The Influences of Weather and Moonlight on the Light Trap Catches of Moths

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(Received November 20, 1982)

A quantitative evaluation of the influences of weather and moonlight conditions on the light trap catches of moths was needed to compare samples of different stands and time. Multiple regression analysis was employed to establish which factors were important in determining the collected number of species and individuals and other characteristics of a moth sample. Data of seventeen August samplings taken from 20:00-21:00 and the weather and moonlight conditions prevailing at that same time were used. Regression analyses showed that most of the variation in the number of collected species could be described by an equation involving wind velocity, fog density, change in temperature from the previous night and lightness of the sky during the night. Standard partial regression coefficient showed that fog density was the most important positive effect component and wind velocity the main negative effect component. The equation for estimating the number of collected individuals described a smaller portion of the variability than the number of species. Air temperature did not significantly affect either the number of species or individuals.

INTRODUCTION

Moths feed on a wide variety of plants and a single night sampling by light trap often gathers thousands of individuals and hundreds of species in a forested area. Light trap sampling of these insects is thus one of the best ways to obtain information on the relationship between the moth community and its environment. For example, the method is most suitable for the study of community diversity in relation to vegetation and that of biological indicator of the environment.

The effects of weather conditions on moth flight to a light have been previously studied. Several weather factors and their influence on insect light trap catches were investigated systemically by Williams (1940). However, his study was concerned mainly with the total number of individuals, and there has been no investigation concerning both the number of species and of moth individuals in relation to weather conditions.

Many investigations indicate that moonlight also has an influence on moth catches (Williams, 1936, 1940; Nemec, 1971; Siddorn and Brown, 1971; Nowinszky et al., 1979). It is considered that light trap collection is largely influenced by the activity of the moths and/or the trapping efficiency of a light trap (Williams, 1940; Nowinszky et al., 1979), and that both these factors are greatly affected by weather and moonlight conditions.
Consequently, a quantitative evaluation of the effect of each factor on light trap catches of moths was needed for the comparison of samples of different stands and times. This may in turn aid in the study of the diversity of moth communities. Multiple regression analyses were used to identify the factors related to the variation in catches. The application of the equations proposed in this paper may be useful in many investigations relating to moth light trap sampling.

**METHODS**

Sampling of moths was carried out on the campus of the Sugadaira Montane Research Center of the University of Tsukuba, Chiisagata-gun, Nagano Prefecture, which is in the central part of Japan and about 1,300 m above sea level.

An electrode-type light trap, which was double-baffled and equipped with one vertically mounted 10-watt blacklight fluorescent lamp (MIZUTANI et al., 1982) was employed in the experiment. At the center of a grassland bordered on two sides by forest, two light traps were set so that the light source was about 2 m above ground level and the baffles of the two traps were at right angles to each other (Fig. 1).

Collection of moths was carried out from 20:00 to 4:00 between August 11 and August 30, 1977 except for August 22, 24 and 25. Air temperature, relative humidity, fog density, wind velocity, lightness of the sky and precipitation were measured simultaneously during the night.

*Measurement of weather and moonlight conditions*

*Air temperature.* Air temperature was measured by a thermister sensor enclosed in a screen 1.5 m above the ground on the grassland about 100 m from the trapping point, and was recorded continuously by a meteorograph during the collection periods. The data used in the analysis are the average temperature of an hourly period.

*Relative humidity.* Relative humidity was measured hourly by an Assman aspiratory psychrometer in the same screen as the air sensor.
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Fog density. The observation of fog density was carried out hourly. The 100-watt mercury vapor lamp light source (HF 100W) was observable from a distance of 100 m. A condition of no fog was classified as rank 0. A density of fog which did not hide the light source was classified as rank 1. A density which hid the light source was classified as rank 2. In rank 2 only an obscure circle of illuminated fog could be observed around the light source. The ranks at the beginning and the end of an hourly period were totalled, and their sum referred to as "density" of the period. Therefore, the "density" was graded into 5 ranks, from 0 to 4; for example, if the density at 20:00 was rank 1 and that at 21:00 was 2, the "density" of the period is shown as 3.

Wind velocity. Wind velocity was measured by an aerovane (combined wind vane and anemometer) on the 4 m high roof of the laboratory building 150 m from the trapping point. The data were continuously recorded by a meteorograph and averaged hourly for analysis.

Precipitation. Precipitation was measured continuously by an electric rainfall recorder and averaged hourly.

Moonlight. Lightness of the sky during the night, which was mainly influenced by the moon condition, was measured hourly by a newly devised cumulative photographic illuminometer. A negative film (Fuji Neopan SS) was set under strips of gelatin filters of perviousness from 1/2 to 1/500 and exposed to the night sky. Lightness was ranked by the density of negatives developed under defined conditions so as to be doubled per increased rank. Therefore, rank 10 represents a lightness 32 (=2^5) times greater than the lightness in rank 5.

A multiple regression analysis was employed to identify the variation factors in the light trap catches of moths. Independent variables used in the analysis included several expressions of the weather conditions and the lightness of the sky during the sampling period. This regression includes the following prime independent variables: air temperature, change in air temperature from the previous night, relative humidity, fog density, wind velocity and lightness of the sky. Since only 2 of the 17 nights had drizzly rain of less than 1 mm/hr, precipitation data were not among the analysis variables.

As dependent variables, the number of individuals, number of species, number of species of three dominant families and a diversity index were used. For the index, the SHANNON-WIENER function was used:

\[ H' = \sum p_i \log p_i, \]

where \( p_i \) = \( n_i / N \), \( N \) = total number of individuals in each sample, \( n_i \) = the number of individuals of ith species, and unit of \( H' \) is bit.

Seventeen consecutive samples taken during the 20:00–21:00 period and the weather and moonlight conditions of the same period were used in multiple regression analysis. A Statistical Package for the Social Sciences (SPSS) was used in calculation. Independent variables were added to the equations in a stepwise fashion beginning with the one having the highest correlation coefficient with a dependent variable. Additional independent variables were added singly and their effect in reducing the variation calculated. The final regression equations selected were those that described the largest portion of the variation with the fewest equational terms.
Table 1. Mean, S.D. and range of dependent and independent variables during the experimental period

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of species</td>
<td>40.29</td>
<td>23.09</td>
<td>11 – 86</td>
</tr>
<tr>
<td>No. of individuals</td>
<td>165.76</td>
<td>137.93</td>
<td>22 – 443</td>
</tr>
<tr>
<td>No. of noctuid species</td>
<td>23.35</td>
<td>11.82</td>
<td>9 – 45</td>
</tr>
<tr>
<td>No. of geometrid species</td>
<td>6.47</td>
<td>4.27</td>
<td>0 – 15</td>
</tr>
<tr>
<td>No. of pyralid species</td>
<td>5.82</td>
<td>3.61</td>
<td>0 – 12</td>
</tr>
<tr>
<td>Diversity index (H')</td>
<td>3.99</td>
<td>0.77</td>
<td>2.20 – 4.98</td>
</tr>
<tr>
<td>Wind velocity (m/sec)</td>
<td>1.32</td>
<td>1.07</td>
<td>0 – 3</td>
</tr>
<tr>
<td>Fog density</td>
<td>0.82</td>
<td>1.19</td>
<td>0 – 3</td>
</tr>
<tr>
<td>Lightness of the sky</td>
<td>6.50</td>
<td>1.78</td>
<td>4.5 – 10</td>
</tr>
<tr>
<td>Relative humidity (%)</td>
<td>97.80</td>
<td>3.11</td>
<td>91 – 100</td>
</tr>
<tr>
<td>Air temperature (°C)</td>
<td>16.99</td>
<td>1.69</td>
<td>14.5 – 19.8</td>
</tr>
<tr>
<td>Change in temperature from the previous night (°C)</td>
<td>0.22</td>
<td>1.49</td>
<td>−2 – 3</td>
</tr>
</tbody>
</table>

Fig. 2. Weather and moonlight conditions of the 20:00-21:00 period of 17 sampling nights in August.

RESULTS

The mean, standard deviation (S.D.) and range of each dependent and independent variable of the 20:00-21:00 period are shown in Table 1. Large daily variation was seen in both dependent and independent variables, though the air temperature and relative humidity were rather stable. There was no significant correlation between any combination of independent variables of the 17 days of data, and therefore there was no need to consider an interaction between them which may have distorted the real effect of each one.
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Fig. 3. Observed and estimated numbers of species during the 17 20:00-21:00 sampling periods.

Total number of species

The multiple regression equation calculated from the data set of a 20:00-21:00 period for estimating the total number of species \( Y(S) \) was:

\[
Y(S) = 75.0 - 14.3X_1 + 10.2X_2 + 4.10X_3 - 3.85X_4
\]

\[ R^2 = 0.87 \quad F = 19.51^{**} \quad (d.f. = 4,12) \]

where \( X_1, X_2, X_3 \) and \( X_4 \), the independent variables, were wind velocity, fog density, change in temperature from previous night and lightness of the sky, respectively. F-tests indicated that the coefficient for each independent variable was significantly different from zero. Daily fluctuation of these variables for the 17 sampling days are shown in Fig. 2. August 15 was a new moon and August 30 was a full moon. Observed and estimated numbers of species under these conditions are shown in Fig. 3. The estimates were reasonably close to the observed values.

Standard partial regression coefficients are those in the following equations where all variables have been standardized, that is, measured from their means in units of standard deviations. The standard regression equation for the number of species was:

\[
Y'(S) = -0.667X'_1 + 0.526X'_2 + 0.265X'_3 - 0.297X'_4
\]

\[ Y'(S) = \frac{Y(S) - \bar{Y}(S)}{S_y(S)}, X'_i = \frac{X_i - \bar{X}_i}{S_{X_i}} \]

Total number of individuals

The multiple regression equation to estimate the total number of individuals \( Y(I) \) was:

\[
Y(I) = 372 - 57.2X_1 + 56.7X_2 - 27.3X_4
\]

\[ R^2 = 0.71 \quad F = 10.87^{**} \quad (d.f. = 3,13) \]

F-tests indicated that the coefficient for each independent variable was significantly
different from zero. The coefficient for change in temperature ($X_3$) was insignificant, for the F-value was slightly smaller than significant level.

The standard regression equation was:

$$Y'(l) = -0.445X'_1 + 0.488X'_2 - 0.352X'_4$$

(2)

Number of noctuid, geometrid and pyralid species

The multiple regression equations to estimate the number of species of three dominant families (Noctuidae, Geometridae and Pyralidae) were,

$$Y(N) = 37.6 - 4.65X_1 + 6.27X_2 - 2.03X_4$$

$R^2 = 0.86$ $F = 27.04^{**}$ (d.f. = 3,13)

$$Y(G) = 10.4 - 3.00X_1$$

$R^2 = 0.57$ $F = 19.85^{**}$ (d.f. = 1,15)

$$Y(P) = 9.64 - 2.88X_1$$

$R^2 = 0.73$ $F = 41.53^{**}$ (d.f. = 1,15)

where $Y(N)$, $Y(G)$ and $Y(P)$ are the number of noctuid, geometrid and pyralid species, respectively. The equation of Noctuidae was similar to that of total species number (1), but in Geometridae and Pyralidae wind velocity was the only factor significantly affecting the number of species. Among the three dominant families, the noctuid species most influenced the value of coefficients for the total number of species (1) because it accounted for more than half of the total species in mean number (Table 1).

Diversity index

The equation for estimating the diversity index ($Y(D)$) was:

$$Y(D) = 4.43 - 0.486X_1 + 0.246X_2$$

$R^2 = 0.79$ $F = 26.82^{**}$ (d.f. = 2,14)

In all cases (1)–(6), there were no significant partial regressions on the independent variables of air temperature and relative humidity.

DISCUSSION

Air temperature

The sign and value of the coefficient of each independent variable to estimate the number of species and individuals (1), (2) seem in large part to agree with the expectation of those in Japan who study moth communities by light trap. Contrary to expectations, the results of this study showed that there was no influence of air temperature on moth catches in any case (1)–(5). TAYLOR (1963) clearly showed that flight occurrence increased with temperature for a heterogeneous population, so it had been expected that moth catches would also increase with rising air temperature.

Within the lower threshold range of flight activity of a component species of a moth community the number of species collected must increase with temperature (TAYLOR, 1963). However, once the temperature exceeds the range of thresholds, the influence of air temperature should disappear. So it is considered that, at the altitude
of this study area, the temperature within the range of 14.5–19.8°C (Table 1) exceeded the threshold range of all component species and did not influence moth flight activity (in other words, all species were active). Taylor and Carter (1961) reported that the thresholds were very low in two moth species: Amphipyrta tragopogis at 10.5°C and Agrochola lychnidis at 9.0°C.

The influence of air temperature on moth flight activity may vary at different altitudes if the population adapted to each altitude responds differently to a certain temperature.

It was interesting that the moths responded to the comparative change in temperature from the previous night instead of to the temperature itself (1). The proportion of active individuals in each species may change according to the change in air temperature, reflecting the total number of species collected by light traps.

Fog

The influence of fog on the moth catch in this study was similar to a result observed by Williams (1940). One foggy night of sampling in September at Rothamsted Experiment Station resulted in a larger catch of noctuid species than under normal conditions, though the air temperature was far below the range of this study.

Among the three dominant families, only the number of noctuid species was influenced by fog density (3), which affected the estimation of the total number of species (1). The standard partial regression coefficient, which gives a measure of the relative importance of the independent variables, shows the importance of fog density as a positive effect component (1)', (2)'.

Moonlight

A few entomologists have investigated the influence of moonlight intensity on the light trap catch of moths (Williams, 1936, 1940; Nemec, 1971; Siddorn and Brown, 1971; Bowden and Church, 1973). Most of these studies were based on sampling data from three or more years so that the influence of other conditions might be minimized. In almost all of these studies, a regular lunar cycle was common in the catch of moths and more individuals were caught at new moon than at full moon. Williams (1936) found that the catch ratio of noctuid moths was 2.7:1 (new moon to full moon), and according to the estimation of Nowinszky et al. (1979) the ratio was 2.6:1, though 2 of 7 species examined were coleopterous. Even for the 17 nights of collection in this study, the calculation with the multiple regression equation resulted in a catch ratio of new moon to full moon similar to that of other studies. According to Eq. (2), the ratio individuals caught at new moon to those at full moon is 3.1:1. On the other hand, according to Eq. (1), the catch ratio of the number of species is 1.8:1.

Nowinszky et al. (1979), on the other hand, found from 14 years of data that light traps caught the highest numbers during the first and the last quarters of the lunar cycle as well as at new moon. They demonstrated that not only moonlight intensity but also the polarization rate (PR) of moonlight influenced the moth light trap catch numbers. So the PR values shown in Nowinszky et al. were added to the independent variables of the multiple regression analysis in estimating the total number of individuals. No significant partial regression on PR was obtained, but nevertheless the collection could not be done thoroughly on the days when PR was at its peak because of excessively heavy wind. For this reason, the result of the multiple regression analysis
in this study cannot be considered contradictory to the conclusions of Nowinszky et al.

Wind

The regression coefficients for wind velocity were significantly different from zero in all the equations for estimating the number of species and individuals (1)-(5). The standard partial regression coefficient shows the importance of wind velocity as a negative effect component (1'), (2').

Among the three families, the noctuid species seems to be much less affected by the wind (3), (4), (5). One hundred species of Geometridae in a 0 m/sec condition decrease to 71.5 in a 1 m/sec condition and Pyralidae decreases to 70.1 in a case where other independent variables are of mean value; Noctuidae, meanwhile, decreases to only 84.3. If the wind velocity increases to 3 m/sec, the rate will be 13.5, 10.4 and 52.8, respectively. Judging from this, moth size and manner of flight may affect their sensitivity to wind velocity.

Diversity index

It is known that \( H' \) tends to increase to some extent with increasing sample size until it levels off (Pielou, 1966; Heyer and Berven, 1973). \( H' \) calculated from only an hour of light trap sampling fluctuates mainly with the fluctuation of sample size. \( H' \) is divided into two factors, namely “species richness” measured by number of species, and “equitability” measured by relative species diversity. In this study, \( H' \) fluctuated with the number of species \((r=0.86)\) among 17 nights' samples and not with relative species diversity \((J')\) (Pielou, 1966) \((r=-0.15)\). Therefore, weather conditions considered to have influenced the diversity index \((H')\) by affecting the number of species (1).

The multiple regression analysis showed that most of the variation in the total species number can be described by an equation involving wind velocity, fog density, change in air temperature from the previous night and lightness of the sky during the night. The standard partial regression coefficient showed that, among these variables, fog density was the most important as a positive effect component and wind velocity as a negative effect component.

It is considered that the residual between observed and estimated species number (Fig. 3) is due partly to collections of the previous nights which might, in turn, have altered the population densities.

There is a question as to why most of the variation in moth light trap catch can be ascribed to weather and moonlight conditions. These conditions are thought to affect the flight activity of moths and/or effective trapping area. Nowinszky et al. (1979) concluded that the moonlight influences both the effective trapping area and the flight activity of the insects through changes in light intensity and PR. However, the question has not yet been completely solved, and the reason moths are lured to the light is still not understood.

Should the light trap sampling of moths be used as a method to study insect community diversity and as a biological indicator of the environment, standardized evaluation of weather and moonlight conditions will be valuable for quantitative comparisons between samples from different times and locations.
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ACKNOWLEDGEMENTS

The author wishes to thank Dr. J. MISHIMA, University of Tsukuba, for his continuous guidance and reading of the manuscript. Thanks are also due to Prof. H. ANDO, Sugadaira Montane Research Center, University of Tsukuba, for his helpful suggestions.

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