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# IX—The Influence of Moonlight on the Activity of Certain Nocturnal Insects, Particularly of the Family Noctuidae, as Indicated by a Light Trap

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## Introduction

For many years amateur entomologists have considered that on nights of full moon it is of little use going out to catch specimens, as insects will be few in number. This belief applies to all methods of collecting, including bait (sugaring) and light, and is supposed to apply particularly to the Lepidoptera.

Scattered through the literature on Agricultural Entomology one finds occasionally references to the use of light traps for the destruction of pests, and statements, usually from the tropics, that the catches were less at times of full moon; but so far as I am aware no proper statistical study of the question has ever been made.

One of the most striking series of figures is that produced by Pagden (1932) by trapping with a light trap the two Pyralid moths *Diatraea auricilia* and *Schoenobius incertellus* which are pests of rice in Malaya. He found, between 18 January and 29 June, 1931, six periods of maximum catch in both sexes of both species corresponding more or less to the no moon periods, and six periods of minimum catch corresponding even more definitely to the full moons. Scarcely any insects were captured at the time of full moon.

It has been known for many years that some animals have periodicities of activity corresponding to lunar months. Information about these has been dealt with in recent years chiefly by Fox (1923). The animals concerned are mostly marine, and it is probable that in some cases the effect is produced through the tides; but Dorr (1932) has suggested that there is a lunar influence on the dates of movements of migrant birds. Specific reference to lunar influence on insects, other than captures by means of traps, are rare. Hora (1927) has suggested that some species of May-Flies (Ephemeridae) tend to emerge and make their nuptial flights at definite phases of the moon. The evidence that he brings forward is, however, too slight to be in any way conclusive, and a series of regular observations should be carried out in some suitable locality to see if the theory is supported.

## The Rothamsted Experiments

### *The Light Trap*

In March, 1933, a light trap was started in one of the fields at Rothamsted Experimental Station, about twenty-five miles north of London, and it has been in practically continuous use for nearly three years. The trap was similar to that first designed in Egypt (Williams, 1924) except that an electric light of about 300 candle-power was used instead of acetylene, and an arrangement was added which divided the catch into eight equal periods during the night, so that it is possible to estimate the time of entry of the insects into the trap and hence the time of activity of any group or species. A full description will be found in a more recent paper (Williams, 1935).

The main object of the experiment was to provide material for a statistical examination of the relation of insect activity to climatic and weather conditions, but it is possible to use the figures so obtained to see if there is evidence of lunar periodicity in any or all of the groups into which the catch was divided.

### *The Measurement of Night Cloud and Moonlight*

At an early stage in the investigation it was realized that the " moon " issue was associated with and complicated by, the presence or absence of cloud in the sky in two ways. First, the belief by amateurs that catches were low on moonlight nights might be an example of false reasoning, as nights on which the moon is obvious must be largely clear nights, and these are colder than cloudy nights owing to high radiation. It might therefore easily be that the lower temperature and not the moonlight was causing the low catch.

Secondly, if it is the moonlight that is affecting the catches, then its influence would not be expected to be so great on cloudy nights as on clear ones.

It was necessary, therefore, to have some measure of the cloudiness of each night. This was eventually done in five different ways.

(1) For the first year a note was kept each morning of all that could be recollected of cloud conditions in the late evening and early morning by members of the staff. This was at the best very unsatisfactory.

(2) Towards the end of the first year a " night cloud recorder " was built on the principle of the instrument in use at Greenwich (Anon, 1931). This is a long focus camera which photographs the pole star during the night, and from the tracing so produced the duration of the cloud obscuring the star can be measured. The modifications that were introduced at Rothamsted were chiefly in using a very much smaller camera with a roll film, and in having an automatic clockwork shutter, so that no attention was needed during the night. A description of the modified instrument is being published elsewhere (Williams, 1936, *a*).

(3) In order to supply more reliable information about the cloudiness of the nights in the first year, Greenwich Observatory, which is about 27 miles away to the S.S.E., kindly gave us a list of the nights in both 1933 and 1934, when their instrument indicated either less than 10% of the night cloudy (referred to below as " clear ") or more than 90% of the night cloudy (referred to below as " cloudy " nights). A comparison of the results in the second year with our Rothamsted figures showed a close resemblance so that, in the absence of records at Rothamsted, the Greenwich figures could be used with a fair degree of accuracy.

(4) It was found that there was a certain correlation between the amount of night cloud and the difference between the " air minimum " and the " grass minimum " temperature for that night. This correlation is by no means absolute, but on the whole clear nights tended to have a high difference and cloudy nights a low difference. In spite, however, of many exceptions to the above general rule it was found that in the year 1934, if the difference between the air and grass-minimum

was 2° F. or less, then the night was always cloudy. This relation was therefore used retrospectively for 1933.

(5) The light of the moon was measured directly during most of 1934 and 1935 by a photographic instrument specially designed for the purpose. The instrument has been recently fully described (Williams and Emery, 1935) and it is unnecessary to go into detail here. The principle is that a line image of the moon, produced by a cylindrical lens, is focussed on to a fixed strip of photographic paper. As the moon moves through the sky the lens follows its direction by means of a clockwork mechanism and the light from the moon thus forms a band on the sensitive strip. When the moonlight is bright the strip is darkened and when there is no moon the strip is unaffected.

A comparison of the results of the star recorder and the moonlight recorder shows that the former is much more sensitive to cloud. The clouds that obscure the pole-star still allow a considerable amount of light to pass from the moon. In fact, measurable light from the moon penetrates all but the thickest cloud. This is supported by the results below, which show that the lunar influence on certain insects is detectable even on cloudy nights.

To summarize—the five methods used for obtaining a measure of the night cloud were (1) personal observation, (2) Rothamsted star camera (1934 and 1935), (3) Greenwich star camera, (4) difference between air and grass minimum temperature, and (5) photographic moonlight recorder (1934 and 1935).

### *Note on the Apparent Movements of the Moon*

The moon changes from its highest position in the sky at southing to its lowest and back again during a lunar month. In the summer it is low at full moon and high at no moon, while in the winter it is high at full moon and low at no moon. This results in the light of the full moon being much brighter in winter than in summer. The greatest angular height of the moon at southing above the horizon at London (latitude approx. 51° N.) is 66° and the lowest is 12°.

The moon souths on an average 49 minutes later each night, but within the course of a single lunar month the difference in time may vary from 41 to 66 minutes in a sequence which has two maxima and two minima.

The time of rising or of setting of the moon is later on an average each successive day by the same period (49 minutes) as that of the moon southing, but the variation is much greater and the extremes are approximately from 12 minutes to 1 hour 33 minutes. In each lunar month there is a cycle changing from long differences to short differences and then back again. In December the short differences occur when the moon is rising or setting about midday and the long differences when it is rising or setting during the night. In June the reverse occurs (*see* fig. 3). When the short differences occur during the night on one side of midnight with longer differences on the other side, there is an asymmetry of the lunar influence on successive nights which is discussed more fully later.

Any lunar effect on the activity of insects during the night would be expected to depend on: (A) the duration of the moonlight; and (B) the intensity of the moonlight. The latter will depend on (1) the phase of the moon and (2) the angle of the moon above the horizon, and the latter again will depend on (*a*) the maximum height of the moon above the horizon (at southing) for the night and (*b*) the particular hour between southing and moon-rise or moon-set.

### *Note on the Use of Logarithms in Analysis*

In the statistical treatment of a number of values for captures of insects such as that which follows, it is frequently necessary to combine together the captures on a series of days which have some condition in common, and to compare the total or average with that of a second series of days with different conditions.

The catches, however, vary very considerably from day to day, and if the actual numbers are added together and the arithmetical mean used, there is danger of the results being swamped by one or two abnormally high catches. For example, in the full moon week of October, 1933, the captures of Noctuidae on the seven nights were 0 : 0 : 1 : 62 : 0 : 0 : 0; while in the corresponding no moon week the captures were 2 : 4 : 0 : 0 : 10 : 3 : 3. The higher total for the full moon week is obviously unduly weighted by the single large catch.

Further, when the departures of series of values for catches from the arithmetical mean are studied, it is found that they consist of a large number of small negative departures and a few large positive departures. This gives a skew distribution which does not lend itself to statistical investigation by the normal formulae of standard deviation, etc.

If the logarithm of each value is taken and these summed and averaged, a measure is obtained of the geometric mean of the values. When this is done it is found that the swamping effect of the single large values is much reduced; and if the log values are expressed as departures from a mean, the distribution of departures gives a much more normal curve.

This shows that changes in numbers are equivalent at different levels if they are in similar geometric and not arithmetic proportion. For example, that the change from 100 to 150 insects is equivalent to that from 1000 to 1500 and not to the change from 1000 to 1050.

This result was to be expected from *a priori* reasoning, as it is most probable that variations in climatic conditions would produce similar proportional changes in different populations, but it was necessary to confirm it by actual results before adopting the method of logarithms for general analysis.

A complication ensues if any of the values to be dealt with are zero, as the log of zero is minus infinity and the geometric mean of any series involving zero is itself zero. To overcome this it has been found possible to add one unit to all the values before converting into logs, and then to subtract the unit later when the log is reconverted to an anti-log.

The use of logarithms in the present series of figures emphasizes all differences that are consistent and reduces all that are not so. Thus in the two weeks' figures for the Noctuidae given above the sums of the numbers are 63 : 22, but sum of log $(n + 1)$ are 2·10 : 3·89.

The method has been used in the interpretation of figures showing the time of flight of insects at night (Williams, 1935), and always gives more consistent results than does the use of the actual numbers themselves. This point is dealt with more fully in a separate publication (Williams, 1936, *b*.)

In the present study, therefore, the figures used for comparisons are (unless otherwise stated) log $(n + 1)$ for a single value or $\Sigma$ log $(n + 1)$ for the value of a series.

When the series to be examined is spread over a considerable length of time, during which the total population is likely to have changed, a running mean is made of the log $(n + 1)$ and each night expressed as a departure from that mean. The running mean here used is a 29-day mean, equal to the length of the lunar period, so as to eliminate variations of a longer period than the moon, but to leave the lunar period unaffected.

## Analysis of the Results in the Family Noctuidae (Lepidoptera)

In the past, most supposed effects of moonlight on insects have been reported in the Lepidoptera, so that the first investigation was made on this group. In order, however, that any results should be reliable statistically, it was necessary to obtain figures that would cover a number of lunar periods. No single species of Lepidoptera which was common in the trap complied with this demand, most lasting for only one or two lunar periods or less. It was therefore decided to study first the possible effect on the total numbers of all species of the family Noctuidae (s.l).

If all species so combined are affected similarly by the moon then the effect should be noticeable in the combined results. If some species are affected and others not, the combined results would then show a diluted effect. The only difficulty in interpretation would arise if no effect was found in the group ; as this might mean that there was no effect on any species or alternatively that some were affected positively and an equal number negatively, the two cancelling out each other in the combined total. This, however, did not occur.

There is no doubt that the most interesting results will be finally obtained by investigating single species or even each sex of a species separately, but for this purpose either many years' consecutive work will be necessary with traps in different localities or else some long- or many-brooded species must be chosen, probably in the tropics, such as the Rice borers investigated in Malaya by Pagden.

### *Numbers, Species, and Time of Flight of Noctuidae*

In the course of the three years (1933, 1934, and 1935), 8712 Noctuidae were captured in the trap during the six summer lunar months discussed. The numbers in each year were 1582 in 1933, 1869 in 1934, and 5261 in 1935.

About 110 species were represented in the captures, and Table I shows the 25 species of which more than 50 specimens were captured, together with the total numbers of these in the three years. All these species occurred in each of the three years. The nomenclature is, for convenience, that used in South's "Moths of the British Isles".

These species account for 7838 individuals out of the 8712 captured, leaving 874 individuals distributed over about 85 other species.

TABLE I

More Abundant Species and Numbers of Noctuidae Captured in the Trap in the Three Years 1933–1935

| | | | |
|---|---|---|---|
| *Agrotis exclamationis* | 2074 | *Miana fasciuncula* | 148 |
| *Amathes lychnidis* | 781 | *Cerigo matura* | 146 |
| *Xylophasia monoglypha* | 723 | *Taeniocampa gothica* | 137 |
| *Luperina testacea* | 493 | *Rusina tenebrosa* | 124 |
| *Noctua xanthographa* | 483 | *Leucania conigera* | 112 |
| *Noctua c-nigrum* | 469 | *Miana strigilis* | 102 |
| *Anchocelis lunosa* | 419 | *Leucania comma* | 85 |
| *Apamea secalis* | 289 | *Noctua primulae* | 83 |
| *Epineuronia popularis* | 275 | *Grammesia trigrammica* | 73 |
| *Noctua rubi* | 227 | *Agrotis puta* | 55 |
| *Leucania pallens* | 206 | *Hydroecia micacea* | 51 |
| *Leucania impura* | 184 | *Triphaena pronuba* | 50 |
| *Miana bicoloria* | 164 | | |

The Noctuidae in general are rather late flyers. In the three years, the distribution in the eight equal periods of the night, four before and four after midnight, was as follows: 599 : 826 : 1013 : 1454 : 1759 : 1429 : 955 : 309.

This gives a total of 3892 (47%) before midnight and 4452 (53%) after midnight with the maximum flight just after midnight. These figures are shown graphically in the vertical columns in fig. 5 together with similar ones prepared by a summation of the logarithms.

Table II shows the Noctuidae captured each night in six lunar periods (from full moon to full moon) in 1932 and summaries of the captures in 1934 and 1935, approximately from the beginning of May to the end of October in each year, when the Noctuidae were most numerous. This gives the possibility of investigating eighteen lunar periods.

### *Comparison of Full Moon and No Moon Weeks*

Since if any lunar effect was present it would be expected to be most obvious near the two extremes of full and no moon, a simple comparison can first be made by adding in each lunar month the captures for the first four and last three days (the "full moon" week), and comparing them with the figures for the middle seven days (the "no moon" week). Table III shows the results for the eighteen lunar months, the larger figure of each pair being in heavy type. The table shows first

TABLE II

Noctuidae Captured in Each Day of Six Lunar Months of the Summer of 1933, with Summaries of the Captures for 1934 and 1935

| Lunar Month Starting | Days in Lunar Month | 9 May | 7 June | 6 July | 5 Aug. | 3 Sept. | 3 Oct. | Total | 1934 Total | 1935 Total | 1933–34–35 Total | 1933–34–35 Five-day Smoothed mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Full | 1 | 0 | 9 | 7 | 0 | 8 | 0 | 24 | 20 | 23 | 67 | 3·7 |
| | 2 | 0 | 7 | 8 | 9 | 4 | 0 | 28 | 12 | 71 | 111 | 3·8 |
| | 3 | 1 | 6 | — | 3 | 9 | 1 | 24* | 14 | 54 | 92 | 4·4 |
| | 4 | 2 | 12 | 3 | 8 | 4 | 62 | 91 | 29 | 60 | 180 | 5·0 |
| | 5 | 2 | 9 | — | 5 | 4 | 25 | 54* | 52 | 97 | 203 | 5·7 |
| | 6 | 1 | 5 | 5 | 15 | 3 | 2 | 31 | 51 | 78 | 160 | 6·6 |
| | 7 | 4 | 30 | 4 | 17 | 3 | 2 | 60 | 60* | 106 | 226 | 7·5 |
| | 8 | 2 | 21 | 12 | 10 | 1 | 2 | 38 | 45 | 137 | 220 | 8·6 |
| | 9 | 1 | 39 | 1 | 12 | 9 | 1 | 63 | 48 | 212 | 323 | 11·2 |
| | 10 | 6 | 6 | 11 | 24 | 6 | 0 | 53 | 68 | 234 | 355 | 11·9 |
| | 11 | 3 | 4 | 5 | 15 | 4 | 5 | 36 | 82 | 445 | 563 | 12·4 |
| | 12 | 2 | 5 | 9 | 14 | 4 | 2 | 36 | 78 | 216 | 330 | 12·5 |
| | 13 | 2 | 5 | 6 | 6 | 8 | 4 | 31 | 73 | 182 | 286 | 12·5 |
| | 14 | 8 | 7 | 15 | 17 | 15 | 0 | 62 | 92 | 186 | 340 | 12·9 |
| New | 15 | 3 | 8 | 7 | 17 | 7 | 0 | 42 | 92 | 216 | 350 | 13·3 |
| | 16 | 2 | 8 | 16 | 8 | 9 | 10 | 53 | 74 | 504 | 631 | 13·7 |
| | 17 | 1 | 7 | 13 | 5 | 8 | 3 | 37 | 92 | 261 | 390 | 13·4 |
| | 18 | 2 | 16 | 12 | 10 | 19 | 3 | 62 | 72 | 210 | 344 | 13·0 |
| | 19 | 1 | 44 | 4 | 9 | 10 | 8 | 76 | 74 | 147 | 297 | 11·4 |
| | 20 | 6 | 12 | 6 | 24 | 8 | 6 | 72 | 61 | 150 | 283 | 11·5 |
| | 21 | 1 | 5 | 23 | 38 | 9 | 12 | 88 | 99 | 205 | 392 | 11·5 |
| | 22 | 4 | 4 | 10 | 23 | 13 | 6 | 60 | 129 | 226 | 415 | 12·5 |
| | 23 | 1 | 38 | 4 | 31 | 23 | 0 | 97 | 82 | 171 | 350 | 13·1 |
| | 24 | 0 | 5 | 3 | 39 | 38 | 1 | 88 | 103 | 249 | 440 | 13·8 |
| | 25 | 0 | 15 | 5 | 30 | 29 | 0 | 79 | 55 | 233 | 367 | 12·4 |
| | 26 | 1 | 4 | 5 | 38 | 36 | 0 | 84 | 74 | 344 | 502 | 11·2 |
| | 27 | 2 | 9 | 17 | 24 | 3 | 0 | 55 | 52 | 98 | 205 | 9·1 |
| | 28 | 3 | 4 | 9 | 11 | 1 | 0 | 28 | 43 | 93* | 164 | 7·0 |
| | 29 | 7 | 8 | 6 | 9 | 0 | 0 | 30 | 43 | 53 | 126 | 4·5 |
| | | | | | | Total . | . | . 1582 | 1869 | 5361 | 8712 | |

* Corrected for one missing day.

the figures obtained by adding the actual captures and second those by adding the logarithms of the numbers.

It will be seen that for the actual numbers, in seventeen out of the eighteen lunar months the captures of the Noctuidae in the "no moon" week were above those of the "full moon" week. The only exception is interesting as the 63 insects captured in that full moon week (October, 1933) was made up of no insects on each of five nights, one on one night, and 62 insects on the remaining night. This exceptional night (6 October) gave the highest total capture of Noctuidae of any night in the first two years and actually was a night of heavy cloud and therefore unlikely to be influenced by the moon. It will therefore be seen that the only exception to the rule of higher catches at no moon was statistically and meteorologically abnormal.

The second set of figures in Table III shows the same comparison based on the

Table III

Comparison of the Captures of Noctuidae in the Full Moon and No Moon Weeks in the Six Lunar Months of the Summers of 1933–1935. (Maximum of each pair in heavy type.) Also Similar Values for the Minimum Night Temperatures

| Sum of numbers | May | June | July | Aug. | Sept. | Oct. | Years Total | All three years |
|---|---|---|---|---|---|---|---|---|
| 1933—Week of full moon | 15 | 55 | 58 | 64 | 29 | **63** | 284 | |
| No moon | **19** | **95** | **73** | **72** | **76** | 22 | **357** | |
| 1934—Full moon | 2 | 52 | 37 | 69 | 61 | 1 | 222 | 1242 |
| No moon | **25** | **56** | **140** | **76** | **204** | **71** | **575** | **2853** |
| 1935—Full moon | 2 | 15 | 477 | 168 | 64 | 10 | 736 | |
| No moon | **23** | **179** | **917** | **385** | **267** | **133** | **1904** | |
| Sum of logarithms $(n + 1)$ | | | | | | | | |
| 1933—Week of full moon | 2·76 | **7·51** | 6·19 | 6·08 | 4·25 | 2·10 | 29·14 | |
| No moon | **3·59** | 7·36 | **7·15** | **7·14** | **7·34** | **3·89** | **36·46** | |
| 1934—Full moon | 0·60 | 4·20 | 5·31 | 6·63 | 5·77 | 0·30 | 22·81 | 83·41 |
| No moon | **3·64** | **5·86** | **9·01** | **7·11** | **10·20** | **6·95** | **42·77** | **133·20** |
| 1935—Full moon | 0·60 | 2·75 | 10·87 | 8·99 | 6·32 | 1·93 | 31·46 | |
| No moon | **3·49** | **7·93** | **13·86** | **11·70** | **9·92** | **7·07** | **53·97** | |
| Mean minimum temperature | | | | | | | | |
| 1933—Week of full moon | **48·3** | **53·0** | **58·7** | **56·6** | **52·3** | **44·1** | **52·2** | |
| No moon | 45·9 | 49·5 | 56·0 | 51·0 | 50·4 | 42·1 | 49·2 | |
| 1934—Full moon | 41·1 | 48·3 | 51·4 | 51·7 | 48·0 | **48·0** | 48·1 | **49·1** |
| No moon | **41·6** | **49·0** | **53·7** | **54·3** | **51·4** | 46·6 | **49·4** | 48·7 |
| 1935—Full moon | 34·2 | **48·3** | 55·6 | **50·5** | **49·6** | **43·9** | 47·0 | |
| No moon | **45·4** | 45·8 | **55·8** | 47·3 | 47·8 | 43·1 | **47·5** | |

sum of the logarithm of the catches each night. It will be seen that once more 17 out of the 18 comparisons give values in favour of no moon, and only one (that of June, 1933) slightly in favour of full moon. The comparison of the weeks in the lunar month in October, 1933, which gave a number value strongly in favour of full moon now gives a log value quite definitely in favour of full moon.

This indicates that the values in favour of no moon are due to consistent differences and not to occasional large and possibly accidental divergences.

The mean difference per week for the 18 weeks for the numbers is $87 \cdot 6 \pm 27 \cdot 3$ which gives a " $t$ " test of significance of $3 \cdot 2$. On the logarithmic basis the mean difference is $2 \cdot 77 \pm 0 \cdot 44$; which gives " $t$ " equal to $6 \cdot 3$, a value considerably more significant than that obtained from the numbers.

Before assuming that this apparent effect is due to the moon it is necessary to consider the possibility of other factors. It has been found in other investigations, to be published later, that the most important non-periodic single factor in determining the catch is the minimum temperature of the night. The last division in Table III shows the mean minimum temperatures for the same periods dealt with in the same manner as used for the summation of the Noctuidae. From this emerges the curious fact that in 1933 all of the six weeks of " no moon " were cooler than the corresponding week of " full moon " ; while in 1934 the reverse occurred and five successive " no moon " weeks were warmer than the corresponding " full moon " weeks. In 1935 the temperatures were more regularly distributed.

The two sets of figures taken in conjunction show that in 1933 the differences in catch in favour of " no moon " were obtained in spite of an adverse temperature effect which alone would have tended to produce a preponderance in the opposite direction. The differences in 1934, are, on the contrary, in the same direction as those that might be expected from a temperature effect, with the exception of the last period which, curiously enough, gives the most striking example of a large difference in favour of no moon.

A combination of all the eighteen periods gives a very slight temperature effect in favour of the full moon (49·1° F. ; 48·7° F.) with a very definite capture in favour of the moonless nights (1242 : 2853 in total numbers and 83·4 : 133·2 in logs).

This preliminary investigation, neglecting the possible influence of cloud, which we have no reason to suppose is more prevalent at any particular phase of the moon, gives a very definite support to the idea that a real lunar effect is present.

### *Varying Effect Due to the Height of the Full Moon*

It has been mentioned above that the full moons are high in the sky in December and low in June. It would therefore be expected that the full moon would have a greater effect in winter than in summer.

Unfortunately, practically no Noctuidae are captured in the winter months, but the Table IV shows average for the three years of the difference between the logs of the captures at full moon and no moon weeks for each month from May to October.

TABLE IV

Variation in Difference of Lunar Effect in Different Summer Months Due to Height of Full Moon Above the Horizon

| | May | June | July | August | Sept. | Oct. |
|---|---|---|---|---|---|---|
| Difference in week's totals | 2·25 | 2·23 | 2·45 | 1·43 | 3·71 | 4·53 |
| Mean difference per night | 0·31 | 0·30 | 0·35 | 0·20 | 0·53 | 0·65 |

This is shown diagrammatically in fig. 1, and it will be seen that, with the exception of the month of August, the figures fit very closely to the expected results of low difference in June, gradually increasing towards the autumn. The low value for August is undoubtedly due to the fact that in two of the three years the full moons were warmer than the no moon periods in this month.

A daily difference of 0·31 in the logs as in May and June is equivalent to a doubling of the catch at no moon over full moon, while the daily difference of 0·65 in October is equivalent to an increase of over four times.

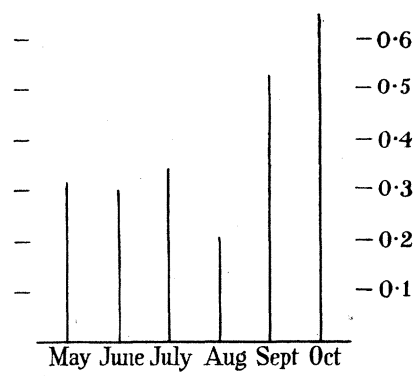


FIG. 1—Diagram showing the difference in lunar effect on the Noctuidae in successive months, according to the height of the full moon.

### *Day-to-Day Departures of Logarithms from the 29-Day Mean*

In order to extend the analysis to include all the days of the lunar period, the value for each night of the eighteen lunar months has been expressed as a departure of log $(n + 1)$ from the twenty-nine-day running mean. This, as has been explained, reduces the swamping effect of high individual catches and eliminates, at least partially, the effect of the rise and fall of the mean catch during the year.

Taking for granted the calculations, which are unnecessary to reproduce here, the figures in Table II now become as shown in Table V. Those for 1933 are given fully, but only the average figures for 1934 and 1935, and there is added a day-to-day mean departure for the three years together and finally the same smoothed to a five-day running mean. The results are shown diagrammatically in fig. 2 and to this has been added (dotted line) the mean minimum temperature calculated by the same method for comparison.

It will be seen that in each of the years there were large negative departures in captures about the time of full moon. In 1933 the positive departures are chiefly between no moon and the first quarter, while in 1934 they are from the last quarter to the first quarter (*i.e.*, the dark half of the cycle). In 1935 the highest positive departures are a few days after no moon. When the figures for the three years are

TABLE V

As Table II but with the Values for Each Day Expressed as Departures from the 29-Day Mean of the Logarithm of the Original Value

| Day in Lunar Month | | 1933 Full Moon on 9 May | 7 June | 6 July | 5 Aug. | 3 Sept. | 3 Oct. | Mean | 1934 Mean | 1935 Mean | 1933–34–35 Mean | Five-day Smoothed |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Full moon | 1 | −0·38 | +0·28 | −0·01 | −0·97 | −0·07 | −0·77 | −0·32 | −0·35 | −0·42 | −0·36 | −0·28 |
| | 2 | −0·37 | +0·04 | +0·03 | +0·05 | −0·32 | −0·78 | −0·23 | −0·28 | −0·60 | −0·37 | −0·28 |
| | 3 | −0·07 | +0·09 | −0·13* | −0·34 | −0·03 | −0·45 | −0·16 | −0·42 | −0·39 | −0·32 | −0·25 |
| | 4 | +0·09 | +0·33 | −0·34 | +0·01 | −0·34 | +1·06 | +0·14 | −0·35 | −0·15 | −0·12 | −0·20 |
| | 5 | +0·10 | +0·17 | −0·20* | −0·18 | −0·34 | +0·69 | +0·04 | −0·09 | −0·21 | −0·11 | −0·14 |
| | 6 | −0·11 | −0·05 | −0·12 | +0·25 | −0·43 | −0·24 | −0·12 | −0·02 | −0·12 | −0·09 | −0·10 |
| | 7 | +0·30 | +0·64 | −0·22 | −0·07 | −0·41 | −0·24 | +0·0 | −0·08 | −0·03 | −0·04 | −0·06 |
| | 8 | +0·07 | +0·49 | −0·46 | +0·04 | −0·71 | −0·22 | −0·13 | −0·17 | −0·08 | −0·12 | −0·03 |
| | 9 | −0·11 | +0·71 | −0·60 | +0·09 | +0·0 | −0·34 | −0·04 | +0·09 | +0·04 | +0·03 | +0·02 |
| | 10 | +0·45 | −0·08 | +0·18 | +0·32 | −0·17 | −0·60 | +0·02 | +0·11 | +0·10 | +0·08 | +0·06 |
| | 11 | +0·22 | −0·27 | −0·10 | +0·12 | −0·31 | +0·25 | −0·02 | +0·26 | +0·19 | +0·14 | +0·09 |
| | 12 | +0·11 | −0·20 | +0·12 | +0·15 | −0·31 | −0·01 | −0·02 | +0·20 | +0·26 | +0·15 | +0·13 |
| | 13 | +0·09 | −0·22 | −0·04 | −0·32 | −0·05 | +0·23 | −0·05 | +0·10 | +0·13 | +0·06 | +0·13 |
| | 14 | +0·54 | −0·10 | +0·30 | +0·04 | +0·21 | −0·46 | +0·10 | +0·32 | +0·21 | +0·21 | +0·14 |
| No moon | 15 | +0·04 | −0·05 | −0·01 | +0·14 | −0·06 | −0·46 | −0·07 | +0·21 | +0·19 | +0·11 | +0·15 |
| | 16 | ±0·0 | −0·04 | +0·32 | −0·19 | +0·07 | +0·58 | +0·12 | +0·10 | +0·28 | +0·17 | +0·16 |
| | 17 | −0·20 | −0·10 | +0·62 | −0·43 | +0·04 | +0·14 | +0·01 | −0·21 | +0·38 | +0·20 | +0·15 |
| | 18 | −0·04 | +0·19 | +0·24 | −0·11 | +0·43 | +0·15 | +0·14 | +0·04 | +0·39 | +0·16 | +0·16 |
| | 19 | −0·24 | +0·66 | −0·18 | −0·14 | +0·18 | +0·57 | +0·14 | +0·09 | +0·13 | +0·12 | +0·16 |
| | 20 | +0·22 | +0·12 | −0·03 | +0·24 | +0·38 | +0·51 | +0·24 | +0·16 | +0·08 | +0·16 | +0·15 |
| | 21 | −0·28 | −0·21 | +0·50 | +0·38 | +0·07 | +0·79 | +0·21 | +0·20 | +0·12 | +0·17 | +0·14 |
| | 22 | +0·09 | −0·26 | +0·15 | +0·28 | +0·22 | +0·34 | +0·13 | +0·34 | +0·02 | +0·16 | +0·13 |
| | 23 | −0·33 | +0·58 | −0·21 | +0·43 | +0·46 | −0·30 | +0·11 | +0·07 | +0·13 | +0·10 | +0·10 |
| | 24 | −0·68 | −0·11 | −0·34 | +0·53 | +0·68 | +0·01 | +0·02 | +0·13 | −0·02 | +0·04 | +0·07 |
| | 25 | −0·68 | +0·31 | −0·16 | +0·44 | +0·58 | −0·29 | +0·03 | −0·05 | −0·13 | +0·03 | +0·05 |
| | 26 | −0·38 | −0·30 | −0·18 | +0·55 | +0·70 | −0·26 | +0·04 | +0·11 | −0·10 | +0·02 | +0·0 |
| | 27 | −0·22 | +0·10 | +0·25 | +0·36 | +0·77 | −0·24 | +0·17 | +0·06 | −0·11 | +0·05 | −0·05 |
| | 28 | −0·10 | −0·21 | +0·28 | +0·05 | −0·25 | −0·22 | −0·08 | −0·11 | −0·17 | −0·12 | −0·12 |
| | 29 | −0·20 | +0·04 | +0·04 | −0·03 | −0·54 | −0·22 | −0·23 | −0·26 | −0·13 | −0·21 | −0·20 |

* Trap not working : average value inserted.

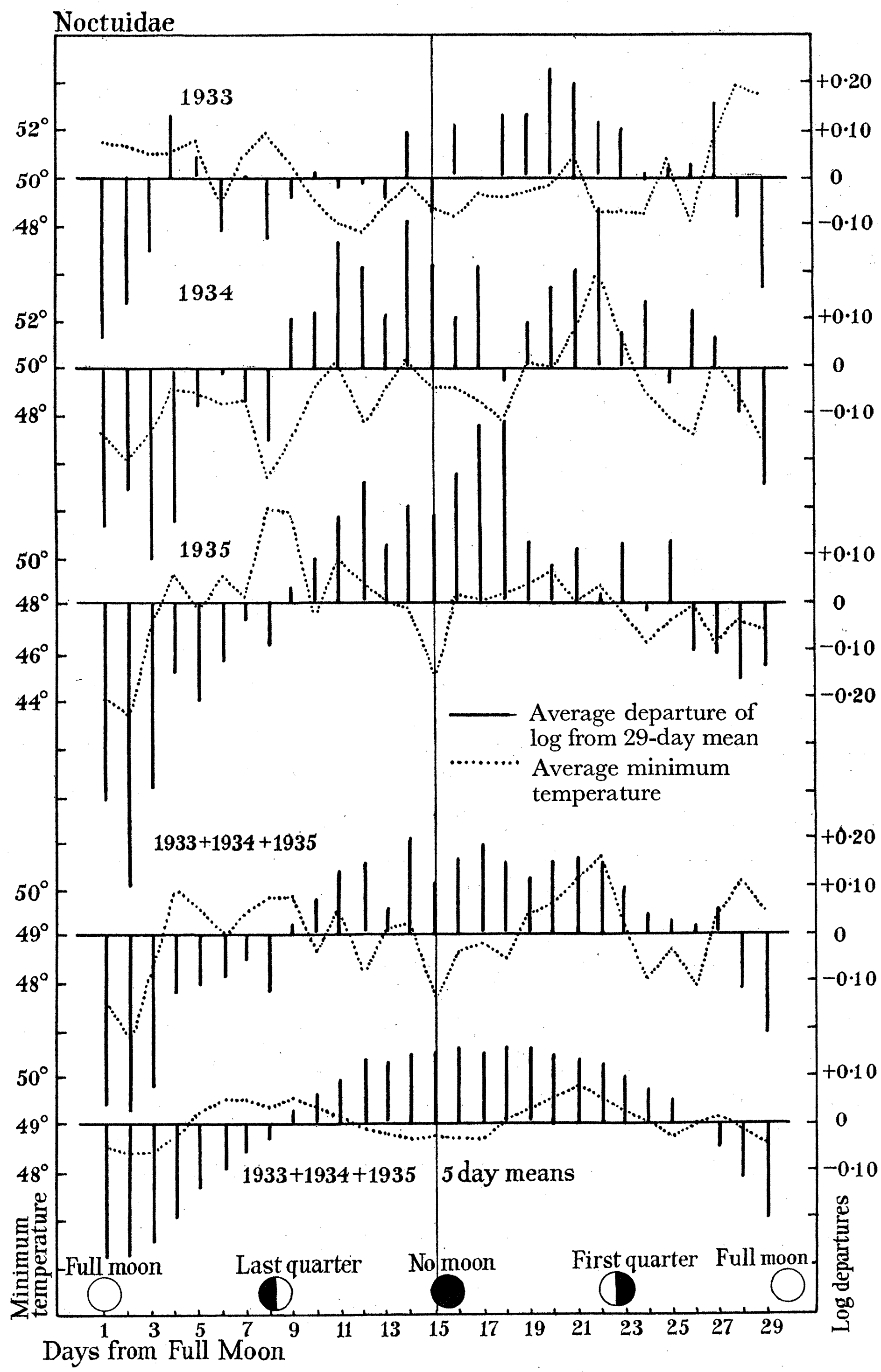


Fig. 2—Diagram showing average departures from the 29-day mean catch of Noctuidae for successive days of the lunar month for six lunar months in the summers of 1933, 1934, and 1935, also (as dotted line) the mean departures of the minimum night temperatures.

combined and smoothed a fairly regular curve is produced giving the lowest captures at full moon ; the change over from negative to positive just after the last quarter ; then steadily increasing positive departures till about half-way between no moon and the first quarter ; and finally a rapid fall and the change-over from positive to negative between the first quarter and full moon.

The maximum positive departure in the five-day smoothed curve is 0·16 and the maximum negative departures — 0·28, giving a total difference of 0·44 which is equivalent to a catch at no moon of approximately 275 when the full moon catch is considered as 100.

*Discussion on the Asymmetry of the Lunar Effect*

The final curve in fig. 2 is asymmetrical in two ways : (*a*) the negative departure at the full moon period is shorter (11 days) and more extreme at its maximum (— 0·28) than the positive departure at the no moon period which lasts for 17 days and has a maximum departure of + 0·16 ;

(*b*) the positive departure continues high for a number of days after no moon, and the cross-over from positive to negative occurs only four days before full moon ; while the reverse change takes place 7–8 days after full moon.

The first asymmetry is almost certainly due to the fact that the intensity of the light of the moon (due to the proportion of its surface illuminated) and the duration of the moonlight through the night are both decreasing simultaneously as we pass from full moon towards new moon ; and at the first quarter not only has the reflected light been reduced to about half, but the duration of its effect during the night has also been reduced to half (on an average). This, with the reverse effect between no moon and full moon, would tend to give the curve a flat top and a narrower and more emphasized minimum.

The second asymmetry appears to be due to the irregularity of the sequence of the hours of setting and rising of the moon on successive days in the lunar month, which has already been mentioned briefly.

Figs. 3A, B, and C show diagrammatically the hours of rising and setting of the moon during a lunar month in May, in July, and in December–January. The figures are for the year 1934–5, but the shape of the curve is identical for the same date in all years.

The dark horizontal lines in the figure show the hours on successive days (from above and downwards) when the moon is below the horizon. Each dark line ends at moonrise and starts at moonset. The converging or diverging vertical lines show the times of the eight successive periods of the night into which the captures in the trap are divided, the centre line being at midnight. The times of sunset and sunrise are shown as broken vertical lines.

An examination shows that in May (fig. 3A), owing to the longer interval between successive risings before midnight, the first half of the night is already dark (*i.e.*, as regards moonlight) three to four days after full moon and well before the " last quarter " ; but owing to the rapidly shortening intervals between successive risings

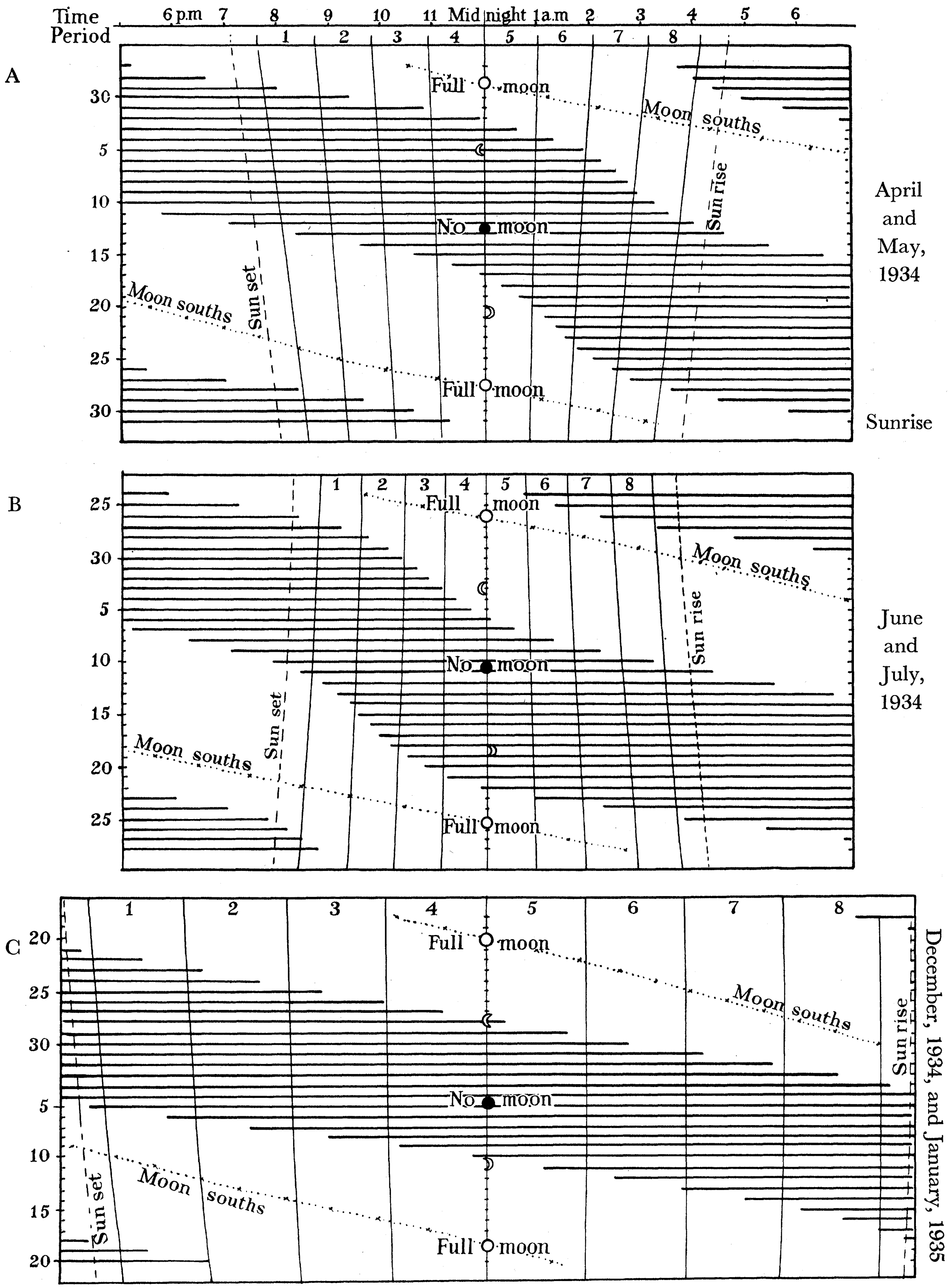


FIG. 3—Diagram showing the hours of rising and setting of the moon at three different times of the year to show particularly the two types of asymmetry before and after mid-June and the symmetrical conditions in mid-winter.

it takes about ten days (the remainder of the half lunar month) for the second half of the night to become dark. A similar course follows with the setting of the moon after no moon; within four days of no moon the first half of the night is light, but ten more days are required for the second half to become light.

One might therefore expect, under these conditions, insects to be more abundant than average at the "last quarter" and less abundant at the "first quarter".

In July (fig. 3B), on the contrary, the reverse effect is found and it is not until about ten days after full moon that the first half of the night is dark, and not until ten days after no moon that the first half of the night is light. One might therefore expect fewer insects than normal at the last quarter and more at the first quarter.

Similar asymmetry continues throughout the autumn, but by mid-winter (fig. 3C) conditions have become practically symmetrical throughout the night. In the

Table VI

Mean Log Departures from the 29-Day Means for Each Day of the Lunar Months, as Table V, but Separated into the Periods Before and After mid-June to Show Differences in Asymmetry. Figures are Smoothed to Five-Day Running Means

| | Day of lunar month | May to Mid-June | Mid-June to October |
|---|---|---|---|
| Full Moon | 1 | −0·15 | −0·34 |
| | 2 | −0·10 | −0·35 |
| | 3 | −0·08 | −0·33 |
| | 4 | −0·07 | −0·25 |
| | 5 | −0·03 | −0·16 |
| | 6 | 0·00 | −0·11 |
| | 7 | +0·05 | −0·09 |
| | 8 | +0·06 | −0·05 |
| | 9 | +0·10 | −0·01 |
| | 10 | +0·10 | +0·04 |
| | 11 | +0·13 | +0·08 |
| | 12 | +0·14 | +0·12 |
| | 13 | +0·13 | +0·12 |
| | 14 | +0·13 | +0·12 |
| No Moon | 15 | +0·11 | +0·14 |
| | 16 | +0·15 | +0·16 |
| | 17 | +0·08 | +0·17 |
| | 18 | +0·13 | +0·17 |
| | 19 | +0·08 | +0·19 |
| | 20 | +0·07 | +0·18 |
| | 21 | −0·01 | +0·19 |
| | 22 | −0·08 | +0·19 |
| | 23 | −0·18 | +0·18 |
| | 24 | −0·23 | +0·16 |
| | 25 | −0·29 | +0·11 |
| | 26 | −0·31 | +0·05 |
| | 27 | −0·26 | −0·02 |
| | 28 | −0·23 | −0·14 |
| | 29 | −0·17 | −0·27 |

spring an asymmetry similar to that for May develops and persists till about mid-June, when there is a rapid change over to that of the July–autumn type.

The asymmetry that we have found to exist in the Noctuid moth captures is of the "autumn" type, but the figures were based on a summation of captures from

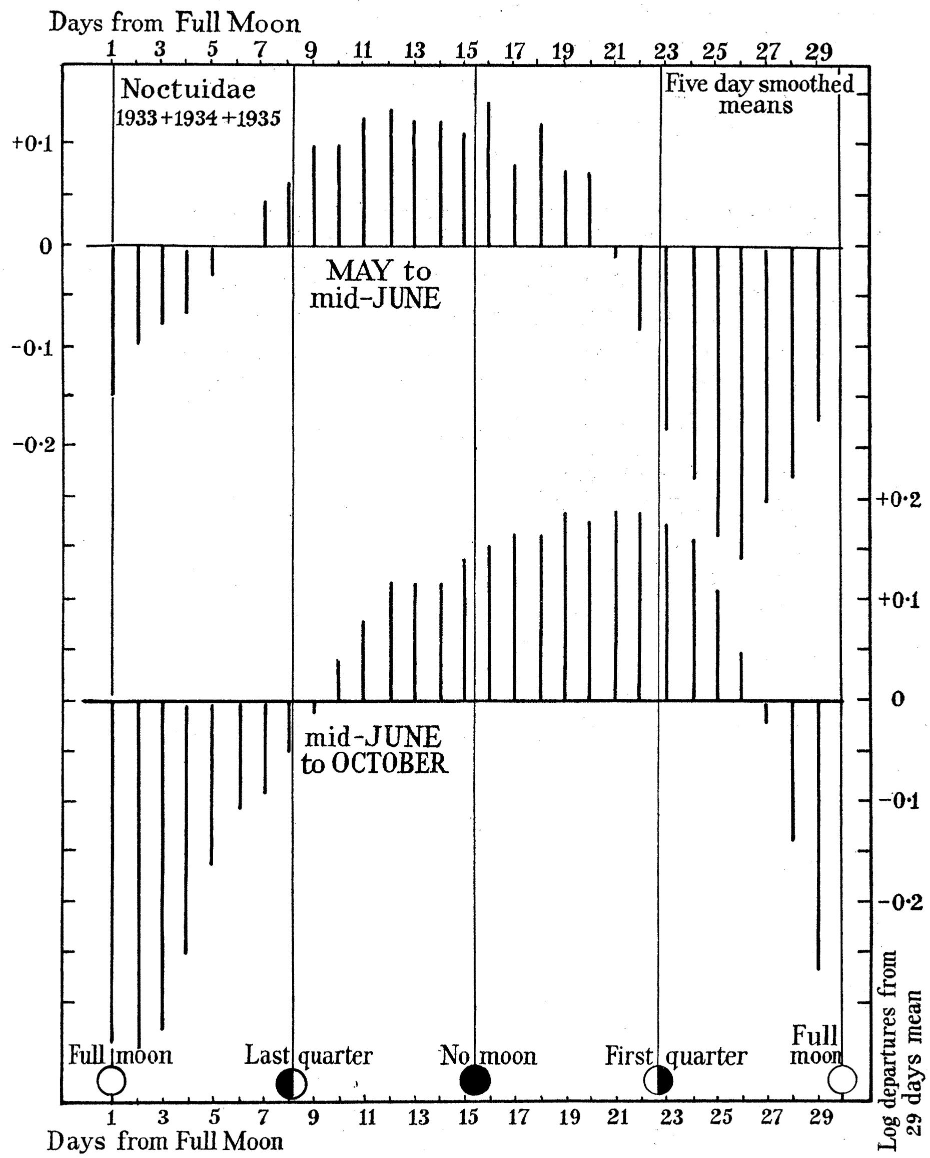


FIG. 4—Departures of the captures from the 29-day mean in the successive days of the lunar month separated into the periods before and after mid-June to show the two opposite types of asymmetry.

May to October. If the above lunar movements are the true cause of the insect asymmetry we should expect the Noctuid curve to show an asymmetry in one direction before mid-June and in the reverse direction after this time.

Table VI and fig. 4 show the results obtained when the captures of Noctuidae are treated as previously, after having been separated into two groups, (*a*) captures





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from the beginning of May to mid-June; and (*b*) captures from mid-June to the end of October. It will be seen that the results support the hypothesis, as the May curve shows higher catches at "last quarter" and lower at "first quarter" while the later curve shows the reverse. The only inexplicable feature at the moment is the very low captures about four or five days before full moon in the May–June curve; but as this is based on a relatively small number of figures it may be accidental.

The original asymmetry of the curve in fig. 2 is therefore only due to the fact that it was based on a larger number of observations after mid-June than before.

### *Effect of the Phase of the Moon on the Time of Flight of the Noctuidae*

Table VII and fig. 5 (histogram) show the normal distribution of the Noctuidae through the eight equal periods of the night into which the trap separates the catches. This is based on all captures in the summers of 1933, 1934, and 1935. It will be seen that the maximum flight is just after midnight in period 5, if calculated on either a number or logarithmic basis, but that almost equal numbers come before and after midnight (47% to 53%).

If the moon is inhibiting activity it would be expected that the catch in the early portion of the night would be reduced when the moon was above the horizon early (*i.e.*, before full moon); and that the catch in the later portion of the night would be reduced when the moon was late (*i.e.*, after the full moon). To test this the night distribution was calculated separately for the weeks before full moon and after full moon for the three summers under discussion. Each set of figures in Table VII thus represents the results of eighteen weeks' captures. The night of full moon is omitted.

TABLE VII

Numbers of Noctuidae Captured in Each Period of the Night for All Nights; for Nights in the Week before Full Moon; and for Nights in the Week after Full Moon

| Period of Night: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| *Actual numbers* | | | | | | | | |
| All captures | 599 | 826 | 1013 | 1454 | **1759** | 1429 | 955 | 309 |
| Weeks before full moon | 115 | 174 | 175 | 362 | **467** | 380 | 230 | 52 |
| Weeks after full moon | 75 | 136 | 150 | **234** | 190 | 152 | 70 | 35 |
| *Sum of logarithm* $(n+1)$ | | | | | | | | |
| All captures | 99·4 | 140·8 | 161·7 | 182·7 | **185·6** | 168·4 | 121·4 | 55·8 |
| Weeks before full moon | 21·1 | 27·8 | 30·7 | 38·9 | **43·0** | 39·3 | 30·0 | 13·1 |
| Weeks after full moon | 16·8 | 26·9 | 27·0 | **32·8** | 29·0 | 27·2 | 16·6 | 8·2 |

| % (*actual numbers*) | Before midnight | After midnight |
|---|---|---|
| All captures | 47 | 53 |
| Before full moon | 42 | 58 |
| After full moon | 57 | 43 |

Fig. 5 shows the results diagrammatically superimposed on the normal distribution, the vertical scale for the separate weeks being four times that of the total (histogram).

It will be seen that the results are according to expectation. There is a slight but distinct shift of the distribution later, in the week before full-moon, when there is still darkness in the second half of the night; and a corresponding shift earlier, in the week after full moon when the darkness is gradually increasing in the first half of the night.

In the week before full moon 58% of the catches are after midnight and 42 before, while in the week after no moon 57% are before midnight and 43 after.

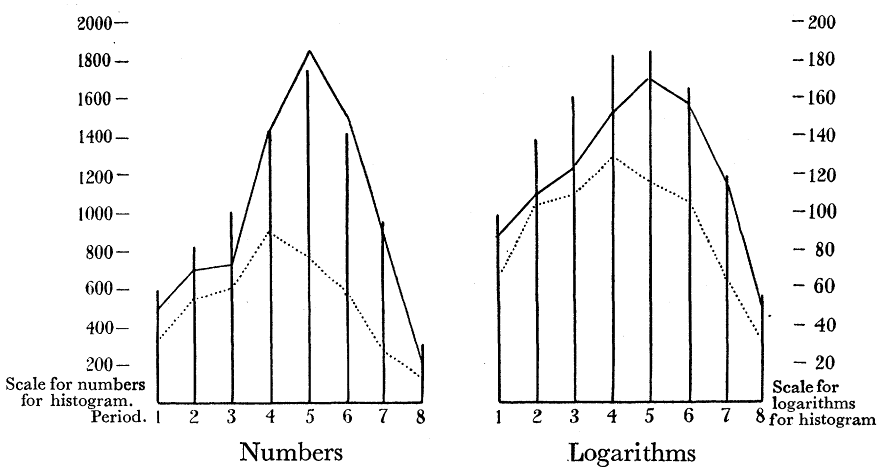


FIG. 5—Diagram showing the normal distribution of the Noctuidae in the eight periods of the night (histogram) and also the distribution in the week before full moon (continued line) and in the week after full moon (dotted line).

### *Interrelation of the Influence of Cloud and Moonlight*

Up till now the figures have been analysed to show the presence of a lunar effect irrespective of the state of the sky.

To show the possible influence of cloud it was decided to divide the days in the lunar months under review in two ways.

(1) As regards the state of the moon, into three divisions :—
- (*a*) nights during the week of full moon ;
- (*b*) nights during the weeks of intermediate moon ;
- (*c*) nights during the week of no moon.

(2) As regards the state of the sky, into three divisions :—
- (*a*) nights with more than 90% of the sky clear (" clear ") ;
- (*b*) nights with 10–90% of the sky cloudy (" intermediate ") ;
- (*c*) nights with more than 90% cloudy (" cloudy ").

The interrelation of these two main divisions gives nine possible combinations as shown in Table VIII.

The next stage was to allot each night of the six lunar months in each year into its proper division. Table VIII shows the actual results for 1933 as an example of the method. It will be seen that the numbers of nights in each division are different, depending entirely on accidental weather conditions.

Table VIII

Nights in 1933 Divided Into Nine Groups According to the Combination of Conditions of Moon and Cloud

| | Clear | Intermediate | Cloudy |
|---|---|---|---|
| Full moon week | June: 4, 5, 6, 7, 8.<br>July: 3, 4, 7.<br>August: 3, 4, 5, 7, 8.<br>Sept.: 2, 4, 5, 6.<br>Oct.: 4. | May: 10, 11, 12.<br>June: 9.<br>July: 6.<br>August: 2, 3.<br>Oct.: 2, 3, 5, 6*. | May: 9.<br>June: 10.<br>July: 5, 9*.<br>August: 31.<br>Sept.: 1, 3, 30.<br>Oct.: 1, 30. |
| First and third quarters | May: 18, 19.<br>June: 1, 2, 3, 28.<br>July: 2, 14, 16, 25, 26, 27.<br>August: 1, 12, 16, 26, 27, 28.<br>Sept.: 7, 8, 9, 10, 14.<br>Oct.: 11, 12, 14, 25*, 27. | May: 14, 15, 17, 20, 29, 30, 31.<br>June: 11, 13, 14, 17, 18, 26, 27, 30.<br>July: 1, 11, 12, 29.<br>August: 9, 10, 13, 14, 24, 25, 29, 30.<br>Sept.: 13, 22, 25.<br>Oct.: 8, 23, 26*. | May: 13, 16, 28.<br>June: 12, 15, 16, 29.<br>July: 13, 15, 17, 28, 29, 31*.<br>August: 11, 15.<br>Sept.: 11, 12, 23, 24, 26, 27, 28, 29.<br>Oct.: 7, 9*, 10*, 13, 22 24*, 28, 29. |
| No moon week | May: 21, 22.<br>June: 19, 21.<br>July: 18, 19, 20.<br>August: 23.<br>Sept.: 15.<br>Oct.: 15, 16*, 17, 19. | May: 23, 26, 27.<br>June: 22, 23.<br>July: 21, 22.<br>August: 17, 18, 19, 20, 21.<br>Sept.: 16, 18, 19, 20, 21.<br>Oct.: 20. | May: 24, 25.<br>June: 20, 24, 25.<br>July: 23, 24.<br>August: 22.<br>Sept.: 17.<br>Oct.: 18, 21. |

* = nights with heavy wind.

Certain of these days, marked with an asterisk, had captures considerably reduced by heavy wind. These have been eliminated from further calculations.

In each of the subdivisions the departures of the logs from the 29-day mean for the correct days were placed and these were summed and divided by the number of days, thus giving an average departure for that particular combination of cloud and moon conditions.

Similarly averages were worked out for each row and column, giving the effect of moon independent of cloud and cloud independent of moon respectively.

Table IV shows the results thus obtained for the Noctuidae in the years 1933, 1934, and 1935 (*a*, *b*, and *c*) separately and also for the three combined together (*g*).

TABLE IX

Analysis of Noctuid Captures and Minimum Temperatures During 1933–35 According to Conditions of Moon and Cloud

Mean log: departures

1933

| | | | | |
|---|---|---|---|---|
| *a* | −0·155 | −0·084 | +0·038 | −0·089 |
| | −0·125 | +0·097 | +0·193 | +0·056 |
| | +0·029 | +0·051 | +0·144 | +0·074 |
| | −0·102 | +0·053 | +0·171 | |

1934

| | | | | |
|---|---|---|---|---|
| *b* | −0·394 | −0·239 | −0·023 | −0·268 |
| | +0·044 | +0·144 | +0·051 | +0·099 |
| | +0·133 | +0·149 | +0·204 | +0·159 |
| | −0·064 | +0·072 | +0·087 | |

1935

| | | | | |
|---|---|---|---|---|
| *c* | −0·437 | −0·360 | −0·059 | −0·292 |
| | +0·001 | +0·083 | +0·113 | +0·060 |
| | +0·110 | +0·243 | +0·332 | +0·207 |
| | −0·086 | −0·015 | +0·139 | |

Mean minimum temperatures: departures

1933

| | | | | |
|---|---|---|---|---|
| *d* | +2·24 | −0·72 | +3·20 | +1·6 |
| | −2·34 | −1·16 | +1·61 | −0·68 |
| | −2·50 | −1·43 | +1·33 | −1·0 |
| | −0·92 | −0·80 | +1·9 | |

1934

| | | | | |
|---|---|---|---|---|
| *e* | −3·0 | +0·16 | +2·6 | −0·86 |
| | −1·8 | +0·63 | +2·1 | +0·18 |
| | −0·57 | −0·14 | +4·1 | +0·83 |
| | −1·9 | +3·9 | +2·9 | |

1935

| | | | | |
|---|---|---|---|---|
| *f* | −3·16 | −1·48 | +0·5 | −0·93 |
| | −1·31 | +0·72 | +3·37 | +0·70 |
| | −4·37 | +0·66 | +2·03 | −0·53 |
| | −2·41 | +0·09 | +2·35 | |

1933 + 1934 + 1935 Mean log: departures

| | | | | |
|---|---|---|---|---|
| *g* | −0·307 | −0·254 | −0·019 | −0·219 |
| | −0·028 | +0·111 | +0·133 | +0·071 |
| | +0·095 | +0·141 | +0·238 | +0·147 |
| | −0·079 | +0·037 | +0·129 | |

Mean log

| | | | | |
|---|---|---|---|---|
| *h* | 0·575 | 0·628 | 0·863 | 0·663 |
| | 0·854 | 0·993 | 1·015 | 0·953 |
| | 0·977 | 1·023 | 1·120 | 1·029 |
| | 0·803 | 0·919 | 1·011 | |

Mean catch (anti-log −1)

| | | | | |
|---|---|---|---|---|
| *i* | 2·76 | 3·25 | 6·30 | 3·60 |
| | 6·14 | 8·84 | 9·35 | 7·97 |
| | 8·48 | 9·54 | 12·18 | 9·69 |
| | 5·35 | 7·30 | 9·26 | |

1933 + 1934 + 1935 Mean per cent catch

| | | | | |
|---|---|---|---|---|
| *j* | 42 | 49 | 95 | 54 |
| | 92 | 133 | 141 | 120 |
| | 128 | 144 | 184 | 146 |
| | 80 | 110 | 140 | |

Mean minimum temperature: departures

| | | | | |
|---|---|---|---|---|
| *k* | −0·94 | −0·78 | +2·26 | −0·07 |
| | −1·79 | +0·17 | +2·43 | +0·08 |
| | −2·43 | −0·42 | +2·44 | −0·23 |
| | −1·71 | −0·07 | +2·32 | |

Key

| | | | | |
|---|---|---|---|---|
| *l* | Full moon clear. | Full moon part cloud. | Full moon cloudy. | Week of full moon. |
| | Inter. moon clear. | Inter. moon part cloud. | Inter. moon cloudy. | Week of inter. moon. |
| | No moon clear. | No moon part cloud. | No moon cloudy. | Week of no moon. |
| | All clear nights. | All nights inter. cloud. | All cloudy nights. | |

It will be seen that in general there is a tendency for the "clear" column to be lower than the "cloudy", and for the "full moon" to be lower than the "no moon" row. The division "full moon—clear sky" gives in each case the greatest negative departure, and the division "no moon—cloudy" gives the greatest positive departures.

Since the mean logarithms for the whole of the captures of the series is known to be 0·882 (equal to a geometric mean catch of 6·62 insects) the mean departures for the three years (Table IX*g*) can be subtracted from or added to this mean and a true logarithm (*h*) and hence an average catch in numbers can be obtained for each division. This is shown in Table IX*i* with the final addition of a Table IX*j* in which the figures are altered to bring the mean catch to 100, so that the figures in each division are percentages of the mean catch.

This table is consistent except for the figure 133 in the "intermediate cloud, intermediate moon" division which is a little higher than might be expected. The figures for the rows and columns separately are quite consistent and show a ratio of 146 : 120 : 54 for nights with no moon, intermediate moon, and full moon respectively ; and a ratio 140 : 110 : 80 for nights of full cloud, intermediate cloud, and clear sky. The ratio of catches in the extreme conditions of "no moon—cloudy" and "full moon—clear" is 184 : 42 or just over 4 : 1.

Another point worthy of notice is that the reduction of catch due to the clearness of the sky is greater on full moon nights (95 : 42) than on moonless nights (184 : 128); and similarly the reduction of catch by moonlight is greater on clear nights (128 : 42) than on cloudy nights (184 : 95).

A three-dimensional model of the nine main values in Table IX*j* is shown in fig. 6 with the full moon row in front and the clear sky row to the right. The height of the vertical columns represents the catch under each combination of conditions.

These figures must next be considered in connexion with possible temperature variations, and for this purpose the minimum temperatures have been treated in the same way as the figures for captures (except that they are not converted to logarithms) and the results are shown in Table IX*d*, *e*, *f*, and *k*.

It will be seen that in each year there is a consistent temperature gradient from cloudy nights to clear which is to be expected owing to the action of clouds in preventing radiation. On the average of the three years the difference is 4·03° F., which is possibly sufficient to explain the differences in captures in favour of cloudy nights. A fuller investigation of this will be made later.

The temperature in relation to moon phase shows (as has already been mentioned) warmer conditions at full moon in 1933 ; at no moon in 1934 ; and at intermediate moon in 1935.

On the three years combined there is still a bias of about 0·3° F. in favour of the full moon, so that the results obtained are not due to any accidental temperature effect, and, in fact, if temperature had been normally distributed the effect of the moon might be expected to be slightly greater than that shown.

It will also be seen that the temperature departure in the division " intermediate moon—intermediate cloud " is considerably less than that in " no moon—intermediate cloud ", so that the inconsistence of the catch figures for the former division is at least partly explained.

To sum up—the ratio of catches in the Noctuidae in the three years combined is shown to be about 2·7 : 1 when no moon is compared to full moon (in spite of a small temperature effect in favour of full moon) ; and 1·75 : 1 when cloudy nights are compared with clear nights, this being associated with a temperature difference of about 4° F. in favour of the cloudy nights (owing to reduction of radiation by the clouds), and possibly explicable on this basis alone. Finally the ratio between

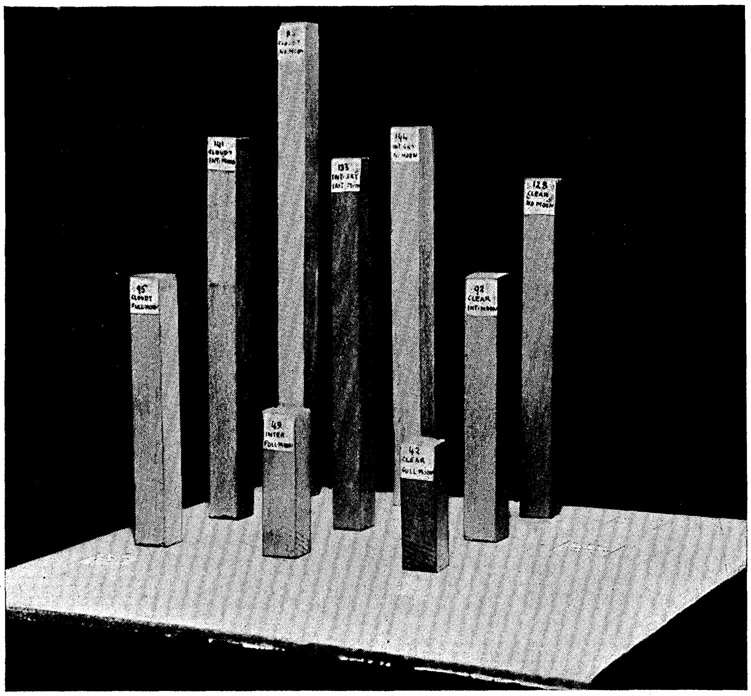

FIG. 6—Photograph of three-dimensional model showing the average numbers of Noctuidae captured in the trap on nights of various combinations of moon phase and cloud conditions.

" no moon—cloudy " and " full moon—clear " is just over 4 : 1, while in the cross-relation, clear nights with no moon give distinctly larger catches than cloudy nights with full moon (128 : 95). It must, however, be recollected that the group " cloudy " nights includes any night with less than 10% of the sky clear, so that slight lunar influence could be expected on some of these nights, particularly as the light of the moon can penetrate clouds of considerable thickness.

### *Correction of the 29-Day Mean Curve for Lunar Influence*

In fig. 7 are shown as vertical columns the log of the catches (+ 1) of the Noctuidae each day during the six lunar months of the three years under consideration. There


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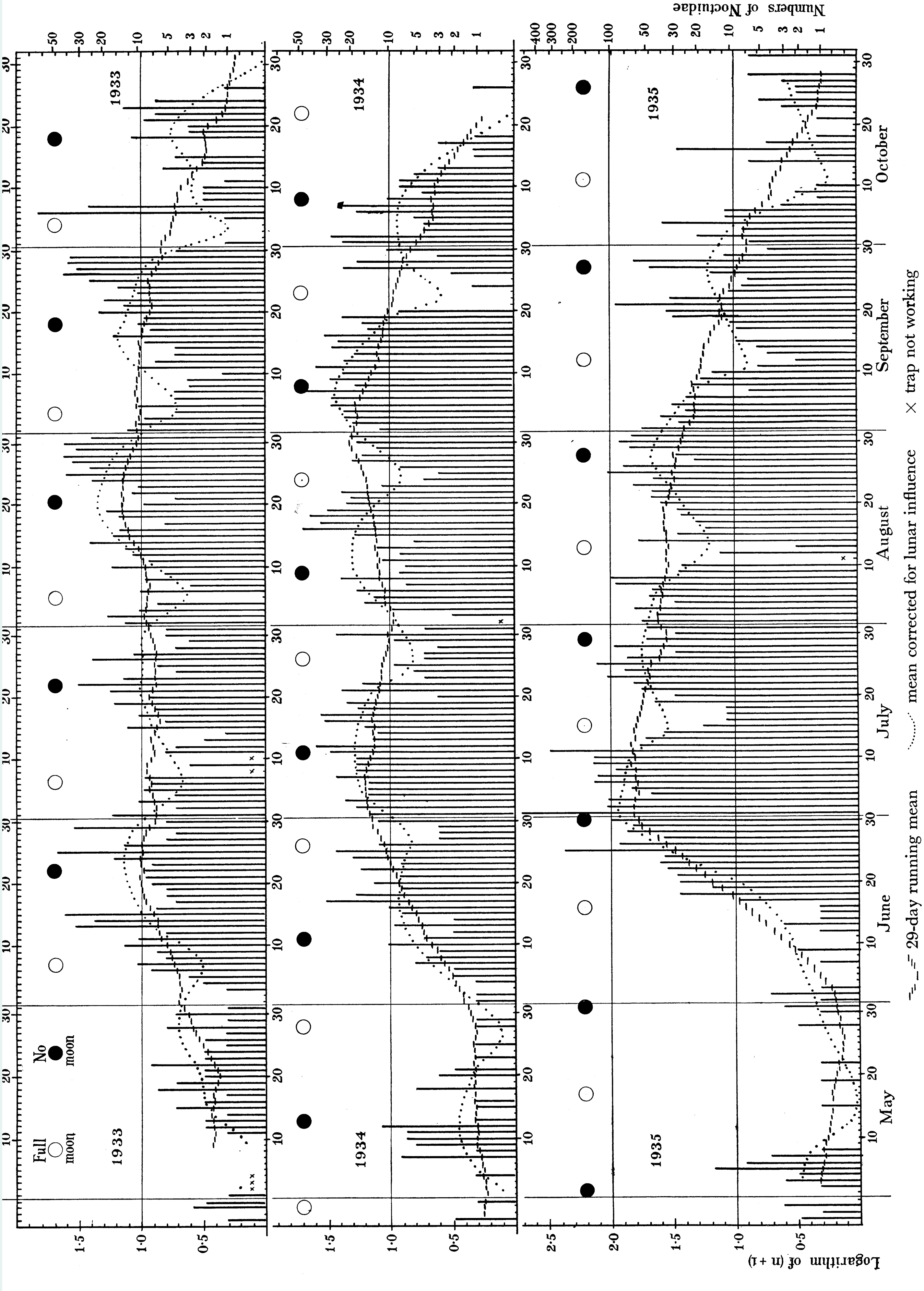


FIG. 7—The captures of Noctuidae during the summer months of 1933–35 (represented as log $(n+1)$) together with the 29-day running mean of their values, and the same mean (dotted line) corrected to eliminate the lunar influences.

is also shown as a series of short horizontal lines the running 29-day mean of these values. The difference between the value for any one day and the 29-day mean for the same day is due to the conditions of that day, including such non-periodic factors as wind, temperature, cloud, and humidity, which change rapidly from day to day, and also to the phase of the moon which is not eliminated by taking the mean over the same period as the length of the lunar months.

With the information we have gained above, however, it is now possible to correct this 29-day mean for the expected lunar influence based primarily on the curves shown in figs. 4 and 6 and the information in Table IV.

The factors that have to be considered are

(1) the mean + and − departures at no moon and full moon ;

(2) the fact that the differences are at their minimum in June and maximum in October ;

(3) the alteration in asymmetry of the corrections from the months before mid-June to those after.

With these facts as a basis, there has finally been added to fig. 7 a third curve (dotted) showing the 29-day mean corrected as nearly as possible for the lunar influence.

It will immediately be seen how much more closely the curve fits the changes in the log histogram, than did the 29-day mean ; thereby showing what a high proportion of the variation is due to the lunar influence.

For example, the log $(n + 1)$ value for 25 July, 1934, is about 0·1 below the 29-day mean, but actually about 0·15 above the corrected mean. Thus the more rapidly changing weather conditions such as temperature, etc., are actually responsible for an increase in the captures above normal and not a decrease as would appear if the lunar effect were neglected.

From this figure, therefore, it is possible to start with a new set of values for each day showing departures from which the lunar periodicity has been practically eliminated, and from which the influence of other factors can now be studied with considerable simplification due to the elimination of a periodic change.

## Lunar Influence on Other Groups of Insects

### *Comparison of Full Moon and No Moon Weeks in Various Groups*

Table X shows the comparison of full and no moon week captures, calculated in a way similar to that shown for the Noctuidae in Table III, for a number of other groups of insects into which the night catches were sorted. They are all based on the logarithm of the numbers to eliminate as far as possible chance high catches.

It will be seen first of all that in 1934 there are very few exceptions to the rule that catches are highest in no moon weeks. In 1935, there are several exceptions, particularly in the month of August ; while in 1933 the exceptions are quite numerous

Table X

Difference in Captures in Weeks of Full Moon and No Moon in Various Groups of Insects for Comparison with Table III

| 1933 | | | | | | | 1934 | | | | | | | 1935 | | | | | | | All |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Total | | | | | | | Total | | | | | | | Total | years |
| All insects | | | | | | | | | | | | | | | | | | | | | |
| 15·5 | **18·7** | 16·8 | **19·0** | **16·4** | 10·3 | 96·7 | 8·7 | 14·8 | 16·0 | 16·1 | 14·3 | 11·8 | 81·6 | 7·6 | 16·9 | 21·5 | **19·7** | 15·3 | 11·9 | 93·0 | 271·2 |
| **20·8** | 17·3 | **23·0** | 12·1 | 14·5 | 10·8 | 98·5 | 9·3 | **17·8** | **20·0** | 17·0 | **16·8** | **17·4** | **98·2** | **17·2** | **19·3** | **25·5** | 17·3 | **17·7** | **17·5** | **114·4** | 311·1 |
| All Lepidoptera | | | | | | | | | | | | | | | | | | | | | |
| 9·3 | 14·0 | 15·5 | **13·1** | **11·2** | 3·7 | 66·7 | 3·2 | 11·1 | 13·7 | 12·4 | 7·6 | 1·4 | 49·4 | 1·6 | 10·6 | 17·8 | 14·7 | 8·2 | 2·7 | 55·6 | 171·7 |
| **10·7** | 13·7 | **18·4** | 8·7 | 9·7 | 3·9 | 65·2 | **5·0** | **13·7** | **17·6** | 13·1 | **11·6** | **7·7** | **68·8** | 8·2 | **12·2** | **20·2** | 14·5 | **10·8** | **7·5** | **73·3** | 208·3 |
| Geometridae | | | | | | | | | | | | | | | | | | | | | |
| 3·6 | **6·2** | 6·9 | **5·6** | **2·4** | 1·1 | 25·7 | 1·3 | 3·9 | 2·2 | 3·3 | 0·8 | 0·0 | 11·5 | 0·0 | 3·6 | 7·0 | 5·7 | 1·4 | 0·8 | 18·5 | 55·7 |
| 8·3 | 4·9 | **11·1** | 1·2 | 0·6 | 1·5 | 27·5 | 1·3 | **6·9** | **8·6** | **5·4** | **3·3** | **2·3** | **27·8** | **2·6** | 3·9 | 6·6 | 5·2 | **2·6** | 1·2 | **22·1** | 77·3 |
| Crambidae | | | | | | | | | | | | | | | | | | | | | |
| **2·7** | 9·2 | 12·5 | **5·7** | 0·3 | 0·0 | 30·5 | 0·0 | 6·2 | 12·4 | 9·6 | 1·6 | 0·0 | 29·8 | 0·0 | 7·9 | 15·8 | **12·3** | 0·0 | 0·0 | 36·0 | 96·3 |
| 0·6 | **10·4** | 15·8 | 3·2 | 0·0 | 0·0 | 30·0 | 0·0 | **9·9** | **14·8** | 10·4 | 2·3 | 0·0 | **37·3** | 0·0 | 7·4 | **19·2** | 10·5 | **3·2** | 0·0 | **40·3** | 107·6 |
| Coleoptera | | | | | | | | | | | | | | | | | | | | | |
| 2·0 | **4·6** | 5·6 | **5·2** | 0·5 | 0·0 | **17·9** | 2·3 | 3·6 | 1·7 | 2·6 | 2·0 | 1·3 | 13·5 | 1·1 | 1·2 | **7·1** | **4·0** | 1·0 | 0·9 | 15·4 | 46·8 |
| 2·7 | 1·4 | **7·0** | 1·6 | 0·8 | 0·6 | 14·1 | **3·7** | 4·2 | **4·1** | 3·5 | **3·8** | 2·3 | **21·6** | **2·8** | 1·6 | 4·8 | 2·8 | 2·0 | 1·4 | 15·4 | 51·1 |
| Psocoptera | | | | | | | | | | | | | | | | | | | | | |
| 0·0 | 1·4 | 3·0 | **5·5** | **5·5** | 0·8 | **16·1** | 0·0 | 0·0 | **2·3** | 1·5 | 3·9 | 0·3 | 8·0 | 0·0 | 0·0 | 0·3 | 0·0 | 0·0 | 0·3 | 0·6 | 24·7 |
| 0·0 | 0·6 | **4·4** | 1·5 | 2·3 | 0·3 | 9·1 | 0·0 | 0·9 | 0·0 | **2·7** | 8·3 | **2·4** | **14·2** | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·5 | 0·5 | 23·9 |
| Jassidae | | | | | | | | | | | | | | | | | | | | | |
| 1·0 | **6·6** | **9·6** | **10·5** | **5·9** | 0·8 | **34·8** | 0·0 | 1·2 | 2·0 | 0·9 | 2·1 | 0·0 | 6·2 | 0·0 | 0·0 | **4·9** | **6·7** | 1·9 | 0·3 | 13·8 | 54·8 |
| 0·0 | 2·6 | 7·2 | 0·8 | 1·9 | 0·7 | 13·1 | 0·3 | 0·8 | **7·0** | **4·1** | **7·6** | **5·5** | **25·2** | 0·0 | 1·0 | 3·0 | 2·2 | 2·1 | **3·5** | 11·7 | 50·3 |
| Aphidae | | | | | | | | | | | | | | | | | | | | | |
| 3·0 | **6·2** | 9·0 | **10·1** | **6·1** | 1·5 | 35·8 | 0·0 | 1·1 | 2·0 | 0·9 | 0·8 | 0·6 | 5·3 | 0·0 | 0·3 | **2·0** | **4·0** | 0·6 | 0·3 | 7·2 | 48·3 |
| 0·9 | 2·5 | 9·8 | 2·6 | 1·2 | 0·6 | 17·7 | 0·0 | 0·8 | 2·3 | 1·8 | **3·2** | 1·1 | 9·1 | **1·1** | 1·3 | 0·6 | 2·5 | 1·1 | 0·6 | 7·1 | 34·0 |

| 1933 | | | | | | | 1934 | | | | | | | 1935 | | | | | | | All |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Total | | | | | | | Total | | | | | | | Total | Years |
| Capsidae | | | | | | | | | | | | | | | | | | | | | |
| 0·0 | **2·3** | 6·3 | **2·8** | 0·0 | 0·0 | 11·4 | 0·0 | 1·2 | 2·0 | 0·9 | 1·8 | 0·0 | 5·9 | 0·0 | 0·0 | 5·0 | **3·1** | 0·0 | 0·0 | 8·1 | 25·4 |
| 0·0 | 0·3 | **7·4** | 0·0 | 0·8 | 0·3 | 8·7 | 0·3 | 0·8 | **7·4** | **4·1** | **7·6** | 0·3 | 20·4 | 0·3 | 0·0 | 4·2 | 1·6 | **1·4** | 0·0 | 7·4 | 36·6 |
| Borboridae | | | | | | | | | | | | | | | | | | | | | |
| 2·1 | 2·7 | 0·0 | **2·8** | **3·8** | 1·2 | 12·5 | 0·7 | 1·4 | **4·3** | 8·6 | 3·3 | 1·3 | 19·5 | 2·8 | **8·7** | 2·7 | **12·7** | 3·4 | 4·5 | 34·9 | 66·8 |
| 2·6 | **4·6** | **3·4** | 1·1 | 1·5 | 1·6 | 14·5 | 1·3 | **2·5** | 0·0 | 8·3 | **5·0** | **6·7** | 23·7 | **4·5** | 6·7 | 8·5 | 5·6 | **12·0** | 8·2 | 45·6 | 83·7 |
| Cecidomyidae | | | | | | | | | | | | | | | | | | | | | |
| 4·0 | 10·1 | 14·0 | **13·6** | **8·1** | **1·6** | 51·4 | 0·0 | 6·2 | 7·6 | 8·2 | 7·8 | 0·0 | 29·7 | 0·0 | 4·7 | 15·9 | **14·7** | 8·4 | 0·7 | 44·4 | 125·5 |
| **8·1** | 9·7 | **18·7** | 5·0 | 6·0 | 0·0 | 47·5 | **1·4** | **9·4** | **13·7** | **12·1** | 8·3 | **3·0** | 47·9 | **4·0** | **6·9** | 15·2 | 10·1 | 5·5 | **4·9** | 46·4 | 141·8 |
| Ceratopogon | | | | | | | | | | | | | | | | | | | | | |
| 7·3 | 9·5 | 11·9 | **11·3** | 4·5 | 3·2 | 47·8 | 2·9 | 5·1 | 3·9 | 7·7 | 7·4 | 2·8 | 29·8 | 2·8 | 4·5 | **8·3** | **10·9** | 6·5 | 6·2 | 39·3 | 116·8 |
| **14·3** | 10·5 | **17·9** | 3·3 | **7·2** | 2·4 | 55·6 | **4·1** | 5·4 | **7·3** | 8·6 | 8·4 | **10·0** | 46·8 | **7·1** | **5·6** | 6·6 | 7·7 | **9·3** | **8·2** | 44·3 | 143·7 |
| Chironomidae (excluding *Ceratopogon*) | | | | | | | | | | | | | | | | | | | | | |
| 7·0 | 11·2 | 11·8 | **12·1** | **11·6** | **6·3** | 60·1 | **5·2** | 8·0 | 9·6 | **10·4** | 7·8 | 7·5 | 48·5 | 1·7 | 11·1 | 13·4 | **11·7** | **13·1** | 7·1 | 58·1 | 166·6 |
| **9·0** | 10·2 | **14·2** | 6·4 | 9·6 | 0·6 | 49·9 | 3·9 | **14·5** | **12·3** | 7·9 | **11·8** | **10·4** | 59·9 | **10·3** | 10·7 | 13·0 | 8·0 | 10·6 | **10·9** | 63·4 | 173·2 |
| Psychodidae | | | | | | | | | | | | | | | | | | | | | |
| 11·4 | **14·5** | 11·4 | **10·4** | **7·7** | **2·0** | 57·3 | 2·9 | 7·4 | 5·5 | 7·1 | 4·9 | 2·2 | 30·0 | 2·2 | 12·2 | 15·6 | **13·2** | **7·9** | 4·2 | 55·3 | 142·6 |
| **19·0** | 11·2 | **16·8** | 2·1 | 4·5 | 0·8 | 54·4 | 2·4 | **11·8** | **13·8** | 6·4 | 5·7 | **9·1** | 49·0 | **14·9** | **15·3** | **20·8** | 5·8 | 4·4 | **6·9** | 68·2 | 171·6 |
| Mycetophyllidae (chiefly *Sciara*) | | | | | | | | | | | | | | | | | | | | | |
| 3·4 | 6·2 | 7·1 | **5·9** | **4·7** | 0·5 | 27·7 | 0·0 | **1·8** | 2·7 | 2·7 | 3·6 | 6·4 | 17·2 | 1·1 | **10·5** | 11·4 | **8·1** | 2·8 | 1·6 | 35·5 | 80·4 |
| **11·7** | 8·8 | 6·4 | 1·1 | 0·5 | 0·8 | 29·2 | **2·3** | 0·3 | **4·2** | 3·2 | **5·1** | **11·8** | 26·9 | **10·5** | 8·7 | **13·9** | 2·5 | 3·5 | **4·5** | 43·6 | 99·6 |

(although not outnumbering the others). This general result is due to the fact already explained that in 1934 the temperatures were highest at no moon and in 1933 at full moon ; while in 1935 August was one of the months that had a distinct temperature difference in favour of full moon.

However, in spite of this there are distinct differences in behaviour between the groups, and these are summarized in Table XI which shows the groups with their

TABLE XI

Principal Groups of Insects Dealt with Arranged in Sequence of the Difference Between Captures in Full and No Moon weeks

| | | Mean log diff. per week | Standard deviation | $t$ | Significance |
|---|---|---|---|---|---|
| 1 | Noctuidae (L) | 2·77 | ± 0·44 | 6·30 | certain |
| 2 | All insects | 2·11 | 0·94 | 2·24 | probable |
| 3 | All Lepidoptera | 1·97 | 0·64 | 3·01 | certain |
| 4 | Psychodidae (D) | 1·62 | 1·33 | 1·22 | not sig. |
| 5 | Ceratopogon (D) | 1·47 | 0·88 | 1·67 | doubtful |
| 6 | Geometridae (L) | 1·20 | 0·61 | 1·98 | possible |
| 7 | Mycetophilidae (D) | 1·07 | 0·95 | 1·14 | not sig. |
| 8 | Borboridae (D) | 0·95 | 0·88 | 1·08 | ,, ,, |
| 9 | Crambidae (L) | 0·93 | 0·61 | 1·52 | doubtful |
| 10 | Cecidomyidae (D) | 0·92 | 0·89 | 1·03 | not sig. |
| 11 | Capsidae (R) | 0·73 | 0·64 | 1·15 | ,, ,, |
| 12 | Chironomidae (D) | 0·43 | 0·94 | 0·46 | ,, ,, |
| 13 | Coleoptera | 0·24 | 0·40 | 0·60 | ,, ,, |
| 14 | Psocoptera | 0·08 | 0·68 | 0·01 | ,, ,, |
| 15 | Jassidae (R) | − 0·24 | 0·98 | − 0·24 | ,, ,, |
| 16 | Aphidae (R) | − 0·85 | 0·61 | − 1·39 | ,, ,, |

L = Lepidoptera. D = Diptera. R = Rhynchota.

mean weekly log difference ; the standard deviation of that difference ; and the "$t$" test of significance (otherwise the mean difference divided by the standard deviation). The groups are placed in order of the value of the log difference.

The following facts may be noted :

(*a*) The Noctuidae are far above the other groups with a higher log difference, and a very much higher value for $t$.

(*b*) Out of the first six groups four are either Lepidoptera or include Lepidoptera (*e.g.*, all insects).

(*c*) Families of Diptera hold positions 4, 5, 7, 8, 10, and 12.

(*d*) Five out of the last six positions are groups that are neither Lepidoptera nor Diptera.

It would appear from this that the effect was at its maximum in the Lepidoptera, next in Diptera, and lower in other groups. Since all the differences dealt with are logarithmic or geometric ratios the fact that the Diptera make up a large proportion of the catch should not affect their position.

There is, however, one other point of possible importance. Work on the distribution of insects during the night (Williams, 1935) has shown that Noctuidae have their maximum flight round about midnight (in periods 4 and 5), the Geometridae a little earlier in period 3, and the Crambidae still earlier in period 2. On the other hand, the Chironomidae have their maximum flight at dusk in period 1 with a sub-maximum at dawn (period 8); the Coleoptera and Psocoptera both have their maximum in period 1; the Jassidae resemble the Coleoptera, and the Aphidae had a rather indefinite maximum flight in period 1 in one year and period 2 in the next.

Thus it appears that a possible explanation of the order of sequence in Table XI might be that the insects which fly late are most affected, while those that fly at dusk or dawn (12, 13, 14, 15, 16) are least affected.

In order to test this it is necessary to make a new comparison between full and no moon weeks of the insects caught in each successive period of the night separately.

### *Effect on all Insects at Different Periods of the Night*

Table XII shows for comparison with Table XI the mean differences, standard deviation, and value of $t$ for the 18 full and no moon weeks, for all the insects captured in each of the eight periods of the night separately. It will be seen that: (*a*) the standard deviation is (with one exception) remarkably constant; (*b*) the mean difference is always in favour of no moon—it is low in periods 1 and 8 but higher in all the others; (*c*) the test of significance ($t$) shows that the results in periods 2–7 are quite significant and approximately equally so.

The probability of the results being due to chance is about 1 : 50. But in period 8 and particularly in period 1, the results although positive are not significant and in the latter period the probability of the result being due to chance is 0·4 : 1·0.

Table XII

Difference Between Captures in Full and No moon Weeks, for all Insects, Considered According to the Time of Entry into the Trap

| Period | Mean log difference | Standard deviation | $t$ | |
|---|---|---|---|---|
| 1 | 0·71 | 0·85 | 0·83 | not significant |
| 2 | 1·94 | 0·84 | 2·30 | significant |
| 3 | 1·82 | 0·80 | 2·30 | ,, |
| 4 | 2·10 | 0·81 | 2·60 | ,, |
| 5 | 2·22 | 0·87 | 2·56 | ,, |
| 6 | 1·81 | 0·72 | 2·52 | ,, |
| 7 | 2·12 | 0·84 | 2·50 | ,, |
| 8 | 1·38 | 0·85 | 1·60 | doubtfully significant |

The lunar influence is therefore very low in the first period at dusk, significant and almost equally high in periods 2–7, and low again at dawn in period 8.

Further, the mean difference in the Noctuidae differs very definitely from the mean values of other insects caught in the same periods (4 and 5), so that the lunar effect on this group at least cannot be entirely due to their time of flight.

On the other hand, the low position of the dawn and dusk flyers, the Coleoptera, Chironomidae, Psocoptera, Jassidae, and Aphidae in Table XI is undoubtedly due in part to the low lunar influence at the times of their flight.

### *Separate Effect of Moonlight and Cloud on All Insects*

Table XIII shows the results obtained when the values for all insects captured each night in all three years together are treated similarly to those for the Noctuidae in Table IX.

The logarithmic mean catch per night was 208 insects. Reducing the values to percentages it will be seen from Table XIII C that on nights of "full moon, no cloud" the catch is 63; on "full moon with cloud" the catch is 115; on "no moon, no cloud" the catch is 81; while on "no moon, cloudy" the catch is 381. All the values in the table are consistent and show quite definitely the separate influence of moon and cloud; but the most remarkable difference from the Noctuid table is the very high value obtained on the nights of no moon with cloud, which is almost three times the value of any of the adjoining groups and nearly six times the number of the opposite extreme "full moon, no cloud".

Table XIII

Effect of Various Combinations of Moon and Cloud Conditions on All Insects, for Comparison with Table IX

| A. Mean log | | | | B. Mean catch (anti-log — 1) | | | | C. % of mean catch | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2·12 | 2·16 | 2·38 | 2·19 | 131 | 144 | 239 | 154 | 63 | 69 | 115 | 74 |
| 2·17 | 2·34 | 2·43 | 2·31 | 147 | 218 | 268 | 203 | 70 | 105 | 129 | 97 |
| 2·23 | 2·46 | 2·90 | 2·50 | 169 | 287 | 793 | 315 | 81 | 138 | 381 | 151 |
| 2·19 | 2·32 | 2·54 | | 154 | 208 | 346 | | 74 | 100 | 166 | |

Another curious fact is the small difference between the values for full moon and no moon on nights when there is no cloud.

If one were to attempt an explanation of the differences at the present early stage in the investigation it might be suggested that the insects as a whole (which include a very large majority of small Diptera) are more sensitive to "optimum" conditions, which are cloudy (and hence warm and damp) nights with no moon, and do not fly if these conditions are not existing, while the Noctuidae are more tolerant of their climatic environment and are only seriously reduced by the poorest conditions, which are cool clear nights with full moon.

### *Effect of Moonlight and Cloud on the Sub-family Tipulinae (Diptera)*

Pinchin and Anderson (1936) have applied similar methods to the study of the Tipulinae captured in the trap and have obtained the following values (expressed as percentages) for the final moon-cloud diagram for the years 1933 and 1934 combined. The results are once more consistent and show a ration of about 4 : 1 between the extremes of " full moon, no cloud " and " no moon, cloudy".

TABLE XIV—EFFECT OF VARIOUS COMBINATIONS OF MOON AND CLOUD CONDITIONS ON THE FAMILY TIPULINAE

| | | | |
|---|---|---|---|
| 54 | 81 | 162 | 77 |
| 73 | 127 | 162 | 116 |
| 100 | 139 | 200 | 135 |
| 73 | 116 | 173 | |

## GENERAL DISCUSSION

It would appear from the above results that when certain groups of insects are attracted to a trap by means of a light, the captures show a lunar periodicity with a minimum at full moon and a maximum at or just after no moon. This is particularly definite in the family Noctuidae of the Lepidoptera which have their maximum activity round midnight, but is very much less marked in certain other groups, such as Coleoptera and Jassidae which fly chiefly at dusk and dawn. The Noctuidae, however, differ significantly from other insects flying at the same time.

Certain asymmetries in the effect can be traced to similar asymmetries in the apparent movements of the moon, and when the asymmetry of the moon changes that of the captures does also.

When the cloud effect is analysed separately it is found that cloudy nights have larger captures than clear nights, but these nights are, on an average, distinctly warmer than the clear nights, and this may be sufficient to account for the differences in catches.

The fullest effect of the moon is noticeable on clear nights when the ratio of captures in the Noctuidae between no moon and full moon is 128 : 42 or 3 : 1 ; on cloudy nights the ratio is 184 : 95 or 2 : 1 ; while on all nights irrespective of cloud conditions the ratio is 146 : 54 or about 2·7 : 1.

The reality of the reduction of catches by the moon may therefore be considered to be definitely established.

This reduction may be due to one of two effects. First may be that the moonlight is reducing the activity of the insects, so that the active population available to be sampled by the trap is smaller. Secondly, it is possible that the light of the trap has to compete with the light of the moon and so is less efficient and attracts insects from a smaller area.

It is not at present possible to distinguish between these two alternatives with certainty, but the fact that the Noctuidae differ considerably in their response from other insects flying at the same time suggests the effect may be partly at least physiological.

Further investigation is proceeding to settle this point by the use of traps not dependent on light for their attractive power. During 1935 a mechanical trap was constructed and tested (Williams and Milne, 1935), but while very successful for the smaller insects it did not catch the larger Lepidoptera in any numbers. During 1936 experiments are being started on the use of a bait trap.

If a reduction at full moon is shown by these traps, then the effect of the moon must be a general lowering of activity of the insects concerned, as is the popular belief among insect collectors. If on the contrary the mechanical and bait traps show no lunar periodicity, the effect of the moon must be merely to lower the efficiency of the light as an attractant.

## Summary

The object of the investigation was to test the truth of a general belief that insect night activity in certain groups, particularly Lepidoptera, is reduced at full moon. This belief was held to apply to insect activity in general, but in particular to the number of insects attracted to light.

A light trap was placed in a field at Rothamsted in March, 1933, and has been in continuous use since that date. The captures of the Noctuidae during the summers of 1933, 1934, and 1935 were selected for special study.

Three main methods of analysis were used. (I) A comparison of total captures and of the sum of the logarithms of captures, in the full moon and no moon weeks of eighteen lunar months, six in each summer. (II) Averaging over the eighteen lunar months the mean departures of the log of the catch from the 29-day mean for each of the 29 days of the lunar cycle. (III) A calculation of the mean departures of the log from the 29-day mean for all days of the period grouped into nine divisions according to moon conditions (full, intermediate, and no moon), and to cloud conditions (clear, intermediate, and cloudy sky).

The amount of night cloud was measured chiefly by an adaptation of the Greenwich pole-star camera ; while the moonlight was measured by a specially designed photographic recorder.

In the Noctuidae all three methods gave a definite indication of lunar periodicity. The first comparison showed 17 of the 18 lunar months with a higher catch at no moon than at full moon and a mean difference of six times the standard deviation.

The second method gave a curve with a definite minimum very close to full moon and a maximum slightly after no moon. This curve is asymmetrical and further analysis showed that it was compounded of two curves with opposite asymmetries, each explicable by similar asymmetries in the moon's apparent movements.

The third method shows a ratio of 3 : 1 between no moon and full moon week captures when the sky is clear, and 2 : 1 when the sky is cloudy. The same method shows that the ratio of captures on cloudy nights to clear nights is about 1·75 : 1, but this is associated with warmer conditions on cloudy nights (about 4° F. higher on minimum temperature) due to the reduction of radiation by the clouds.

A difference has been demonstrated between the hours of flight during the night of the Noctuidae in the week before and after full moon, corresponding to the effect of the early or late portion of the night being under the moonlight.

Other groups of insects analysed by the first method show varying lunar effects, never, however, so striking as that in the Noctuidae and in a few groups (*e.g.*, Coleoptera, Jassidae, and Aphidae) it is non-significant or slightly negative.

The groups showing least effect are shown to be those that fly chiefly at dusk or dawn, whereas the Noctuidae have their maximum activity at midnight; but a separate analysis of all insects, according to the different times of the night at which they are captured, shows that this time of flight is not sufficient to account entirely for the difference found.

When the total insects captured are analysed by the third method consistent results are obtained, but with a very large increase in captures on the days of no moon—full cloud. It is suggested that the explanation of this may be a narrowly limited range of optimum conditions of moon, cloud, temperature, and humidity in the smaller Diptera which make up most of the catch.

It is considered that the lunar effect on the captures is definitely demonstrated, and that there is distinct evidence that it differs in different groups apart from any difference in their time of flight. Therefore, it is probably a physiological effect on the activity of the insects and not merely due to reduction in the efficiency of the light trap when the moon is shining. Further experiments to test this more fully are being carried out, by using traps not dependent on light for their attracting power.

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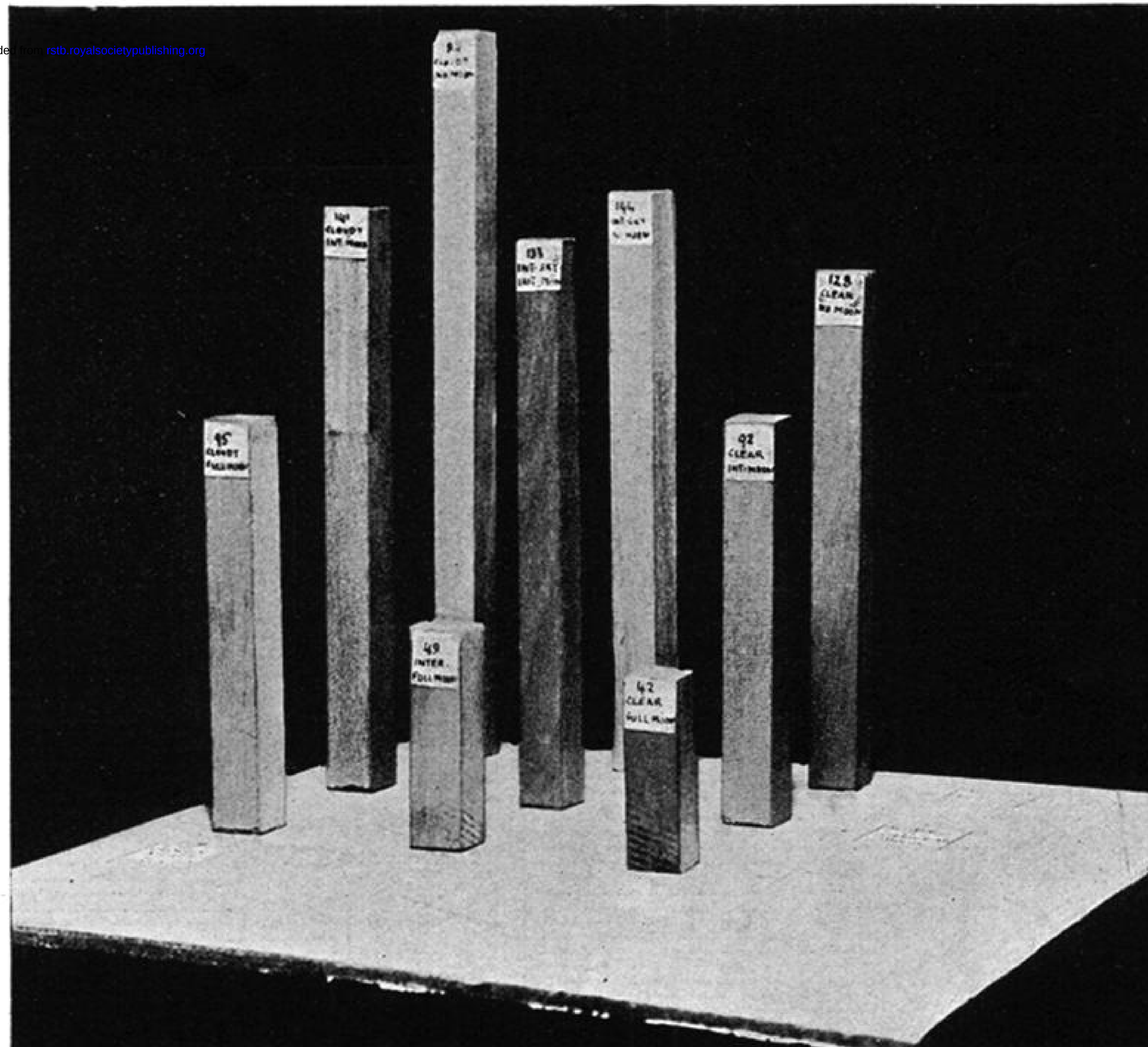

FIG. 6—Photograph of three-dimensional model showing the average numbers of Noctuidae captured in the trap on nights of various combinations of moon phase and cloud conditions.



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