults than the filtered version for all three species. There was a significant light effect

Table 1. Maximum (centerline) floodlight intensities

	Mercury floodlight		Sodium floodlight		Units
	Without filter	With filter	Without filter	With filter	
Luminous intensity, I_v	3,700	2,170	7,400	4,900	$lm \cdot sr^{-1}$ (candela)
Radiant intensity, I_e					
>500 nm	7.4	4.5	18.0	12.0	$W \cdot sr^{-1}$
<500 nm	4.2	—	1.7	—	$W \cdot sr^{-1}$

Luminous intensity, or candlepower = lumens per steradian. Radiant intensity (i.e., without weighting for the eye response) = watts per steradian.

for all three species ($P = 0.000$ for *L. mathura*, $P = 0.009$ for *L. dispar*, and $P = 0.005$ for *L. monacha*).

Daily temporal activity for each lymantriid was computed from the total adults captured at each 10-min interval for the UV lamp during the 17 nights of study. These catches demonstrated different diel patterns of activity for the three species (Fig. 4). *L. mathura* and *L. dispar* commenced activity at approximately the same time in early evening. However, *L. dispar* activity peaked between 2300 and 0100 hours in contrast with that of *L. mathura*, which peaked from 0100 to 0300 hours, but spanned the activity periods for the other two species. Activity of *L. monacha* peaked between 0200 and 0500 hours.

Discussion

Based on spectral emission patterns for the five lights, maximum adult attractancy of all three lymantriid moths occurs below 500 nm. Differences in numbers of each lymantriid captured per hour may be related to their relative abundance in the Russian Far East. While rendering high-intensity discharge lamps unattractive, filtering does not inhibit flight initiation by *L. dispar* females, either

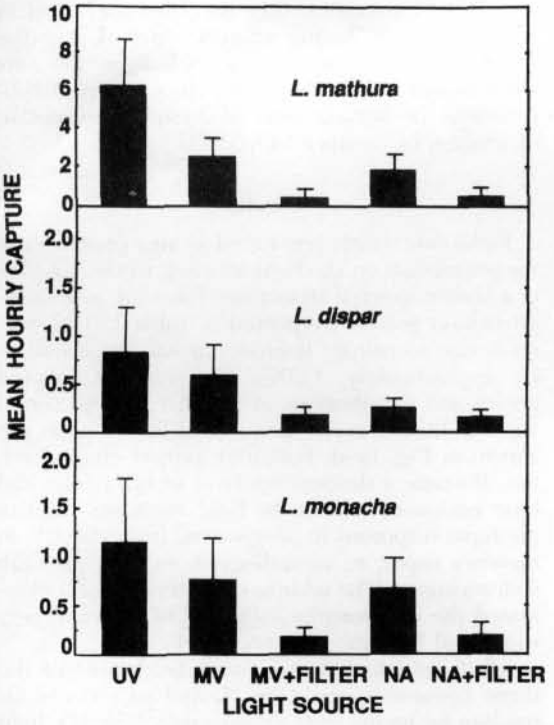

Fig. 3. Relative attraction of lighting devices to adults of three lymantriid moths, Mineralni, Russia, 1992. Note differences in scales on *y* axis. UV, ultraviolet; MV, mercury vapor; NA, high-pressure sodium.

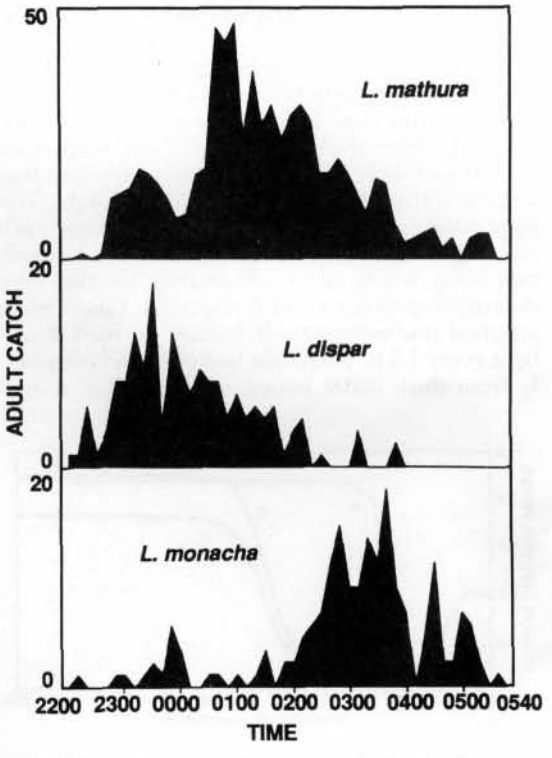

Fig. 4. Daily activity rhythms, based on adult captures during each 10-min interval, for *L. dispar*, *L. mathura*, and *L. monacha* captures at an ultraviolet lamp, Mineralni, Russia, 1992. Note differences in scales on *y* axis.

mated or unmated and up to 3 d old, under controlled tests in quarantine facilities (W.E.W., unpublished data). Thus, with the onset of scotophase, diminishing light in the visual spectrum >500 nm can promote adult flight activity (Dreisig 1980). Once flight is achieved, radiant power of <480 nm attracts *L. dispar* adults to artificial lights. These results parallel Brown & Cameron's (1977) observations on the electroretinogram response of *L. dispar* males. They reported maximum sensitivity at 480–590 nm, low sensitivity in the ultraviolet region, and migration of screening pigments during the day, ensuring that the eye acts in the photopic mode. Linn et al. (1992) noted increased sensitivity to pheromone by males of *L. dispar* with the transition from photophase to scotophase. Thus, even though Lymantriidae are generally nocturnal, *L. dispar* may have bimodal spectral sensitivity, activity, and pheromone response rhythms. Cardé et al. (1974) and Charlton & Cardé (1990) suggested that lack of response by males to visual cues by females are behavioral remnants retained by *L. dispar* in North America from ancestral nocturnal habits. No known comparable information is published for either *L. mathura* or *L. monacha*.

All three species demonstrated a range of attractivity to the five different lights with the UV light being most attractive, based on the relative rates of capture. UV light is frequently used for collecting and sampling insects (Hollingsworth 1968), and is known to attract both males (Brown & Cameron 1977) and females (Baranchikov 1988, Turova 1992) of *L. dispar*. In our studies, the ratio of males to females was 2:1 for *L. mathura*, 11:1 for *L. dispar*, and 20:1 for *L. monacha*. In contrast, the radiant power of mercury vapor and sodium contain less intense peaks of emission in the blue and ultraviolet wavelengths, possibly reducing attractiveness. Although the sodium high-intensity discharge emits limited spectral power (<500 nm) and attracted fewest adults of the high-intensity discharge unfiltered lamps tested, it attracted all three lymantriids and, thus, would require filters if used at the ports.

Alteration of spectral emission can be achieved by the addition of a UV light and blue blocking filter to mercury vapor and sodium high intensity discharge lamps. This is necessary to make them less attractive to adult moths. Because of the urgency of reducing or preventing ship infestations destined for North American ports without disrupting international trade, the filtering of existing mercury vapor and incandescent lighting in Russian Far East ports should be considered. Additionally, UV light traps could be used in conjunction with filtered high-intensity discharge lamps to intercept or deflect incoming females from port regions.

There is a limiting distance (D) at which an attraction response occurs as determined by some minimum irradiance (W/cm^2) (Baker & Sadovy 1978). The high-intensity discharge lamps in this study were of equal electrical power rating (100 W); but comparisons should be made with those having equal light levels. This can be done by assuming a constant relative spectral power distribution, a constant relative spatial distribution of radiant intensity (I), and a somewhat uniform spatial density distribution of lymantriids. Using the inverse square law, $D \propto I^{1/2}$, the volume of space within the limiting distance and, thus, the number (N) of lymantriids, have the relation $N \propto D^3$. Consequently, $N \propto I^{3/2}$. The light output of the sodium high-intensity discharge lamp as based on centerline intensity (Table 1) is twice that of the mercury vapor lamp. This suggests that, if the light output of the sodium lamp was reduced to match that of the mercury vapor lamp, the hourly captures at the sodium lamp would be reduced by a factor of about $0.5^{3/2}$, or to ≈35% of the values shown in Fig. 3.

Although adults of all three lymantriids were captured throughout the late evening and early morning, there were different diel patterns of peak activity (Fig. 4). The abundance of each species varied but the numbers of captures were sufficient to ascertain differences in patterns of activity. The diel patterns mirror precisely *L. dispar* male hourly captures at pheromone traps operated concurrently nearby the light experiments. The onset and duration of adult diel activity rhythms ensure that *L. dispar* and *L. monacha* are temporally isolated. This difference in activity was postulated as essential by Charlton & Cardé (1990) to avoid "interference by chemical noise" between these two species because some cross attractancy to pheromone is known for *L. dispar* and *L. monacha* (Beroza et al. 1973, Kovalev et al. 1980). The differences in diel rhythms of attraction to light may, thus, reflect differences in the rhythms of sexual attraction. In contrast, the cross attractancy of *L. dispar* and *L. mathura* to pheromone is not well understood (cf., Wallner et al. 1984, ODell et al. 1992). Because the period of *L. mathura* activity overlaps the other two lymantriid species, the time of sexual activity may not be important in isolating *L. mathura* from *L. dispar* or *L. monacha*.

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References Cited

Anonymous. 1992. Nat. Geogr. Magazine 182: 12.

Baker, R. R. & Y. Sadovy. 1978. The distance and nature of the light trap response of moths. Nature (Lond.) 276: 818–821.

Baranchikov, Y. N. 1988. Ecological basis of the evolution of host relationships in Eurasian gypsy moth populations, pp. 319–338. *In* W. E. Wallner & K. A.

McManus [technical coordinators], Proceedings, Lymantriidae: a comparison of features of New and Old World tussock moths. U.S. Dep. Agric. Gen. Tech. Rep. NE-123.

Bejer, B. 1988. The nun moth in European spruce forests, pp. 211–231. *In* A. A. Berryman [ed.], Dynamics of forest insect populations: patterns, causes, implications. Plenum, New York.

Beroza, M., K. Katagiri, Z. Iwata, H. Ishizuka, S. Suzuki & B. A. Bierl. 1973. Disparlure and analogues as attractants for two Japanese lymantriid moths. Environ. Entomol. 2: 966.

Bogdanowicz, S. M., W. E. Wallner, J. Bell, T. M. ODell & R. G. Harrison. 1993. Asian gypsy moths (Lepidoptera: Lymantriidae) in North America: evidence from molecular data. Ann. Entomol. Soc. Am. 86: 710–715.

Brown, E. A. & E. A. Cameron. 1977. Studies on the compound eye of *Lymantria dispar* (Lepidoptera: Lymantriidae) males and behavioral implications. Can. Entomol. 109: 255–260.

Cardé, R. T., C. C. Doane & W. T. Roelofs. 1974. Diel rhythms of male sex pheromone response and female attractiveness in the gypsy moth. Can. Entomol. 106: 479–484.

Charlton, R. E. & R. T. Cardé. 1990. Orientation of male gypsy moth, *Lymantria dispar* (L.), to pheromone source: the role of olfactory and visual cues. J. Insect Behav. 3: 443–469.

Deay, H. O., J. R. Barrett & J. G. Hartsock. 1965. Field studies of flight response of *Heliothis zea* to electric light traps, including radiation characteristics of lamps used. Proc. North Cent. Branch Entomol. Soc. Am. 20: 109–116.

Dreisig, H. 1980. The importance of illumination level in the daily onset of flight activity in nocturnal moths. Physiol. Entomol. 5: 327–342.

Eby, J. E. 1970. A computer based spectroradiometer system. Appl. Optics 9: 888–894.

Forbush, E. H. & C. H. Fernald. 1896. The gypsy moth and brown tail moth. Wright & Potter, Boston.

Frost, S. W. 1954. Response of insects to black and white light. J. Econ. Entomol. 47: 275–278.

Hollingsworth, J. P., W. W. Hartsock & D. A. Lindquist. 1968. Influence of near-ultraviolet output of attractant lamps on catches of insects by light traps. J. Econ. Entomol. 61: 515–521.

Kovalev, B. G., V. D. Bedney & R. T. Cardé. 1980. Attractancy of disparlure enantiomers for the gypsy and nun moths. Insect Chemoreception (Mechanisms of Pheromone Reception) 5: 109–112. Lithuanian Academy of Sciences (in Russian).

Linn, C. E., M. G. Campbell & W. L. Roelofs. 1992. Photoperiod cues and the modulatory action of octopamine and 5-hydroxytryptamine on locomotor and pheromone response in male gypsy moths, *Lymantria dispar*. Arch. Insect Biochem. Physiol. 20: 265–284.

Markov, V. A. 1988. Prolonged embryonal diapause in the gypsy moth pp. 13–14, *In* Y. N. Baranchikov [ed.]. Neparny Shelkopryad: itogi i perspectivy issledovanii. Krasnoyarsk (in Russian).

Nelson, S. O. 1967. Electromagnetic energy pp. 89–145. *In* Pest control. Academic, New York.

ODell, T. M., C. H. Xu, P. W. Schaefer, B. A. Leonhardt, D. F. Yao & X. D. Wu. 1992. Capture of gypsy moth, *Lymantria dispar* (L.) and *Lymantria mathura* (L.) males in traps baited with disparlure enantiomers and olefin precursor in the People's Republic of China. J. Chem. Ecol. 18(12): 2153–2159.

Rozhkov, A. S. & T. G. Vasilyeva. 1982. Gypsy moth in Middle and Eastern Siberia, pp. 4–19. *In* Neparny Shelkoprayo v srednai i Vostochnoi Sibiti. Novosibirsk: Nauka. Russian Academy of Sciences, Siberian Branch, Novosibirsk (in Russian).

Schaefer, P. W., R. M. Weseloh, X. Sun, W. E. Wallner & J. Yan. 1984. Gypsy moth, *Lymantria* (*Ocneria*) *dispar* (L.) (Lepidoptera: Lymantriidae), in the People's Republic of China. Environ. Entomol. 13: 1535–1541.

Sotthibandhu, S., & R. R. Baker. 1979. Celestial orientation by the large yellow underwing moth, *Noctua pronuba* L. Anim. Behav. 27: 736–800.

Stewart, P. A. & A. J. Lam. 1968. Catch of insects at different heights in traps equipped with blacklight lamps. J. Econ. Entomol. 61: 1227–1230.

Tashiro, H. 1961. Relationship of physiological development and condition of insects to photosensitivity. Response of insects to induced light. U.S. Dep. Agric. Agric. Res. Serv. ARS 20–10.

Taylor, R. A. 1986. Time series analysis of numbers of Lepidoptera caught in light traps in East Africa and the effect of moonlight on trap efficiency. Bull. Entomol. Res. 76: 593–606.

Turova, G. 1992. Peculiarities of gypsy moth biology in the Far East, pp. 117–124. *In* Problems of rational forest management in the Far East. Far East Forestry Institute, Khabarovsk (translation from Russian).

U.S. Department of Commerce. 1978. Self-study manual on optical radiation measurements. Nat. Bur. Stand. Tech. Note 910-2.

Wallner, W. E., R. T. Cardé, X. Chong-hua, R. M. Weseloh, S. Xilin, Y. Jingjun & P. W. Schaefer. 1984. Gypsy moth (*Lymantria dispar* L.) attraction to disparlure enantiomers and the olefin precursor in the People's Republic of China. J. Chem. Ecol. 10: 753–757.

Weis, H. B. 1945. Color perception in insects. J. Econ. Entomol. 36: 1–17.

Wyszecki, G. & W. S. Stiles. 1982. Color science. Wiley, New York.

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