BEETLES COLLECTED IN LIGHT-TRAPS DURING THE NORTH AMERICAN TOTAL SOLAR ECLIPSE OF 21 AUGUST 2017 WITH A REVIEW OF ARTHROPOD BEHAVIOR DURING SOLAR ECLIPSES[1]

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ABSTRACT: Insect behavior during solar eclipses has been the subject of numerous observations and studies. A total solar eclipse that passed through Clemson, South Carolina, USA, during 21 August 2017 offered a rare opportunity to test for beetle flight activity during the short-lived daytime-darkness. Ultraviolet light traps were run during three periods: 1) during the eclipse; 2) again the next day (22 August) at the same time; and 3) later in the evening the day after the eclipse. Forty-nine specimens within 16 species and eight families of Coleoptera were collected. The number of specimens collected was not significantly different between the eclipse and the next day, indicating the eclipse had no effect on beetle flight activity. A list is provided of all published studies and notes that could be found on insect behavior during solar eclipses.

KEY WORDS: Coleoptera, UV light, light trapping

"The world will finish one of these years. If it finishes to-day I'll not see it, because I'll shut mine eyes till to-morrow." -Portuguese woman during the solar eclipse of 1900 (Maunder 1901:214)

INTRODUCTION

In the story *Nightfall* by Isaac Asimov (1941), the people of the planet Kalgash, upon experiencing a solar eclipse for the first time in innumerable generations, go insane and destroy their civilization. The solar eclipse across North America that occurred during 21 August 2017 offered an opportunity to look for a similar, but perhaps less dramatic, behavior among insects—might night flying beetles go "crazy" and fly during the daytime-darkness of the eclipse?

Recorded observations of animal behavior during solar eclipses extend as far back as the 16th century (Wheeler et al., 1935). Solar eclipses are so infrequent in a given area that it is unlikely that they have an evolutionary impact on any given species. However, humans (*Homo sapiens* L., Primates: Hominidae) have exploited the predictability of solar eclipses for personal or institutional gain over the past several centuries. More recently, solar eclipses, which offer unique views of the sun and other physical phenomena, have been an important instrument in modern research (Littmann et al., 1999).

A compilation of all published studies and notes on insect behavior during solar eclipses was attempted (Table 1), but certainly many more brief observations

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exist within and outside of the primary literature. Observations of insect behavior during solar eclipses range from the very simple ("…the butterflies became uneasy…", Moucha, 1964) to the very elaborate (flight path and acceleration

Table 1. Publications that include observations or research on arthropod behavior during solar eclipses. [Inoue 1936, Kuwayama 1937, and Mori 1936 are partially summarized in English in Mori 1939.]

	Taxa	Publication(s)
1	**Crustacea**	Cadwallader and Eden 1977, Giroud and Balvay 1999, Mori 1936, 1939, Ugolini *et al*. 2004
2	**Araneae**	Briceño and Ramírez 1993, Uetz *et al*. 1994
3	**Ephemeroptera**	Cadwallader and Eden 1977
4	**Odonata**	Boshko and Ermolenko 1955, Dubrovsky and Tytar 2015, Kiauta and Kiauta 1999, Mitra 1996, Szövényi *et al.* 2001, Wheeler *et al*. 1935, Wojtusiak and Majlert 1956
5	**Plecoptera**	Cadwallader and Eden 1977
6	**Blattodea**	Wheeler *et al*. 1935
7	**Orthoptera**	Buckley *et al*. 2018, Dubrovsky 2015, Fischer 2001, Kullenberg 1955, Lockyer 1970, Maunder 1901: 215, Pfeifer 2001, Székely 1999, Szövényi *et al.* 2001, Wheeler *et al*. 1935, Wojtusiak and Majlert 1956
8	**Cicadidae (Hemiptera)**	Buckley *et al*. 2018, Inoue 1936, Sanborn and Phillips 1992, Wheeler *et al*. 1935
9	**Lepidoptera**	Boshko and Ermolenko 1955, Dubrovsky 2015, Hall 1932, Inoue 1936, Kullenberg 1955, Maunder 1901: 214, Moucha 1964, Murdin 2001, Székely 1999, Szövényi *et al.* 2001, Wheeler *et al*. 1935, Wojtusiak and Majlert 1956
10	**Trichoptera**	Cadwallader and Eden 1977
11	**Diptera (general)**	Dubrovsky 2015, Cadwallader and Eden 1977, Inoue 1936, Mori 1963, 1939, Moucha 1964, Smirnov 1981, Székely 1999, Wheeler *et al*. 1935, Wojtusiak and Majlert 1956
12	**Culicidae (Diptera)**	Boshko and Ermolenko 1955, Dubrovsky 2015, Murdin 2001, Wheeler *et al*. 1935, Wojtusiak and Majlert 1956
13	**Chironomidae (Diptera)**	Boshko and Ermolenko 1955, Mori 1939, Murdin 2001, Wheeler *et al*. 1935
14	**Coleoptera**	Branham and Faust 2019, Cadwallader and Eden 1977, Hukusima 1949, Kâto 1937, Kullenberg 1955, Kuwayama 1937, Legros 1913, Newport 1837, Wojtusiak and Majlert 1956
15	**Hymenoptera (general)**	Grebennikov *et al*. 1981, Inoue 1936, Kullenberg 1955, Székely 1999, Wheeler *et al*. 1935
16	**"Bees" (general)**	Dubrovsky 2015, Galen *et al.* 2019 (multiple spp. Observed), Inoue 1936, Grebennikov *et al*. 1981, Murdin 2001

17	**Honeybees (*Apis mellifera* L.) (Hymenoptera)**	Briceño and Ramírez 1993, Demianowicz and Zniszczński 1954, Divan 1980, Hains and Gamper 2017, Holmes 1963, Legros 1913, Lenkiewicz 1962, Lubertowicz and Wlodek 1962, Lundie 1940, Maunder 1901: 212 and 214, Nakano 1958, Newport 1837, Nitschmann 1999, Özbey *et al*. 2004, Pechhacker 1999, Roonwal 1957 (*Apis dorsata* F.), Waiker *et al*. 2019, Wheeler *et al*. 1935, Wojtusiak and Majlert 1956, Woyke 1955, Woyke *et al*. 2000
18	**Bumblebees (*Bombus* spp.) (Hymenoptera)**	Grebennikov *et al*. 1981, Hall 1932, Løken 1954, Szövényi *et al.* 2001, Wheeler *et al*. 1935
	Formicidae (Hymenoptera)	Délye 1974, Dubrovsky 2015, Grebennikov *et al*. 1981, Kullenberg 1955, Majlert and Wojtusiak 1962, Maunder 1901: 215, Santschi 1923, Skrochowska-Gertych and Wojtusiak 1968, Smirnov 1981

tracking of individual honeybees leaving and returning to a hive [Hains and Gamper, 2017]). In the only observation of carrion feeder behavior during an eclipse, Mori (1936) recorded a reduction of flies (56 before, 14 during, 50 after) around dead cod bait during an eclipse. In general, during a solar eclipse: day flying insects such as butterflies (Lepidoptera) and dragonflies (Odonata) reduce their movements; evening-calling insects, such as crickets (Orthoptera) and cicadas (Hemiptera: Cicadidae), begin calling; honeybees (*Apis mellifera* L., Hymenoptera: Apidae) return to the hive more than they leave; and some spiders begin elaborate end-of-day behavior as the light dims only to reverse things as soon as the light returns.

Only one report of a light trap used to collect insects during an eclipse was found. During the total solar eclipse of 11 August 1999 at Pasărea Forest near Bucharest, Romania, Székely (1999) placed a light sheet next to the woods approximately 25 minutes before totality. Numerous insects were attracted to the screen: Diptera, Orthoptera, Hymenoptera, and Lepidoptera. Sadly, no Coleoptera were reported.

Nine comments on beetle behavior during solar eclipses were found.

1. During the 15 May 1836 eclipse at Chichester, Sussex, England, *Geotrupes stercorarius* (L.) (Geotrupidae) was reported "on the wing" about 15 minutes before the eclipse met its maximum (Newport 1837:307).

2. Legros (1913:145) quoted J. H. Fabre who reported that during a solar eclipse all the animals settled down, except for a captive weevil. "Only a weevil, the *Lixus* [F.] [Curculionidae] continues, step by step, without the slightest emotion, his amorous byplay, as though nothing unusual were happening…is a weevil to be upset because the sun threatens to go out?"

3. In Hokkaido, Japan, Kâto (1937) recorded the egg laying behavior of the

strawberry weevil, *Anthonomus bisignifer* Schenkling (Curculionidae) during the eclipse that occurred 19 June 1936. Kâto monitored over 300 strawberry plants at 100 minute intervals over three days and showed that the reduction of light during the eclipse reduced egg laying activity.

4. In Hokkaido, Japan the activity of *Oulema oryzae* (Kuwayama) (as *Lema oryzae*) (Chrysomelidae: Criocerinae) was observed during the solar eclipse (96% coverage) of 19 June 1936 (Kuwayama, 1937). Normal beetle activity consisted of being on leaf surfaces in the sun during the day and retreating beneath leaves during rain or wind. Male and females were placed into enclosures and flying, walking, standing still, and mating activities were recorded. Activity such as walking and flying was reduced during the eclipse and increased after the sun reemerged. However, mating continued uninterrupted, which differed from the usual practice of suspending mating at dusk.

5. In Hokkaido, Japan, Hukusima (1949) observed the behavior of *Phyllotreta vittata* Fabr. (Chrysomelidae) during an eclipse that occurred 9 May 1948. Normal daily activity was reduced to inactivity at the peak of the eclipse, activity resumed after the eclipse, but not at the pre-eclipse level.

6. During the 30 June 1954 eclipse at Öland, Sweden, a *Cetonia aurata* (L.) (Scarabaeidae) "…that had settled to sleep during the eclipse was eagerly attended by ants intent on licking its body." (Kullenberg, 1955).

7. During the eclipse of 30 June 1954 observations were made of animal behavior at two zones, full and partial eclipse, near Dąbrówka, Poland (Wojtusiak and Majlert, 1956). Within the area of total eclipse, *Amphimallon solstitiale* (L.) (Scarabaeidae) emerged from the ground and began flying in the treetops and returned to the ground after the eclipse. The species' normal behavior is to fly in the evening and remain buried during the day. In an area of partial eclipse, individuals of *Carabus* spp. (Carabidae) were seemingly not affected by the eclipse and did not emerge from hiding, as would have been expected if they mistook the eclipse for evening.

8. Invertebrate drift was studied the day before, after, and during the total solar eclipse of 23 October 1976 at Snobs Creek, Victoria, Australia. Larvae of Scirtidae (as Helodidae) exhibited standard dark-active drifting behavior during all three evenings. Additionally, there was also an eclipse-related increase in drift during the period one hour after the eclipse occurred (Cadwallader and Eden, 1977).

9. Daytime flashing by the firefly *Photinus pyralis* (L.) was observed at ten sites from Missouri to North Carolina during the solar eclipse that occurred 21 August 2017 across North America (Branham and Faust, 2019).

The solar eclipse of 21 August 2017 (Fig. 1) offered an opportunity to study the effect of a solar eclipse on UV-light trap catch. The attraction of insects to lights at night is well known but poorly explained. To date, no satisfactory answer dealing with the issue has been given (see Nowinszky, 2003 for a good review). The phenomenon has been known since antiquity and long recognized as useful by collectors. Packard (1873:45) stated that to collect Trichoptera "a bright light placed in damp situations by streams, etc., will attract large numbers, the smaller species, like moths, being attracted a great distance by light." In contrast, the Encyclopedia of Insects (Resh and Cardé, 2003) is entirely silent on insect attraction to lights, as are several other notable entomology textbooks (Gullan and Cranston, 2010; Triplehorn and Johnson, 2005). Considering how important the issue is for biodiversity studies (Hammond, 1990), monitoring (Leasure and Hoback, 2017), pest control (Shimoda and Honda, 2013), and conservation issues (Barghini and de Medeiros, 2012; Eisenbeis, 2006) one would expect that the behavior/mystery would at least warrant a mention in general entomology works.

MATERIALS AND METHODS

The study was conducted at Wildcat Creek (N 34.7563°, W -82.8555°) in the Clemson University Experimental Forest, Pickens County, South Carolina during 21 and 22 August 2017. During 21 August 2017 the total solar eclipse began at 1:08:25 PM local time, reached totality at 2:37:12, totality ended 2 min 37 sec later at 2:39:49, and the eclipse ended at 4:02:36 pm (Espenak, 2017).

Specimens were collected using three bucket-style blacklight traps (Bioquip.com, Catalog #2851M: 22W DC Light Trap) with ethyl alcohol as a killing and preservative agent. Traps were placed approximately 100 m apart in a line along a forest trail and were not visible from one another. Traps were run during three periods: 1) "eclipse" during the eclipse, 1:30–3:30 pm, 21 August; 2) "day" post-eclipse during the day, 1:30–3:30 pm, 22 August; 3) "evening" post eclipse during the evening, 7:30–8:30 pm, 22 August. Sunset was at about 8:10 PM, and evening traps were only run for one hour to simulate the falling light effect of the eclipse.

Specimens were identified using the appropriate literature or identified by authorities (see Acknowledgments) and deposited in the Clemson University Arthropod Collection (CUAC), Clemson University, Clemson, SC, USA.

Statistical analysis was performed using Analysis ToolPak in Microsoft® Excel® for Office 365 MSO. Single factor Analysis of Variance (alpha = 0.05) was used to determine differences in number of specimens collected between 1) eclipse, 2) day, and 3) evening. Number of specimens was doubled for the evening collection due to the shortened collecting time. Post-hoc analysis was performed using a t-Test (two-sample assuming equal variances).

Fig. 1. Three views of the total solar eclipse as seen from the Clemson Experimental Forest, Clemson, SC, 21 August 2017.

RESULTS

In total, 49 specimens representing 16 species within eight families of Coleoptera were collected (Table 2). Collection included 13 specimens and six species during the eclipse, eight specimens and four species during the daytime the next day, and 28 specimens and 10 species during the evening. Thirteen species were unique to their time period, one species was collected during the eclipse and daytime, another species was collected during the eclipse and evening, and an unidentified species of Staphylinidae was collected during all three collection periods.

Number of specimens collected was significantly different among trapping times ($F = 9.947$, $P = 0.012$). Post-hoc pairwise comparisons between eclipse and day showed no significant differences ($P = 0.252$). However, post-hoc pairwise comparisons between eclipse and evening ($P = 0.039$) and day and evening ($P = 0.028$) were significantly different and both showed that the number of specimens collected during the evening was significantly higher than those caught during the eclipse and day, respectively.

DISCUSSION

While exceptions exist, most observations of insects during solar eclipses are qualitative and/or provide no controlled comparison with activity during a non-eclipse time. This study is the first to look at general beetle flight behavior and attraction to a blacklight during a solar eclipse. Additionally, it is the first eclipse blacklight study to provide "control" comparisons with daytime and evening activity.

Table 2. Species of Coleoptera collected during the eclipse.

Family	Species	Eclipse	Day	Evening
Buprestidae	*Pachyschelus laevigatus* (Say)	1		
Clambidae	*Clambus* sp.			2
Curculionidae	*Cnestus mutilatus* (Blandford)		1	
	Euplatypus compositus (Say)			1
	Hylastes tenuis (Eichhoff)	1		
	Hypothenemus seriatus (Eichhoff)		1	
	Xyleborinus saxeseni (Ratzeburg)	2		14
	Xyleborus bispinatus Eichhoff			1
Leiodidae	*Agathidium exiguum* Melsheimer			1
	Aglyptinus laevis (LeConte)			1
	Isoplastus fossor (Horn)			1
Ptiliidae	Ptiliidae gen. sp.			1
Scarabaeidae	*Onthophagus hecate* (Panzer)	2		
Sphindidae	*Sphindus americanus* (LeConte)			1
Staphylinidae	Staphylinidae gen. sp.	1	1	5
	Xenistusa sp.	6	5	
	Total Specimens	13	8	28
	Total Species	6	4	10

Analysis showed no significant difference between trap catch during the eclipse and daytime the next day but did show significantly more specimens collected during the evening when compared to the other two times. Based on these results, beetle flight activity was not affected by the eclipse—apparently the beetles were not fooled.

However, previous studies have shown that daytime-active beetles reduced activities during a solar eclipse (Kâto, 1937; Kuwayama, 1937; Hukusima, 1949), and evening- or night-active beetles either increased activity (Branham and Faust, 2019; Cadwallader and Eden, 1977; Wojtusiak and Majlert, 1956) or were unaffected (Wojtusiak and Majlert, 1956) by a solar eclipse. If reaction to an eclipse varies among taxa (a reasonable assumption) then a survey of beetle activity using a UV light trap (a general collection technique) would require a large number of specimens to show any conclusive trends. Unfortunately, few specimens were collected at any time.

The poor catch during the evening, and perhaps during the eclipse, may be because the forest was exceptionally dry. For seven days prior to the eclipse no rain had fallen in the area and daily temperature maximums were above 32°C (90°F) (Weather Underground, 2018). Had conditions been more favorable there is a real possibility a greater contrast may have been found between eclipse, daytime, and evening catches.

Eclipses are singular events that cannot be replicated at a particular location, but because an eclipse moves across a landscape a type of experimental replication can occur where observations are made at multiple locations over time as the eclipse passes (see Branham and Faust, 2019 for an example). Collaboration with colleagues in other states would have allowed for replication of the experiment, an important consideration for future studies. However, the presence of different taxa in distant states (say, Texas and Virginia) may confound results in the proposed design.

Despite the statistical conclusions, the limitations of the experiment and the poor trap catch led to results that were sufficiently ambiguous to make future studies exciting. Clearly the question of beetle flight activity during a solar eclipse has not been put to rest. Amazingly, an opportunity to repeat the experiment will soon be at hand. During 8 April 2024 another total solar eclipse will travel across the United States from Texas to Maine (Littmann et al., 1999). Presumably the spring weather conditions, especially in the southern portion of the eclipse path, will be favorable to insects and, should this experiment or one like it be repeated, a better understanding of beetle flight during a solar eclipse can be obtained.

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