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EFFECT OF TEMPERATURE VARIABLES ON ULTRAVIOLET TRAP CATCHES OF *ACTIAS LUNA* AND *DRYOCAMPA RUBICUNDA* (SATURNIIDAE) IN WAYNE NATIONAL FOREST, OHIO

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ABSTRACT.Counts of the luna moth, *Actias luna* (Linnaeus) and the rosy maple moth *Dryocampa rubicunda* (Fabricius) from ultraviolet traps in southeastern Ohio reveal that different temperature factors affect catch size. High and low counts of *A. luna* (Saturniinae) were generally not influenced by short term temperature trends, difference temperatures, or maximum temperatures on the trap day itself. Conversely, high counts of *D. rubicunda* (Ceratocampinae) were associated with maximum temperatures, indicating a response to more immediate factors. It is recommended surveys of saturniids include sampling days that cover a wide range of temperatures. Influences of life history characteristics and body sizes on temperature responses are discussed.

Additional key words: *Actias luna, Dryocampa rubicunda*, light trap, emergence temperature, flight temperature, photoperiod, life history strategy, body size, saturniids, moonlight, diapause, survey

This study investigated the influences of warming trends, daily temperature differences, maximum temperatures, low temperatures, and average temperatures on ultraviolet light catches of *A. luna* and *D. rubicunda* in southern Ohio from 1995 to 1998. Knowledge of the environmental factors affecting development, phenology, and behavior may be especially useful for biologists who inventory, survey, or monitor populations of saturniids in forested regions of the northeastern USA.

Light trapping studies with moths have investigated their diversity, abundance, migration times, population trends, development, phenology, and life history cues (Gregg *et al.* 1994, Thomas & Thomas 1994, Robinson & Tuck 1993, Frank 1988, Bowden 1982, Worth 1979). Moth emergence and flight times to light traps are affected by abiotic factors such as photoperiod, moonlight, temperature, wind speed, wind direction, functioning of the light trap, and background illumination (Manley 1993, Bowden 1982, Wright 1970). Certain environmental conditions break diapause and initiate adult development while other conditions stimulate emergence. For example, Wright (1970) reported photoperiod played a significant role in the number of days required for emergence of unchilled *Actias luna* pupae; a 16-hour photophase resulted in earlier emergence than a 24-hour photophase. Truman (1985) noted eclosion in giant silkmoths was determined by light-dark cycles and was regulated by the brain with the release of eclosion hormone. Young (1997) discussed the effectiveness of ultraviolet traps and lunar cycles; catch size is partly dependent upon trap light contrasts with their background.

Heinrich (1993, 1997) noted that large saturniid moths shiver to warm up flight muscles to 37° C, a response that depends, in part, upon ambient temperatures. In Georgia and Florida, *Automeris io* (Fabricius) emerged from late morning to mid-afternoon if temperatures were above 10°C with no heavy rain, dense fog or high wind (Manley 1993). Calling behaviors in the evening were also initiated above 10°C but sudden drops below 8° C resulted in pairs remaining in copula throughout the night.

Stamp and Casey (1993) reported the abrupt appearance of moths, butterflies, and caterpillars at the beginning of the Santa Rosa, Costa Rica, rainy season was cued by temperature drops of 6°C, not by the onset of rain. After a long, dry, hot period, cool air pulses were associated with enormous numbers of moths attracted to lights. Additionally, pupal eclosion of *Rothschildia lebeau* (Guerin-Meneville) (Saturniidae) in airtight plastic bags was more affected by temperature drops than humidity levels; moths in wet bags eclosed an average of 1–2 days later than moths in dry bags.

Unlike adult Sphingidae that harvest fuel and water from flowers, adult Saturniidae mate and die in a relatively short time after eclosion (Janzen 1984). The male generally flies for two to three days after emergence in search of pheromone plumes. Fast, accurate flight to a female may be paramount for reproductive success. Conversely, females specialize in finding suitable host plants for oviposition, a more refined activity that requires fluttering, careful positioning around oviposition sites, and wing strength to support egg bearing weight. Increased catches of female saturniids may occur when light traps are placed near a concentration of host plants (Tuskes *et. al.* 1996).

Light trap catches are affected by environmental factors that influence the entire sequence of a moth's life history such breaking diapause, development, eclosure, oviposition, and flight periods.

MATERIALS AND METHODS

Moths were captured with ultraviolet light traps from 1995–1998 at 6 trapping stations in southeastern Ohio mixed-hardwood forests. One set of 3 traps was located

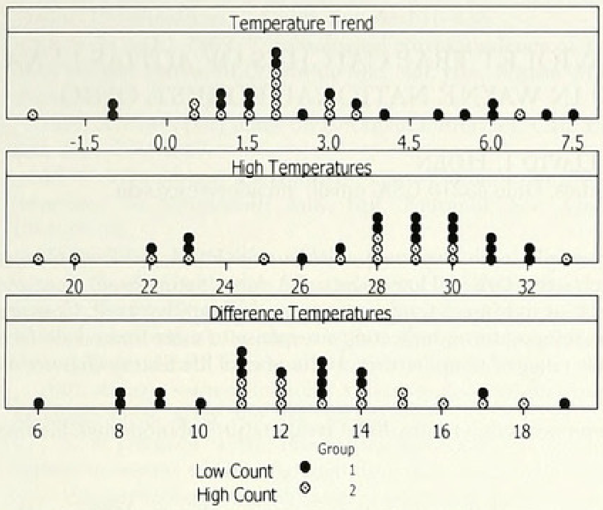

FIG 1. Low and high count samples of *A. luna* caught at different temperature variables by blacklight trapping in Lawrence County, Ohio, from May to August 1995–1998. Mean comparisons of temperature trends, high temperatures, and difference temperatures between the high and low count groups were not significantly different (t-test, $p>0.05$) (n= 16 for low count samples, n=23 for high count samples).

within the Vinton Furnace Experimental Forest near Dundas in Vinton County while another set of 3 traps was located within Wayne National Forest near Kitts Hill in Lawrence County. These different county trap sites were approximately 69.7 kilometers apart. Researchers turned on trap lights for one night a week from dusk to dawn using preset timers and then emptied collection chambers the day after lights turned off. The weekly trapping period ran from April 25 to August 14 in 1995–1997; moths were trapped biweekly in 1998 from May 6 to August 16. A total of 71 samples was analyzed for both county sites, excluding days with thunderstorms, rain, mist and heavy fog. A sample count consisted of summing the number of moths from the three traps on one county site for one trapping night. Each trap consisted of a 20-liter (5 gallon) plastic pail placed beneath a 10 cm, 8 watt ultraviolet Sylvania GTE fluorescent bulb powered by a 12-volt battery between Plexiglas baffles. Traps were hung from limbs approximately 1.5 m above the ground near ridge crests. Insects that fell through the funnel entrances were killed by ethyl acetate.

Temperature and precipitation data were compiled from Climatological Data, 1995–1998, National Oceanic and Atmospheric Administration (NOAA) at Portsmouth, Sciotoville and Athens Ohio. The Portsmouth Station is approximately 25 km due west of Lawrence County trap sites and Athens Station is approximately 25 km due east of the Vinton County trap sites. The nearest station with mist and heavy fog data was Huntington, West Virginia, approximately 70 km from both sites. Nightly moth catches were designated as either high count samples or low count samples for each species. High count samples contained any count equal to or above the four year trap median in that county; low count samples were any count occurring below the four year trap median in that county (Table 1).

Moonlight data also came from the NOAA, National Weather Service Forecast, in Huntington, West Virginia. On nights with greater than 80% of the moon's disk illuminated (N= 21), only 42.8% of *A. luna* catches and 33.3% of *D. rubicunda* catches were ranked as high counts. These results did not account for the influence of cloud cover on moonlight luminescence.

The first analysis compared temperature trends, difference temperatures, and maximum temperatures between high and low count groups of each species in each county. Maximum temperatures were the highest temperatures recorded either on the trap day itself or one to two days preceding the trap day, a time period corresponding to adult emergence and adult life span. Temperature trends were the sums of the 3 to 5 day warming or cooling trend leading up to the maximum temperature. Difference temperatures (maximum minus minimum) were recorded on the trap day itself.

Temperature variables were compared with independent sample t-tests (unequal variances) using Minitab (Release 14: 2004), and checked for normality (Rosner 2000). All hypothesis tests were 2-tailed with a maximum probability of type-1 error set at 0.05. A linear regression analysis determined if maximum

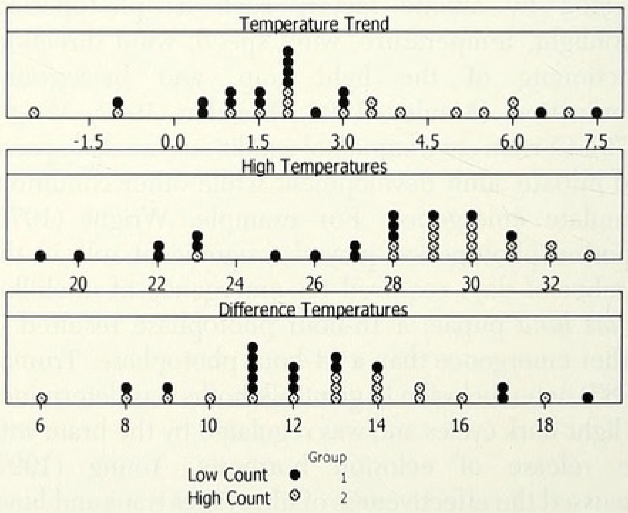

FIG 2. Low and high count samples of *D. rubicunda* caught at different temperature variables by blacklight trapping in Lawrence County, Ohio, from May to August 1995–1998. Mean comparison of high temperatures were significantly different between the high and low count groups (t-test, $p<0.05$) (n=19 for low count samples, n=20 for high count samples). Temperature trends and difference temperatures were not significantly different.

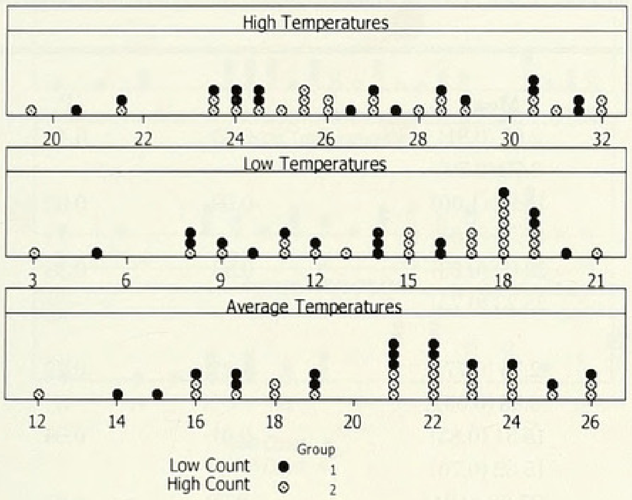

FIG 3. Low and high count samples of *A. luna* caught at different temperature variables by blacklight trapping in Vinton County, Ohio, from May to August 1995–1998. Mean comparisons of high temperatures, low temperatures, and average temperatures between high and low count groups were not significantly different (t-test, p>0.05) (n=16 for low count samples, n=23 for high count samples).

temperatures could reliably predict moth counts. Residual plots were checked for normality, unequal variances, and independence (Durbin-Watson Test) while scatter diagrams were screened for outliers and influential observations (Rosner 2000). Moth counts required square root transformations to reduce unequal residual variances. Finally, we investigated the influence of catch day maximum temperatures, minimum temperatures, and average temperatures on moth groups. These data were also compared with independent sample t-tests (unequal variances) after checking for normality.

RESULTS

At both county sites, the rosy-maple moth, *D. rubicunda*, was trapped in higher counts (mean = 34.25 ± 5.37 at Lawrence) than was *A. luna* (mean = 3.37 ± 0.64 at Lawrence) (Table 1).

TABLE 1. Mean counts (±SE), medians, and high group counts of *Actias luna*, and *Dryocampa rubicunda* using catch data from ultraviolet light trapping in Lawrence and Vinton counties, southeastern Ohio 1995–1998 (N= number of trapping days).

Species	N	Mean	Median	High Group Count
		Lawrence County		
A. luna	32	3.37 (0.64)	2.00	>2
D. rubicunda	32	34.25 (5.37)	25.00	>25
		Vinton County		
A. luna	39	4.18 (0.65)	3.00	>3
D. rubicunda	39	36.51 (7.57)	25.00	>25

TABLE 2. Comparison of temperature trends, difference temperatures, and maximum temperatures (±SE) between designated high and low count groups using ultraviolet light trap catch data from Lawrence County, Ohio 1995-1998. Asterisk indicates means are significantly different (t-tests, p<0.05)

Variable	Group Type	N	Mean	t	P
			A. luna		
Temperature Trend	Low	18	0.95 (0.53)	1.52	0.14
	High	14	3.16 (0.59)		
Difference Temperature	Low	18	13.61 (0.62)	-1.92	0.07
	High	14	11.72 (0.76)		
Maximum Temperature	Low	18	30.15 (0.63)	1.94	0.07
	High	14	26.06 (0.88)		
			D. rubicunda		
Temperature Trend	Low	16	2.20 (0.53)	-1.02	0.31
	High	16	3.05 (0.64)		
Difference Temperature	Low	16	12.43 (0.74)	-0.23	0.82
	High	16	12.67 (0.77)		
Maximum Temperature	Low	16	* 27.63 (0.76)	-3.40	0.00
	High	16	30.84 (0.56)		

Temperature trends, difference temperatures, and maximum temperatures were not significantly different between low and high count groups of *A. luna* (t-test; p>0.05 for all comparisons) in Lawrence County (Table 1) (Fig 1). Conversely, low and high count groups of *D. rubicunda* differed significantly (t = -3.40; p = 0.00) in relation to maximum temperatures (27.63 ± 0.76 and 30.84 ± 0.56 respectively) (Table 2) (Fig. 2).

Temperature trends, difference temperatures, and maximum temperatures were also not significantly different between low and high count groups of *A. luna* (t-test; p>0.05 for all comparisons) in Vinton County (Table 3) (Fig. 3). Low and high count groups of *D. rubicunda* differed significantly (t = -2.72; p = 0.01) on maximum temperatures (27.28 ± 0.24 and 29.82 ± 0.57, respectively) in this county (Table 3) (Fig. 4).

In a comparison of maximum, minimum, and average temperatures on the trap day itself between the different groups of *A. luna*, only minimum temperatures (17.85 ± 1.20 and 13.94 ± 1.00) were significantly different in Lawrence County (Table 4).

TABLE 3. Comparison of temperature trends, difference temperatures, and maximum temperatures (±SE) between designated high and low count groups using ultraviolet light trap catch data from Vinton County, Ohio 1995–1998. Asterisk indicates means are significantly different (t-tests, p<0.05).

Variable	Group Type	N	Mean	t	P
		A. luna			
Temperature Trend	Low	16	2.86 (0.81)	-0.85	0.40
	High	23	3.70 (0.59)		
Difference Temperature	Low	16	15.25 (1.00)	-0.09	0.93
	High	23	15.36 (0.61)		
Maximum Temperature	Low	16	29.09 (0.63)	0.88	0.38
	High	23	28.23 (0.73)		
		D. rubicunda			
Temperature Trend	Low	19	2.75 (0.77)	-1.23	0.22
	High	20	3.93 (0.65)		
Difference Temperature	Low	19	15.31 (0.83)	-0.01	0.99
	High	20	15.32 (0.76)		
Maximum Temperature	Low	19	*27.28 (0.24)	-2.72	0.01
	High	20	29.82 (0.57)		

TABLE 4. Comparison of maximum, minimum, and average temperatures in Celsius between high count groups and low count groups of *A. luna* catches in southeastern Ohio from 1995–1998. These temperatures were recorded on the catch day.

Variable	County	Group	N	Mean (SE)	t	P
			A. luna			
Maximum Temp.	Lawrence	Low	18	28.29 (0.73)	1.28	0.22
		High	14	26.62 (1.10)		
	Vinton	Low	16	26.51 (0.86)	-0.15	
		High	23	26.68 (0.68)		
Minimum Temp.	Lawrence	Low	18	17.85 (1.20)	2.46	0.02
		High	14	13.94 (1.00)		
	Vinton	Low	16	13.26 (1.10)	-1.29	
		High	23	15.12 (0.91)		
Average Temp.	Lawrence	Low	18	22.62 (0.80)	1.70	0.10
		High	14	20.46 (0.98)		
	Vinton	Low	16	20.03 (0.90)		-0.86
		High	23	21.03 (0.76)		

TABLE 5. Comparison of maximum, minimum, and average temperatures between high count groups and low count groups of *D. rubicunda* catches in southeastern Ohio from 1995–1998. These temperatures were recorded on the catch day.

Variable	County	Group	N	Mean (SE)	t	P
			D. rubicunda			
Maximum Temp.	Lawrence	Low	16	25.48 (0.87)	-3.99	0.00
		High	16	29.64 (0.57)		
	Vinton	Low	19	25.03 (0.79)	-3.23	0.00
		High	20	28.11 (0.53)		
Minimum Temp.	Lawrence	Low	16	14.31 (1.4)	-2.21	0.04
		High	16	17.97 (0.82)		
	Vinton	Low	19	12.22 (1.10)	-3.23	0.00
		High	20	16.39 (0.69)		
Average Temp.	Lawrence	Low	16	19.83 (0.98)	-3.33	0.00
		High	16	23.53 (0.53)		
	Vinton	Low	19	18.75 (0.84)	-3.60	0.00
		High	20	22.40 (0.56)		

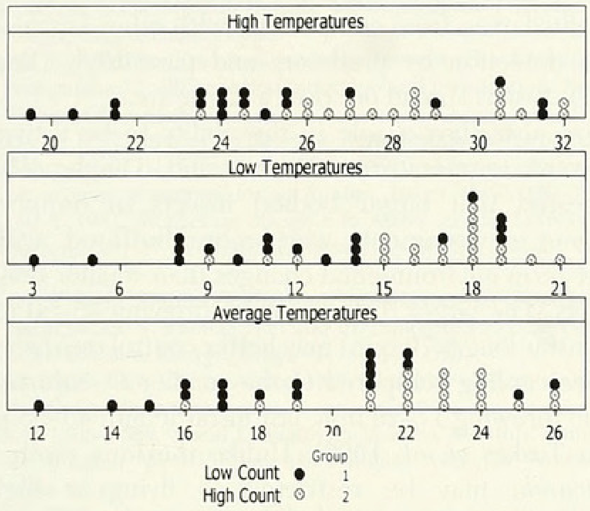

FIG 4. Low and high count samples of *D. rubicunda* caught at different temperature variables by blacklight trapping in Vinton County, Ohio, from May to August 1995–1998. Mean comparisons of high temperatures, low temperatures,and average temperatures were significantly different between the high and low count groups (t-test, $p<0.05$) ($n=19$ for low count samples and $n=20$ for high count samples).

Maximum, minimum, and average temperatures of *D. rubicunda* groups differed significantly (t-test; $p< 0.05$) in both counties (Table 5).

In Lawrence County, *A. luna* counts did not significantly increase or decrease with increasing maximum temperatures (df = 1, R^2 = 0.08, p = 0.12) (Fig 5), but higher counts of *D. rubicunda* were associated with higher maximum temperatures (df = 1, R^2 = 0.43, p = 0.00) (Fig. 6).

The overall patterns of high *A. luna* counts occurring throughout a range of temperatures and high *D. rubicunda* counts occurring at generally higher temperatures is present in Fig. 7 from Vinton County.

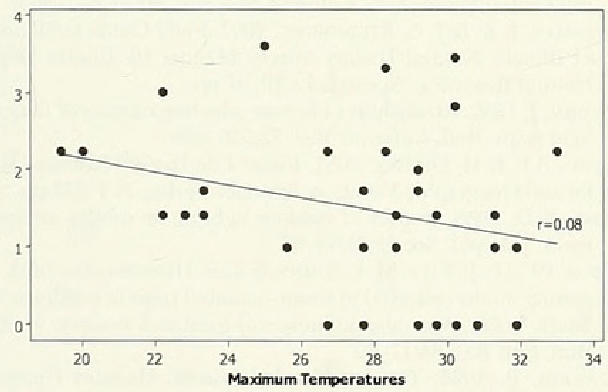

FIG 5. Relationship of maximum temperatures (x) to *A. luna* moth counts (y) on different sampling days in Lawrence County, Ohio, from May to August 1995–1998. Moth counts required square root transformations. The regression equation is $y = 3.835 - 0.084x$.

DISCUSSION

High counts of *A. luna* in ultraviolet light traps were generally not influenced by maximum temperatures, differences in daily temperatures, or short term temperature trends at trapping times. In contrast, high catches of *D. rubicunda* were influenced by maximum temperatures on the catch day itself and by maximum temperatures one to two days preceding the trap night. *D. rubicunda* responded more to immediate maximum temperature cues than did *A. luna*.

Allen (1976) reported that *D. rubicunda* oviposition rates reached a peak during the first 10 days of July in northern Pennsylvania, New York, and New England, a

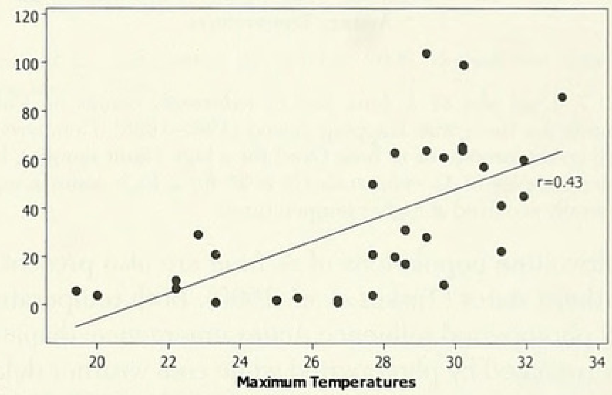

FIG 6. Relationship of maximum temperatures (x) to *D. rubicunda* moth counts (y) on different sampling days in Lawrence County, Ohio, from May to August 1995–1998. Moth counts required square root transformations. The regression equation is $y = -9.045 + 0.515x$.

time period corresponding to the highest mean temperatures in these locations (NOAA 2002). For example, the mean normal temperature of Warren, Pennsylvania, in July from 1971–2000 was 21.1° C compared to a mean of 20.4° C in August. Additionally, Bouseman and Sternburg (2002) noted that *A. luna* pupae from Illinois emerged in May and June, monthly periods associated with cooler temperatures than July (NOAA 2002). In Danville Illinois, the mean temperature in June was 22.1° C compared to 24.1° C in July.

Populations of *D. rubicunda* are univoltine both in the northeastern United States and eastern Canada with adult emergences from mid-may to mid-July (Allen 1976). In South Carolina, first broods appear from the end of April to May while second broods appear from late June through mid-September. Additionally, multivoltine populations are found in southern states (Bouseman 1982). In Canada and the northern states, *A. luna* is univoltine while in the more southern Ohio River Valley, it is bivoltine. Similar to *D. rubicunda*,

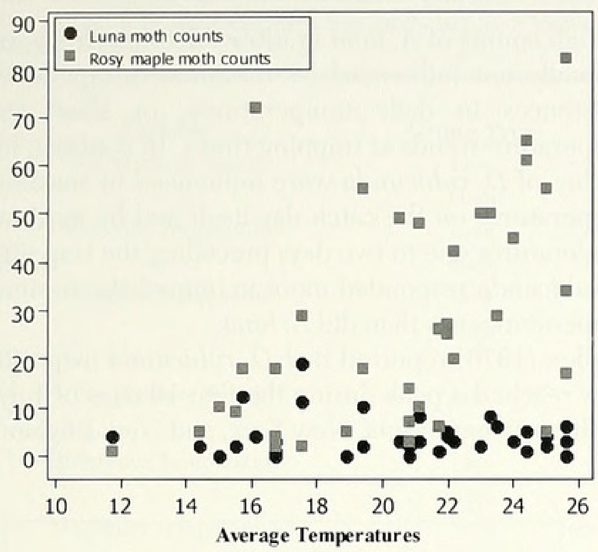

FIG 7. Dual plot of *A. luna* and *D. rubicunda* counts on Vinton County for the entire trapping period (1995–1998). Compared to high count samples of *A. luna* (N≥2 for a high count sample), high count samples of *D. rubicunda* (N ≥ 25 for a high count sample) generally occurred at higher temperatures.

multivoltine populations of *A. luna* are also present in southern states (Tuskes *et. al.* 1996). Both temperature and photoperiod influence *Actias* emergence; diapause is terminated by photoperiod while cool weather delays emergence in some species (Miyata 1971, 1974, 1986).

The different origins and life history strategies of saturniids may also influence emergence and flight temperatures. *D. rubicunda*, a member of the subfamily Ceratocampinae with tropical origins, may be more innately adapted to flight in high midsummer temperatures with humid weather (Tuskes *et. al.* 1996). Conversely, the genus *Actias* is a more temperate Asiatic group with species such as *Actias artemis artemis* (Bremer & Grey) and *Actias gnoma tomariactias* (Bryk) found in Japan (Miyata, 1981, Nassig & Peigler 1984, Tuskes *et. al.* 1996).

Larger-sized females of *A. luna*, *Hyalophora cecropia* (Linnaeus) (Saturiinae) and *Eacles imperialis* (Drury) (Ceratocampinae) travel longer distances to disperse smaller clutches of ova compared to some of the smaller-sized females of Ceratocampinae and Hemileucinae that lay their all their eggs in one or two large clutches (Tuskes *et al.* 1996). These smaller species also have gregarious, brightly colored larvae. Similarly, *D. rubicunda* (Ceratocampinae) lays clutches of 10–30 eggs that hatch into colonial larvae colored with black patches adjacent to dorsal and sub-dorsal tubercles, characteristics associated with warning coloration and distastefulness. *D. rubicunda* may spend limited time in flight due to its life history strategy. Conversely, *A. luna* flies longer distances to disperse single eggs or small groups of eggs, a strategy that benefits larvae from competition with other larvae and from detection by predators and parasitoids (Young 1997). Risk is spread out over a larger area.

Size also plays a role in the ability to be active at different temperatures. Denno and Dingle (1981) suggested that larger bodied insects in temperate summer environments were more buffered against short-term environmental changes than smaller bodied insects. The larger *A. luna* (male forewing 45–60 mm, last instar length 70 mm) may better control overheating or overcooling compared to the smaller *D. rubicunda* (male forewing 17–29 mm, last instar length 45–55 mm from Tuskes *et. al.* 1996). Unlike the luna moth, *D. rubicunda* may be restricted to flying at higher temperatures.

Trapping result differences probably reflect differences in both emergent temperature responses and flight temperature responses of the two species.

This study recommends that surveys of saturniids by ultraviolet traps include sampling dates that cover a wide range of temperatures and not just days considered optimal. Larger-sized saturniids may be caught in significant numbers at both high and low temperatures while smaller-sized saturniids may be more abundant at high temperatures.

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