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Light-trap and suction-trap catches of insects in the northern Gezira, Sudan, in the season of southward movement of the Inter-Tropical Front

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Introduction

This study arose from part of a research project, initiated by Mr. R. J. V. Joyce and organised jointly by Ciba-Geigy Limited and the Sudan Gezira Board in which light-traps, suction traps, and traps carried on an aircraft were used to investigate the air-borne transport of insect pests in the Sudan Gezira. The present paper considers catches only from the light-traps and suction traps and not only of pest species; some of the results of trapping from aircraft are discussed by Rainey & Joyce (1972).

Trapping covered the time of year when movement of insects to cotton from other components of the Gezira rotation, dura (*Sorghum vulgare*), groundnuts (*Arachis hypogaea*) and lubia beans (*Dolichos lablab*), and from weeds on fallow, coincided with passage over the area of the Inter-Tropical Front. During this period, only small numbers of cotton pests were trapped and the species caught in largest numbers were mainly those associated with dura. Therefore, the species that were counted were those that were abundant, of known pest status, or easily recognised. Light-trap catches of *Heliothis armigera* (Hb.), a species of particular interest in the project, are much larger in the Gezira from January to March or even April (Balla, 1970) than when cotton is developing (September–December); knowledge of phenology on hosts other than cotton is probably needed to explain this.

The local status and phenology of most of the taxa discussed are little known. It was, therefore, thought particularly important to remember that many kinds of life-cycles and many environmental factors could produce changes in trap catches, and not to attempt too early to interpret results only in terms of transport mechanisms known to affect certain species. The kinds of change in catch that occured are, therefore, described first, and environmental factors that might correlate with the various observed changes are then sought.

The Inter-Tropical Front

The rainy season in the central Sudan lasts from May to October, and at Khartoum most rain falls in July and August. The duration of the rainy season and the amount of rain depend largely on the presence of the Inter-Tropical Front (ITF) which, in the central Sudan, is at or near the northerly limit of its annual movement. The ITF shifts gradually northward to reach an extreme position about 18° or 19°N in July and August and retreats south again from September onwards. Both the northerly extension and the southerly retreat are not smoothly continuous but are interrupted by back-and-forth fluctuations which may cover several degrees of latitude in a few hours or days. There is a tendency for a diurnal cycle of afternoon decay of the ITF, due to increased afternoon insolation and convective turbulence, followed by evening restructuring which then persists overnight. Usually, southerly movements occur during the day and northerly movements during the night, but a major advance or retreat can continue during the day and night.

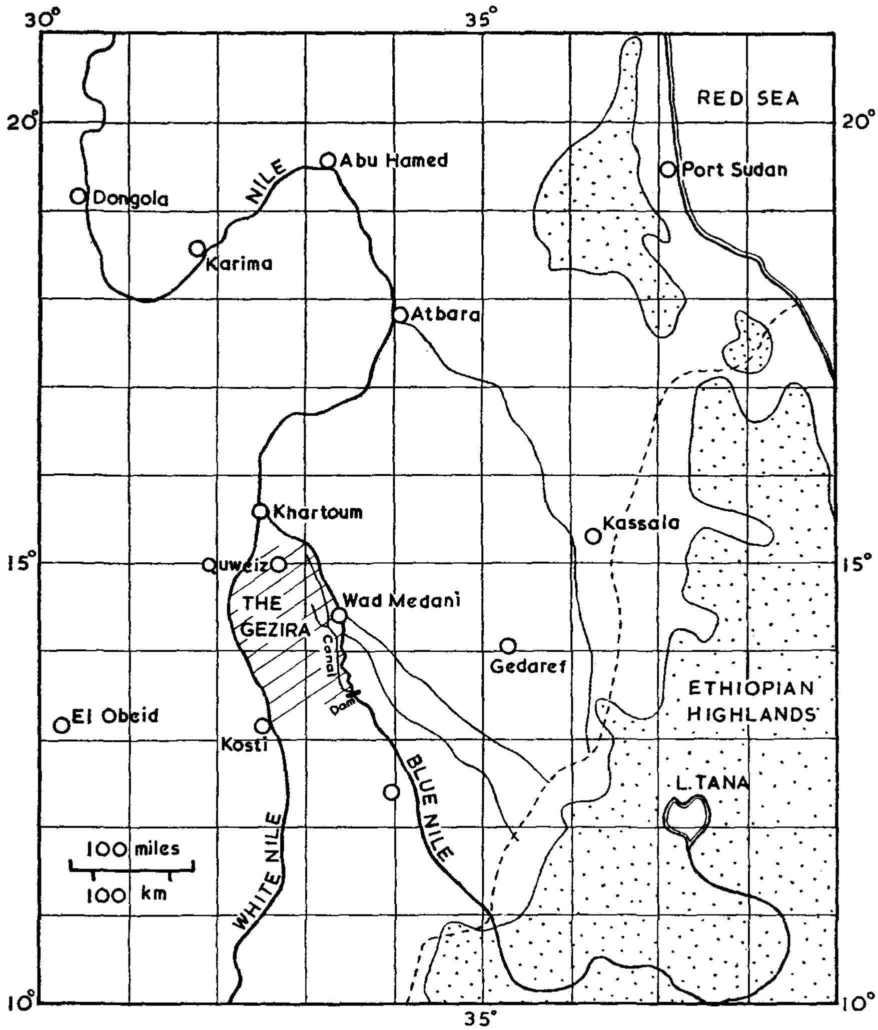


Fig. 1.—Sketch map of east central Sudan to show the Gezira, physical features, and weather stations.

The structure of the ITF is incompletely understood; the term is used here, in the sense of Osman & Hastenrath (1969), to describe a discontinuity in the surface moisture and wind field separating dry warmer air of northern origin from moist cooler air of southern origin. Where the discontinuity exists it is relatively simple to identify opposite sides of it, and in the synoptic diagrams in Fig. 5 the ITF has been indicated as a double dotted line between appropriate stations. The position of the dotted line merely locates the zone in which the opposing winds are thought, on the available evidence, to meet; it is not meant to signify more than the approximate geographical location of the surface discontinuity.

Trapping methods

The trapping site was at Quweiz village, the headquarters of Block No. 42, North-West Gezira group, about 50 miles south of Khartoum. The map (Fig. 1) shows the Gezira irrigation scheme and localities and physical features relevant to the synoptic weather maps discussed later.

Three 12-in. suction traps, described by Johnson & Taylor (1955) and standardised by Taylor (1955), were mounted on a 50-ft tubular steel tower with their air inlets at 50 ft, 20 ft and 10 ft. The tower was situated on the east side of Quweiz village, about 80 m south-east of the nearest building, and adjacent to a 'number'* in fallow. Each trap was colour-coded by paint bands. The traps were adapted to take 2 lb Kilner jars as catch receptacles and each trap was supplied with its own set of appropriately colour-coded jars each containing a 1-in layer of 'Plaster of Paris' to absorb a killing agent (dichlorvos). At each height an anemometer indicated wind direction and speed automatically. Power for the trap and anemometers was supplied by two Petter ABI 230-V diesel generators, used in alternating periods. Technical difficulties prevented suction trapping until 24 October, when it soon became apparent that the size of catch and sorting difficulties precluded continuous operation. Therefore the suction traps were subsequently operated for limited periods and for specific objectives, as described in the appropriate sections below.

The light-trap consisted of the Robinson-type bulb holder and was powered by a 'Champ' portable generator, the light source being an Osram 125 MB/U elliptical bulb. To prevent damage to the catch, crumpled paper was put in the traps and a quick-knockdown killing agent (dichlorvos) was used.

For technical reasons it was only possible to use two light-traps from 21 October onwards. These were situated on the access roads dividing two cotton numbers, and were operated for five hours from sunset each night, that is from 19.00 to 24.00 h until change from summer time to winter time on 16 October, then from 18.00 to 23.00 h. (Sudan Local Summer Time is three hours and Winter Time two hours in advance of GMT.) Light-trapping was interrupted on 21 October and from 4–9 and 26–30 November, and ended on 20 December. The number of taxa that could be counted was limited by the large volume of material and technical considerations.

Suction-trap catches

Because the sampling with suction traps was very fragmentary, the data given are confined to insects of which catches varied much, namely several species of grass-feeding Homoptera (Cercopidae and Cicadellidae), some of which feed on sorghum. During a four-day sampling period in October large variation in the pattern of catch between sunset and midnight gave evidence of displacements that could be correlated with changes in wind direction near the ITF. By contrast, sampling at various times in November showed activity patterns at times when there was no influence of the ITF. Two aspects of activity will be considered, vertical distribution and periodicity of abundance during the day.

Vertical distribution

On 12 and 13 November suction traps were operated simultaneously at three heights. An aircraft also towed a net at 250 ft over the trap site for about an hour immediately before and after sunset. Details of samples obtained by the aircraft will be given in

* The standard unit of irrigation and rotation in the Gezira Scheme, with a cultivable area measuring 1350 × 280 m (37.8 ha).

full by R. C. Rainey *et al.* (in preparation) but some of the data are used here to extend the vertical profile shown by catches from the suction traps.

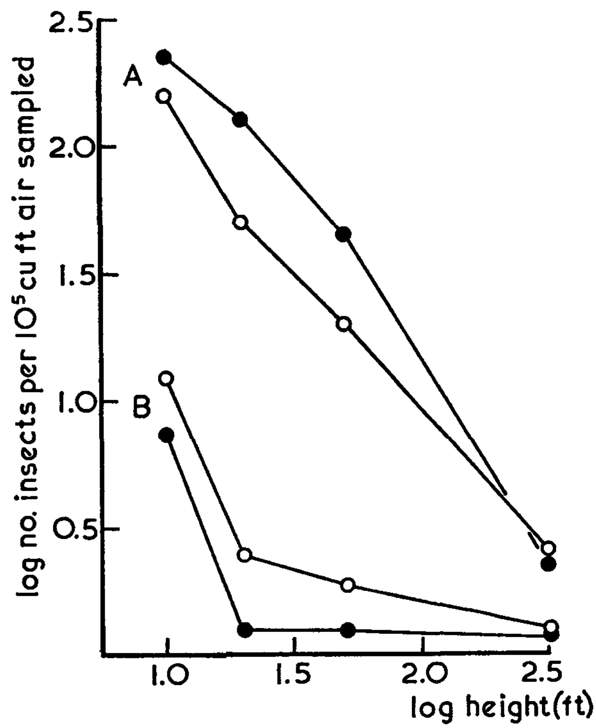


Fig. 2.—Profiles of vertical distribution of all insects (*A*) and grass-feeding Homoptera (*B*) in suction-trap catches at three heights and in aircraft catches at 250 ft, November 12 (*open circles*) and 13 (*closed circles*).

Figure 2 shows the relationship between catch and height after correction for the volume of air sampled by the two kinds of trap. The total catch shows a logarithmic decrease with increase in height of the kind that has been shown in temperate areas (Johnson, 1957). The composition of catches from the aircraft resembled those from the suction traps, with small Diptera (Chironomidae, Ceratopogonidae), Anisotomid beetles and grass-feeding Homoptera the most numerous, in that order. The latter group had a different profile from the logarithmic one of the other groups; catch decreased greatly between 10 and 20 ft, then much more gradually up to 250 ft.

At the time these catches were obtained the trap area had been under light dry north-westerly winds during the evenings for 12 days since the last influence of the ITF; the vertical profile is therefore uncomplicated by arrival of insects displaced in air movements associated with the ITF.

Diurnal flight time

During late October and November suction traps were run for three complete 24-h periods and for periods of between 3 and 20 h on ten other days. Because sampling periods were irregular, some hours out of the 24 were sampled more times than others over the whole period: the minimum was five times, the maximum eleven. Figure 3 shows the mean catch for each hour of the day for all periods sampled, and separately, with 24 and 25 October excluded. A well defined peak of activity occurred at twilight every day, but on 24 and 25 October this was followed by further large catches until midnight. The crepuscular peak probably represents undisturbed local activity, and the circumstances in which catches occur later in the night are discussed below.

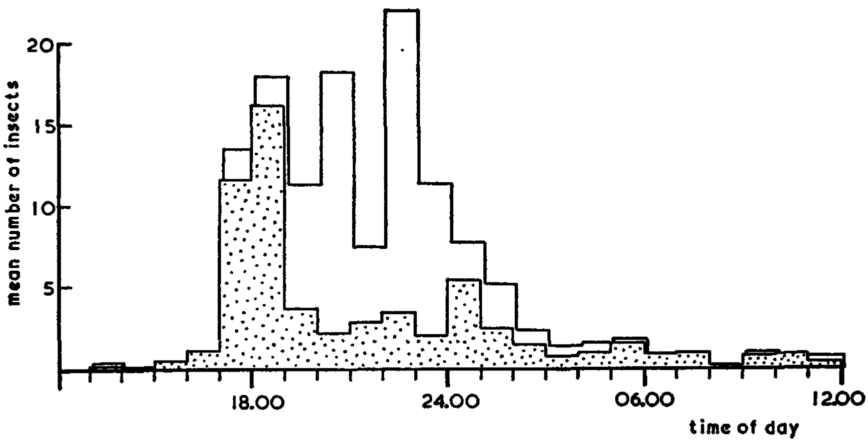


Fig. 3.—Hourly distribution of suction-trap catches of grass-feeding Homoptera (means from several sampling periods of variable length within the period 24 October–26 November (*open histogram*) and with the whole of 24–25 October omitted (*stippled histogram*)).

Displacement of grass-feeding Homoptera

The suction traps were run continuously from 16.00 h on 24 October to 12.00 h on the 26th, then from 16.00 to 24.00 h on the 26th and 27th. Hourly catches at the three heights are shown in Fig. 4. Wind direction and speed were recorded at each trap at the end of each hour's sampling, and some of the changes in catch are closely associated with changes in wind direction. On the 24th, increase in catch at 10 ft occurred in the same hour as wind began to veer from north to south; insects entered the 20-ft and 50-ft traps, particularly the latter, two hours later and continued to enter the 20-ft traps during the following hour. After midnight the wind veered again until it was northerly, and catches from then onwards were small. On the 25th, large catches at 20.00 and 21.00 h also followed veer in wind to the south, and a sharp decrease in catch in the subsequent hour coincided with backing of wind to the north again. On all nights an increase in catch occurred in the hour including sunset (17.00–18.00 h), unaccompanied by southerly winds; this increase was the main event of the night on the 26th but was small and temporary on the 24th.

The recorded changes in wind direction are associated with fluctuations in the position of the Inter-Tropical Front (Fig. 5). A prevailing southerly movement of the front was interrupted from 21 to 28 October, and the front passed over the trap site repeatedly in this period. Diurnal movements of the front north and south over the trap site covered a distance of roughly 100 to 150 miles each day and reached their northerly limit soon before midnight.

The suction traps measured movements of insects occurring in association with changes in wind direction and the question remains whether the evidence obtained is adequate to reconstruct the kind of displacement system that was involved. On the 24th, insects became active at the trap site in the hour up to 21.00 h. This was the time that wind veered from north to south, but though catch increased in the upper traps it did not become maximal till later. Large numbers of insects appeared abruptly in the 50-ft

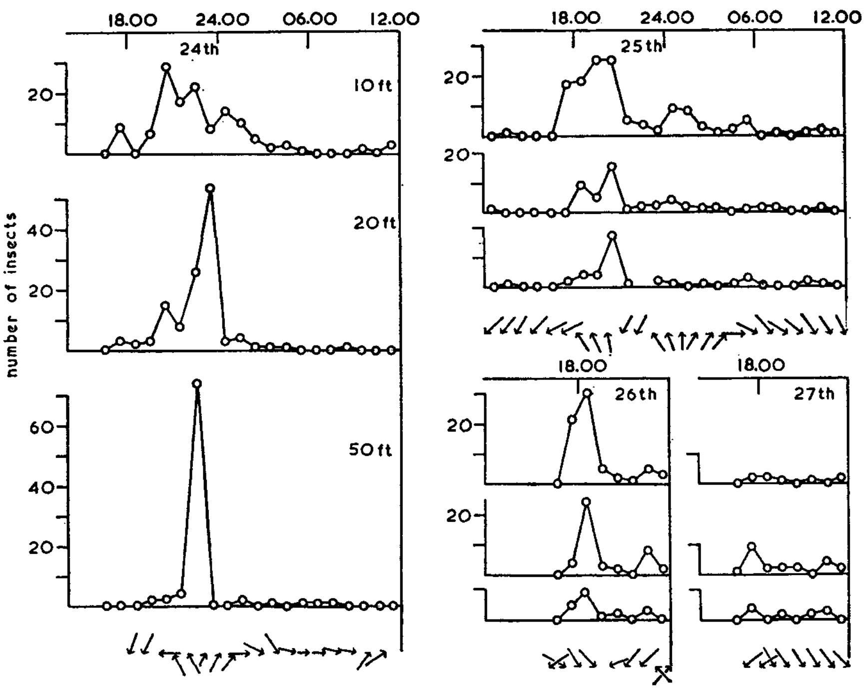
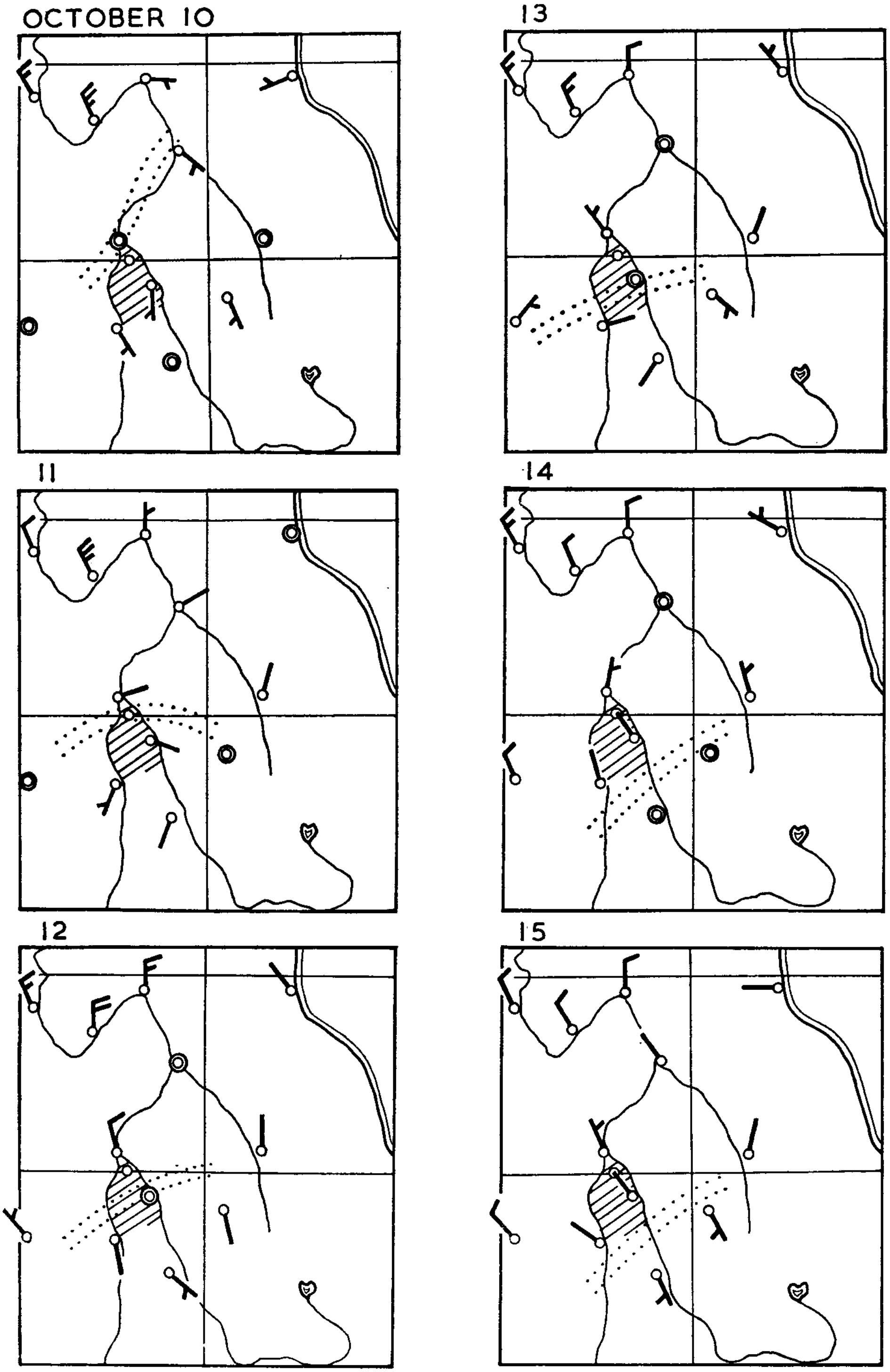


Fig. 4.—Hourly suction-trap catches of grass-feeding Homoptera at three heights, various times in the period 24–27 October, with wind direction and speed at one-hour intervals at 50ft.

trap at 23.00 h, and wind speeds during the interval indicate that the ITF was probably several kilometres north of the trap site by this time. After the brief increase at 50 ft, increase occurred at 20 ft in the next hour and decreasing catches at 10 ft continued an hour or two longer. Insects may have been flying at a greater height over the trap site before their appearance in the 50-ft trap since it is not possible to distinguish between descent and horizontal transport. Therefore it is not possible to reach any conclusion about the mode of transport beyond the fact that behaviour of insects at the place where ascent, presumably in frontal turbulence, led to displacement and subsequent arrival at the trap site was apparently different from behaviour at the trap site, where there was no evidence of ascent or descent.

On the 25th, veer to southerly winds occurred two hours earlier than on the 24th and the increased catches accompanying it were continuous with a peak of activity beginning in the hour of sunset. Two hours after the change of wind direction large catches occurred in the 20-ft and 50-ft traps, although they were smaller and involved a less

Fig. 5.—Surface winds at stations in east central Sudan at 20.00 h local time each day from 10 October to 2 November. (*Double dotted line*, probable position of Inter-Tropical Front. Wind speeds shown by usual conventions: *circle*, calm; *simple arrow*, 2–4 km/h; *half feather*, 5–19 km/h; *whole feather*, 14–23 km/h; *each additional half feather*, a further range of 7–8 km/h.)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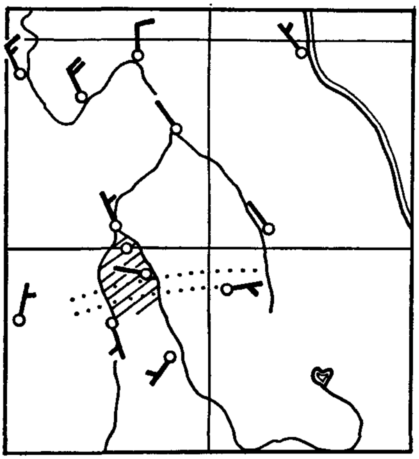

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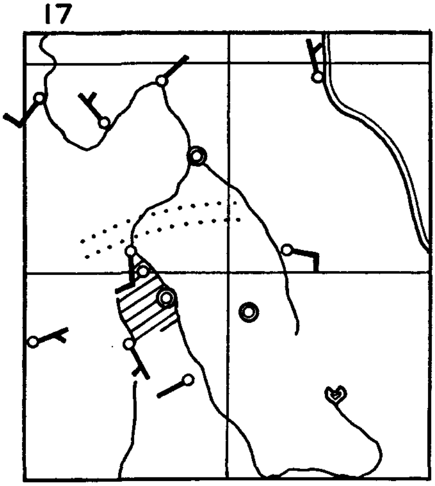

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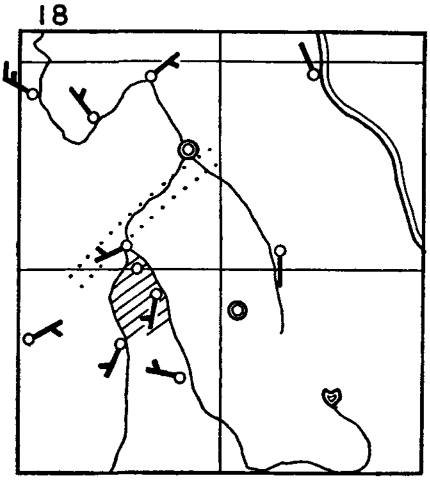

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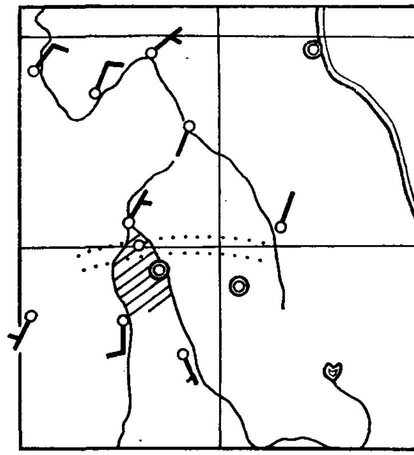

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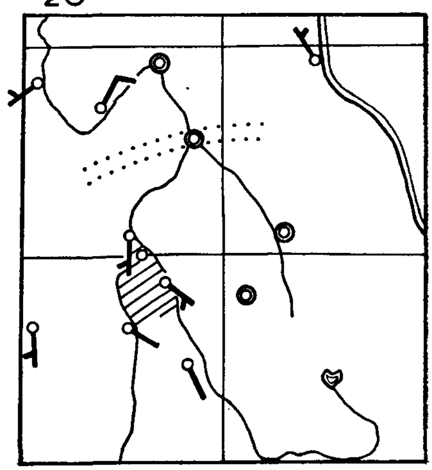

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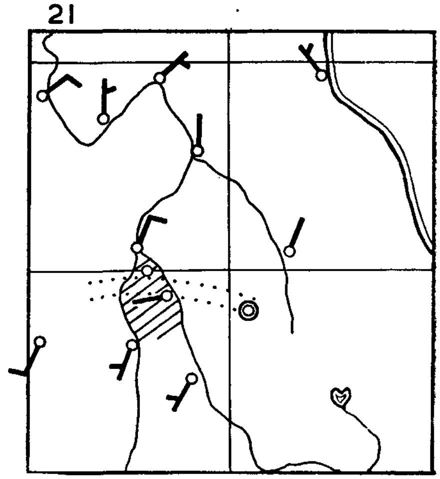

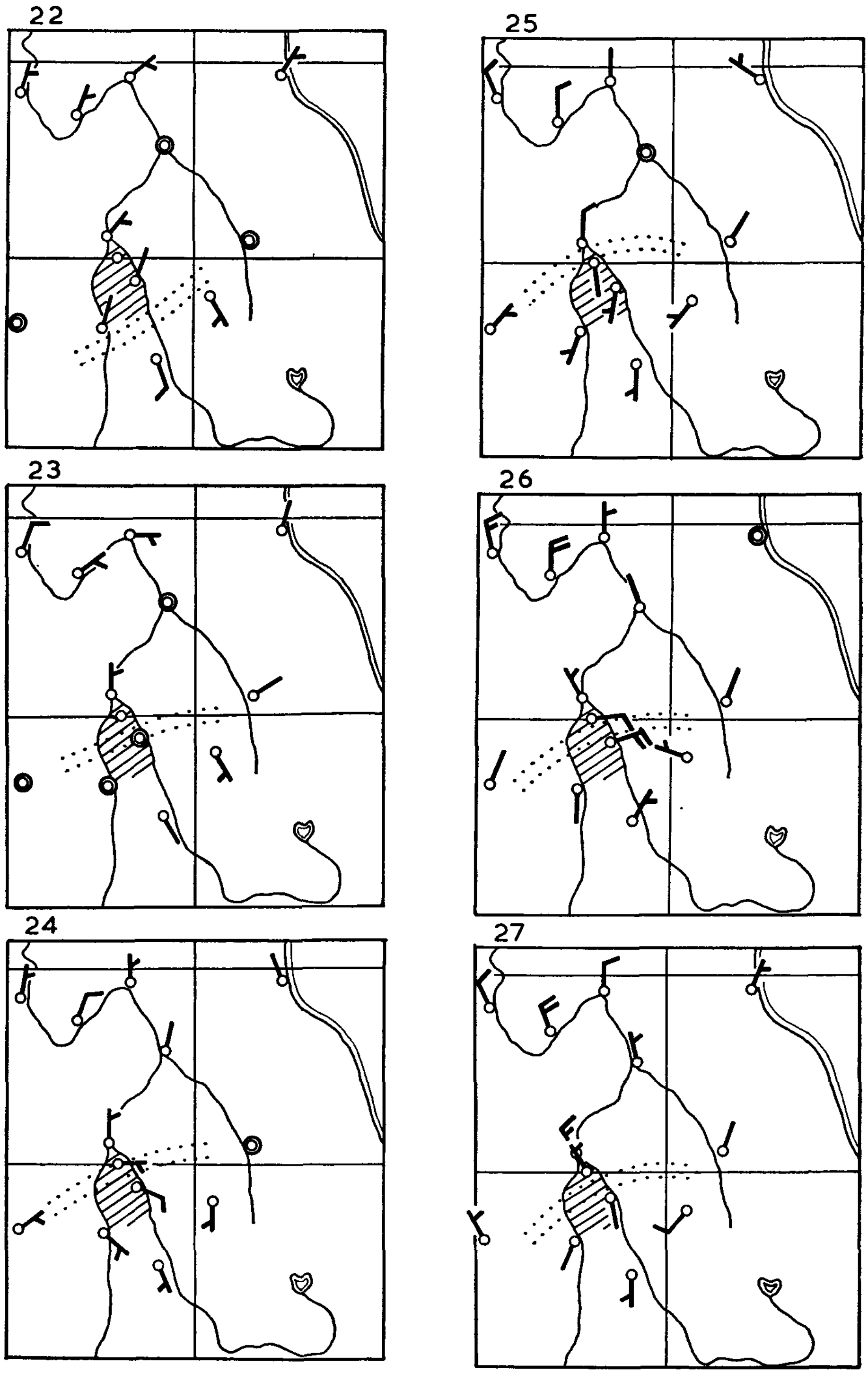
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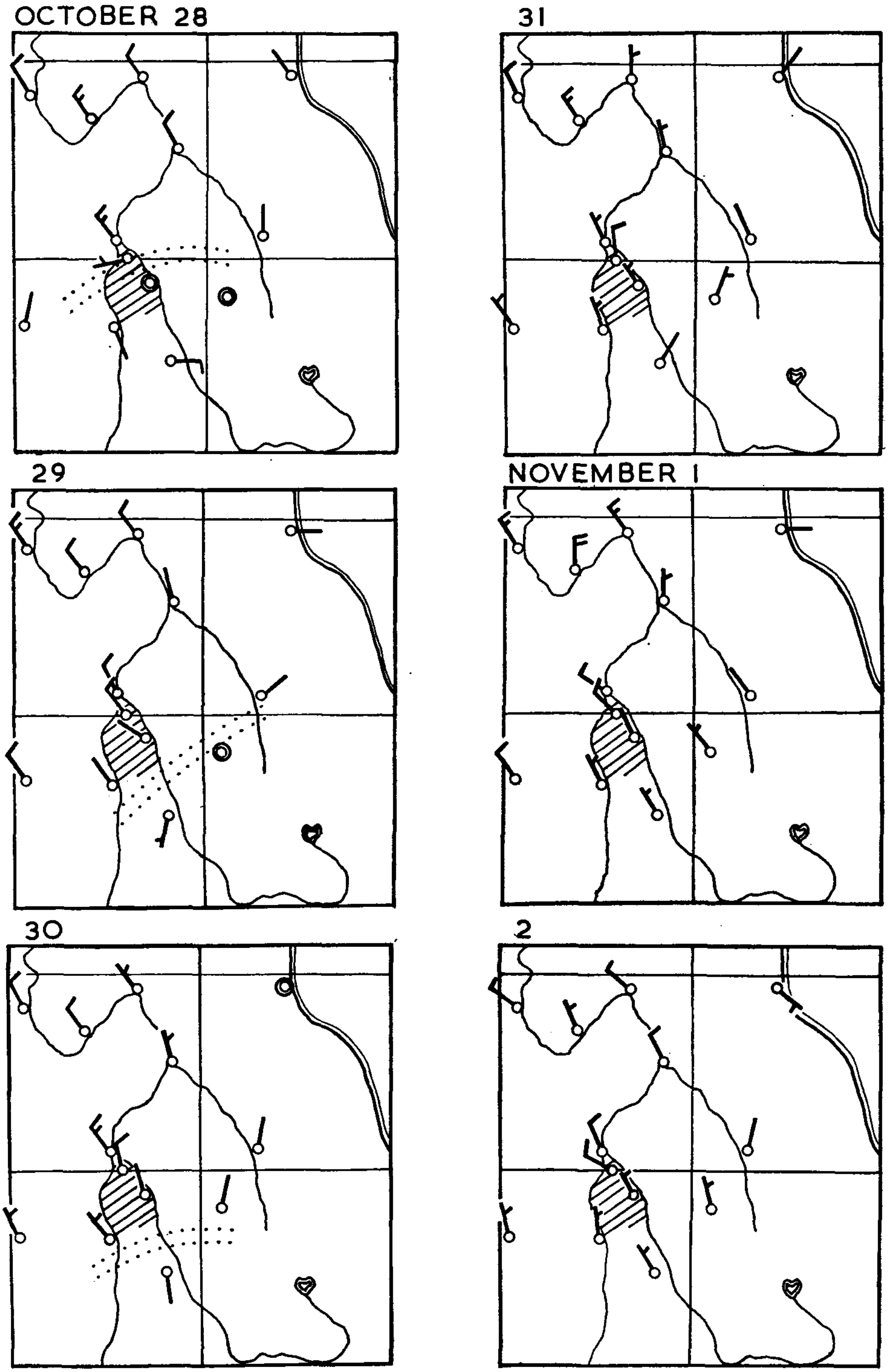
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complete reversal of the vertical distribution than those of the 24th. Initial increase was apparently followed by arrival in the upper traps on both the 24th and 25th, but the two events were more closely superimposed on the 25th. Vertical distribution in the second hour after wind change on the 25th, with a large catch at 20 ft, suggested that the insects were ascending and presumably entering the air circulation. Irregular changes in the wind direction suggest that turbulence associated with the ITF was present, although the front did not move to the north of the trap site until nearly midnight.

It seems likely that, in addition to wind changes associated with the ITF, readiness of the insects to disperse contributes greatly to the observed patterns of catch. More time elapsed between wind change and arrival in the upper traps on the 24th than on the 25th, and on the 26th ascent to the upper trap followed immediately on initial increase. This may mean that the source of insects displaced into the trap area was closer to it on the 25th than on the 24th, and that the trap area itself was a source of dispersing insects on the 26th. An anomaly remains in the initial increase in the 10-ft trap on the 24th. Insects did not become active at the usual time, but later when the wind began to veer; this unusually late activity itself suggests readiness to disperse, but there was very little ascent to the upper traps.

Catches were very small on the 27th, and winds did not veer to the south at any time. They went round to the north-east briefly, however, and Fig. 5 confirms that the ITF was only a short distance south of the trap site on that evening since southerly winds became well established at Wad Medani. The picture that emerges for these grass-feeding Homoptera is of a behaviour pattern closely geared to the close proximity of the ITF. Their dispersal depends on the coincidence of readiness to disperse with proximity of the ITF at or soon after the time of a relatively brief period of crepuscular activity. On 24 and 27 October there was strong northerly wind at 18.00 h and the crepuscular peaks were small; on 25 and 26 October wind shifts associated with the ITF occurred and crepuscular peaks were larger. In the drier northerly winds, therefore, few insects are in the air and ascent is likely to be inhibited by lack of turbulence and the development of inversions. We conclude, therefore, that in the presence or proximity of moist southerly air, increased crepuscular activity leads to greater numbers of insects in flight, and turbulence associated with frontal conditions is likely to assist ascent so that the probability of dispersal is increased.

Light-trap catches

Total catches for the five-hour sampling period each night are given in Fig. 6 for a range of taxa. An attempt has been made to distinguish recurring patterns of night-to-night change in catch, and the data are plotted logarithmically so that patterns of change during periods of small catch are not overlooked in favour of events involving large catches. Associations with external factors, changing reproductive condition of the catch, and aspects of the biology of the taxa concerned were then studied to suggest possible functional relationships.

Patterns of change in catch

Changes in catch show some features that are common to many taxa, others that are more specific, and the main task in describing the data is to separate these components. The example of Gryllids (Fig. 6) illustrates several kinds of change. The large majority of Gryllids sampled were *Acheta lusitanica* (Serv.) which was found in large numbers on the heads of dura near the trap site. Maximum catches were about equal in October and November, much smaller in December. In October the largest increase in catch was from the 17th to 19th. From the 22nd to 28th there was a much more gradual sustained increase with only slight nightly fluctuation from an average linear trend on an arithmetic as well as a logarithmic scale. In November increase was rapid from the 15th to 19th; the average upward trend was approximately linear on a logarithmic scale and, again, nightly fluctuation from the trend was small.

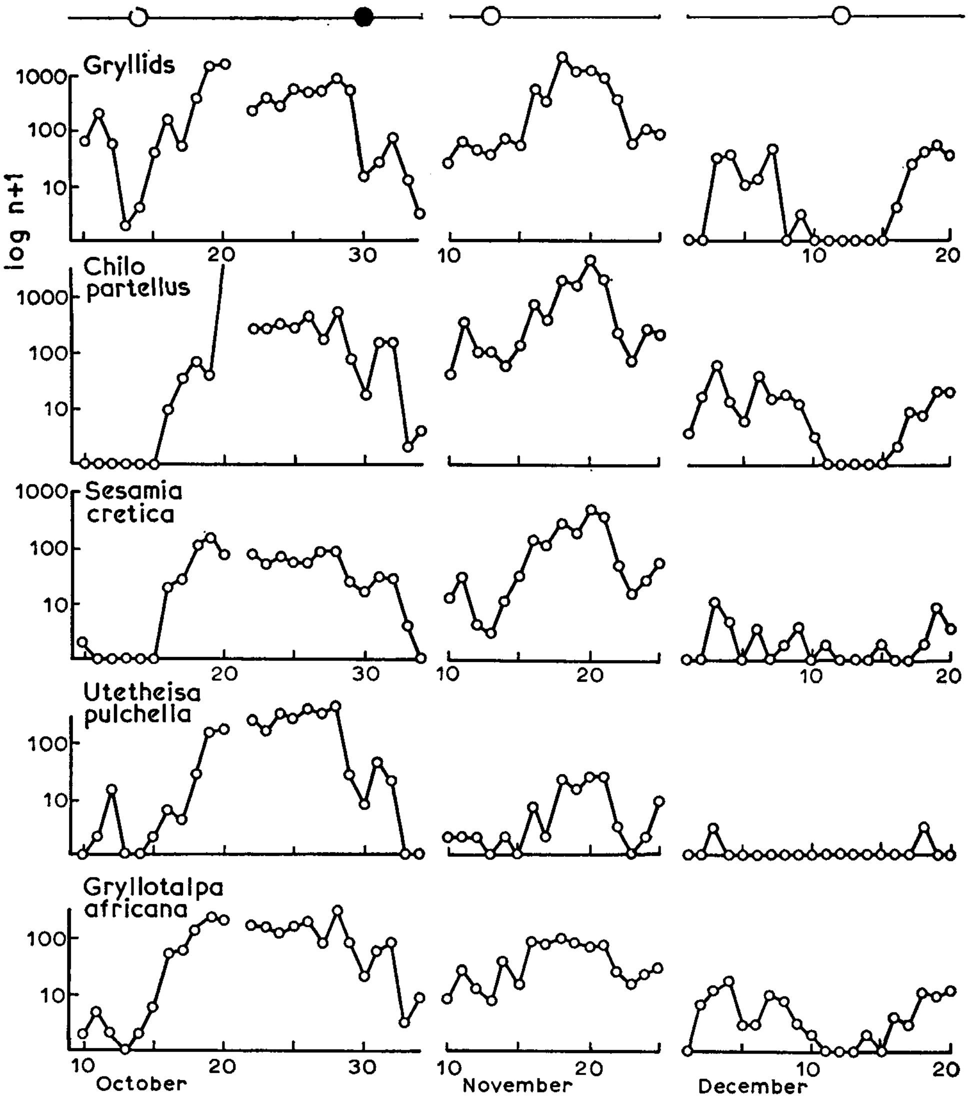

Fig. 6.—Total nightly light-trap catches of various taxa between 18.00 and 23.00 h local time (summer time one hour later up to to 16 October); lunar phase at top.

Larvae of the Pyralid *Chilo partellus* (Swinh.) and the Noctuid *Sesamia cretica* Led. were exceptionally abundant in the stems of dura in the south of the Gezira near Wad Medani, less so at the trap site. In October the largest increase coincided with that of Gryllids, but before the 15th catches were nil. Exact timing varied a little: on the 20th more *C. partellus* were caught than on any other night, but catch of *S. cretica* was similar to those of the previous two days. From the 22nd to 28th catches fluctuated slightly around the average, interrupted only on the 27th by a smaller catch in *C. partellus*. In November the pattern of increase resembled that of Gryllids but was slightly later and at

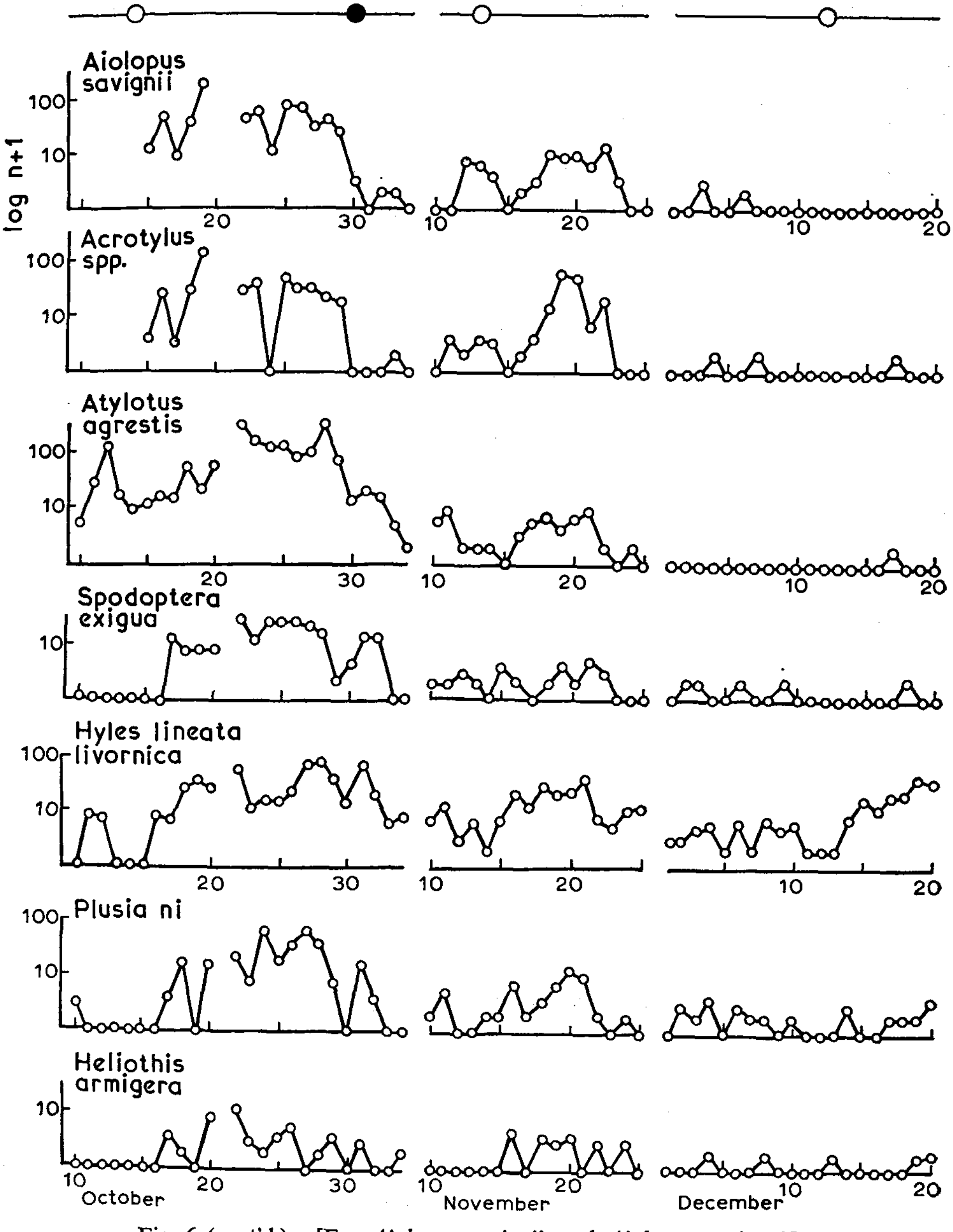

Fig. 6 (cont'd.).—[For *Aiolopus savignii* read *Aiolopus savignyi.*]

a smaller rate. In *S. cretica* the onset of increase showing a pattern like that of Gryllids and *C. partellus* was preceded by two days' increase at a larger rate.

In the Arctiid *Utetheisa pulchella* (L.) catches in October increased as with *S. cretica* in November: several days' abrupt increase up to the 19th was followed by a steady increase from the 19th to 28th. A marked difference from taxa already mentioned was that catches in November were much smaller than those in October.

Catches of *Gryllotalpa africana* P. de B. resembled those of *C. partellus* and *S. cretica* with no net increase from 22 to 28 October. In November also, nightly catches remained almost constant from the 16th to 21st—the period when those of other taxa showed a characteristic increase. Catches of Acridids were mostly *Acrotylus* spp. and *Aiolopus savignyi* Krauss; changes up to 20 October resembled those in Gryllids, and from the 22nd to 28th remained almost constant except for a much smaller one on the 24th that was peculiar to the Acridids. Unlike other taxa, Acridids disappeared from the catches entirely from 31 October to 3 November.

There were never more than 20–30 specimens of *Spodoptera exigua* (Hb.) per night, but a pattern of change like that in other taxa is clearly shown, and like several other Lepidoptera it was absent for the first few days of trapping. Numbers from 22 to 28 October fluctuated little. Other taxa are characterised by marked fluctuations between 22 and 28 October, as in the Sphingid *Hyles lineata livornica* (Esp.), the Noctuid *Plusia ni* (Hb.), and the Tabanid *Atylotus agrestis* (Wied.).

Pests of cotton were of particular interest but few were caught. *Heliothis armigera* was not caught until 17 October (except for one specimen), but then increased to maxima of 8 and 12 specimens on the 20th and 22nd, respectively. After this, only 0–5 were caught per night until 3 November, few from 16 November onwards, and several in December. Of other Noctuids that attack cotton, two or three specimens of *Xanthodes graellsii* (Feisth.) occurred on several nights from 17 to 22 October, a few of *Euxoa* spp. from 15 to 20 October, and two of *Diparopsis watersi* (Roths.) on 18 October.

All taxa, except Acridids, increased temporarily on 31 October following abrupt decrease. Numbers were usually small, but nearly equalled maximum catches in *Hyles l. livornica.*

In December only *H. l. livornica* showed a period of regular nightly increase in catch like that in the other months. December catches of most species were small and fluctuated irregularly, but *G. africana* changed like *H. l. livornica*, and both Gryllids and *C. partellus* reached moderate numbers early in the month and again towards the end of sampling.

The kinds of change described can be summarised as follows. In both October and November, increases leading to periods of sustained large catches occurred within two days in all taxa, from 16 to 18 October and 15 to 16 November. From about 28 October and 21 November, most taxa decreased. On 19 and 20 October a very large catch of some taxa was superimposed on the beginning of the sustained period of nightly increase that continued to the 28th. Other temporary increases, to 11 or 12 October and to 31 October or 1 November, involve smaller catches of most taxa.

Local activity, immigration and emigration

A major problem in the interpretation of light-trap catches is to determine whether insects are entering or leaving the trap area or are only active near the trap. Evidence on this was sought by considering associations between changes in catch and the limited available information on probable sources of insects caught.

The largest catches in November, equalling or exceeding those in October, involve the Gryllids, *C. partellus,* and *S. cretica* which were plentiful adjacent to, or at most a few miles from the trap, and do not have a long period of migratory activity in their life-cycles. For these reasons, and also because weather was comparatively stable in November, the change in catch shown by these three taxa in November probably reflects a cycle of local activity independent of large-scale emigration or immigration.

In Acridids, local populations had largely disappeared from the trap area at the end of October. Transects on which all Acridids seen were counted were made across the four numbers (fallow, lubia, fallow and dura) immediately east of the suction-trap tower on 17 October and 1 November; totals on the two dates were 158 and 15, respectively. The November catches differed, too, in their species composition, with a ratio of *Acrotylus* spp. to *Aiolopus savignyi* of 2.8 : 1 compared with 0.6 : 1 in October.

H. l. livornica almost certainly lacked breeding populations any nearer the trap site than known centres of infestation feeding on sweet potato (*Ipomoea batatas*), 130 miles south (Kosti) and 220 miles south-west (El Obeid) and outside the Gezira. Nevertheless, the pattern of catches in November differed from that of, say, *S. cretica* only in the smaller daily rate of increase from the 16th to 21st. December catches resembled those of November in both numbers and pattern, while those of October could be interpreted as basically similar but with additional numbers on the 22nd, 27th, 28th and 31st.

Another migratory moth, *U. pulchella* (contrasted with *H. l. livornica* in showing pronounced decrease in total catch in successive months) is known to feed on sann hemp (*Crotalaria juncea*), which is cultivated near the Nile, and on *Heliotropium europaeum*, common in the scrub vegetation outside the Gezira but also occurring to some extent within the Gezira Scheme (Crowther, 1948 p. 503). It is very improbable that local breeding sources, even if they exist, are large enough to account for the large catches of *U. pulchella*. In a migrant, however, a large local population need not imply breeding. Dissected females of *U. pulchella* had their crops full of fluid with the distinctive smell of *Acacia* flowers, which were abundant by the canals in the Gezira at the time of the large October catches; probably migrating *U. pulchella* had been arrested by this food. Crops of *Hyles l. livornica* contained the same material.

Catches of *G. africana* changed in all three months like those of *H. l. livornica*, except that events in the period 22–28 October differed in detail, and decrease between months was more marked. Many *G. africana* were seen above ground in the trap area in the evenings, and specimens from light-traps at this time were nearly all females with full crops and showing various degrees of reproductive development.

Evidence for displacement of insects into or away from the trap area is most likely to be found at the time when wind directions shift during movements of the ITF over the trap area in October. The abrupt peaks in some taxa on 19 and 20 October, in particular, suggest the possibility of mass influx into the trap area, but these peaks exceed those later in the month only in those species that have large breeding populations close by, and are absent in the migrants.

In summary, species with probable sources both near to and far from the trap area have similar changes in catch which do not provide unambiguous clues about origins of the insects involved.

Change in catch in relation to synoptic weather

Figure 5 shows wind situations about halfway through the five-hour sampling period on all days on which light-traps were operating until 2 November. Throughout November and December the trap site was under a dry northerly airstream during sampling periods, and the synoptic situation resembled that for 1 and 2 November. But in October the Inter-Tropical Front moved over the trap site several times while fluctuating in its southward passage.

On most days in October the most northerly position reached during diurnal fluctuations of the front, probably soon before midnight on most nights, was somewhere between Khartoum and a few miles south of the trap site; therefore insects were caught when wind direction frequently changed. An exception occurred on the 20th, when the front was between 50 and at least 150 miles north of the trap site throughout the trapping period; more *Chilo partellus* were then caught than at any other time. More Acridids and Gryllids were also caught on the 20th, but with less difference from preceding days than in *C. partellus*. When all taxa were few on the 13–15th, northerly winds continued to be recorded at Wad Medani 50 miles south of the trap site, at 20.00 h local time, so the front probably remained well south of the trap site. In the three days before these smaller catches, the front passed to the north over the trap site on the 10th and 11th, and may also have reached it at some time during the trapping period on the 12th. On the 16th the front may have just reached the trap site during the trapping period, and on the 17th, 18th and 20th the trap site was under a southerly airstream for all or most of the trapping period.

In the period 22–28 October, when catches of many taxa were either regularly increasing or relatively constant, the front moved to just north of the trap site at some time during the trapping period on all nights except the 22nd and 27th, when it probably just failed to reach it. On the 29th, north-westerly winds were established sharply and persisted throughout all the trapping periods until 3 November. Between 18.00 and 19.00 h on the 30th these wind changes were briefly interrupted by a veer from north to north-east when 12 of the 14 specimens of *H. l. livornica* for that night were trapped. Similar abrupt changes in catch following change from a drier to a wetter airstream have been reported for the Noctuid *Spodoptera exempta* (Wlk.) in Kenya (Haggis, 1971).

A small temporary increase in catch of almost all taxa occurred on 31 October or 1 November. Synoptic charts show no major accompanying change, but dewpoint records for Wad Medani give evidence of some change in airstreams; there was an incursion of dry air on the night of the 30th to 31st, with a temporary return of moister air the following night.

Change in catch in relation to phase of the moon

Full moon was on 14 October, 13 November and 12 December. In all three months the onset of regular logarithmic increase in some taxa or of a period of nearly constant catches in others followed full moon by two to four days (Fig. 6). Catch decreased at new moon in October but much sooner in November; only the association with full moon occurred in all three months.

This relation with phase of the moon seems not to have been reported so possible comparisons in light-trap data of other workers were examined. Bogush (1936) recorded increased catches of *S. exigua* in southern Russia in May and in June. Trapping was apparently begun during the period of increase in the first month, but in June a regular logarithmic increase occurred over seven days and information supplied by the Nautical Almanac Office shows that the increase began three days after full moon. Like other workers who have recorded monthly peaks in light-trap catches of Lepidoptera, Bogush thought his peaks represented separate generations; but generation times as short as a month are exceptional even in the fastest developing Lepidoptera, and identical patterns of monthly peaks can be shown by catches of species with long development, for example the Gryllids discussed above. Nemec (1971) obtained peak catches of *Heliothis zea* (Boddie) in July and August, in Texas; regular logarithmic increase in July began the day after full moon and continued for seven days, and there was a similar but less clear pattern in August. Nemec thought that these changes occurred because moth activity was suppressed by moonlight, but his data show that catches were at a maximum when there was still moonlight and were decreasing again by the time of new moon.

Difficulty in interpretation arises from the need to distinguish between (i) the effect of the moon on trap efficiency, and (ii) its effect on the insects themselves.

The recurring pattern of increase after full moon, as shown most clearly in *U. pulchella* in October and *Sesamia cretica* in November, corresponds closely to the curve of changing radius at which trap brightness equals that of the moon (Bowden, unpubl. data); this value increases abruptly for three days after full moon, then more gradually until new moon. Most of the variation in catch, therefore, might be explained by changing trap efficiency and the clearest examples of increase after full moon are those in which superimposed influences on the relationship between catch and trap effectiveness are minimal. As would be expected, the pattern is shown most clearly in species with sources within the effective range of the trap.

However, the artifact due to trap effectiveness explains only part of the observed variation, because change in catch varies considerably between taxa and between months. It is necessary to consider the additional possibility that the lunar cycle provides cues that are responded to by insects in certain stages of their development. A response to moon phase might result in synchronisation of some activity, *e.g.*, flight or egg-laying. For example, Nemec (1971), found that egg-laying by *H. zea* on cotton increased during a period of several days' logarithmic increase in light-trap catches after full moon and decreased again after this increase had stopped. In our catches the reproductive state of individuals during periods of increased catch after full moon showed some changes, described in the next section. A potential mechanism for a cue following full moon is discussed later.

Change in reproductive condition

All or most females in catches of *Hyles l. livornica, P. ni, Spodoptera exigua*, and *Heliothis armigera* were dissected to assess their reproductive condition throughout the October sampling period and also in December, and some females of these species in November. Reproductive condition was also recorded in samples of *A. savignyi* and *Acrotylus* spp. in October from the 15th, of *G. africana* on 17, 23, and 31 October, of *U. pulchella* on 12 and 27 October, and of *A. agrestis* on 12 and 14 October.

Ovaries and fat bodies were graded from 1–5 and 1–9 respectively. Ovaries: (1) unfertilised female, no ovarian development; (2) fertilised, eggs developing but none mature; (3) fertilised, mature and immature eggs present in roughly equal proportions; (4) fertilised, eggs mostly mature but some immature ones remaining at apices of ovarioles; (5) fertilised but spent, few or no eggs remaining and these all mature, ovaries more or less shrivelled. Fat bodies: (1) entire abdominal cavity full of fat and abdomen more or less distended; (2) all or nearly all of abdominal cavity occupied by fat, remaining space basal and containing air sac, abdomen not distended by fat (although it may be by a full crop or well developed eggs); (3) venter and about three-quarters of abdominal cavity occupied by fat, basal space large; (4) venter and about half abdominal cavity occupied by fat; if developed or developing eggs present then fat evenly and fairly densely spread through ovaries; (5) venter and not more than apical quarter to one-third of abdominal cavity occupied by fat; if eggs present then fat thinly spread through ovaries; (6) fat on venter and at apex of abdomen only, spread thinly through ovaries; (7) fat on venter only, none through ovaries; (8) fat thinly spread over venter; (9) no fat.

In large insects such as *Hyles l. livornica* little practice is required to grade females accurately and quickly with the unaided eye, particularly as in most Sphingids even the most immature eggs are green and contrast with the yellowish fat body. In the smaller species discussed below, and particularly in those in which the eggs resemble the fat body in colour, the use of magnification that is needed to distinguish the middle grades satisfactorily was not practicable, so the classification is rougher for these species than for *H. l. livornica.*

The results for three species of moths are given in Fig. 7–8, on a scale intended to reflect decreasing reproductive potential with increasing age. On some nights the proportion of immature moths in the catches increased. Such changes may indicate arrival of immigrants. *P. ni* showed quite marked differences between nights, with immatures particularly numerous on 18, 24, and 27 October. On the first two of these days, and less markedly on the third, additional numbers were superimposed on trends of total catch that were shown by many of the other taxa (Fig. 6); this supports the suggestion that immigrants were arriving in the area on those nights. Changes in reproductive condition of *H. l. livornica* were less marked, but nights with an increased proportion of immatures were mostly the same as for *P. ni.* The three female *Heliothis armigera* caught on the 29th were distinct from other nights' catches in all being immature.

In *Hyles l. livornica* fat body index tended to increase during October, and there was a less clear tendency for females with well developed eggs to predominate earlier in the month. Other species also showed this trend. Specimens of *U. pulchella* dissected on 12 October were all fertilised and contained mature eggs, while of 32 dissected on 27 October 66% were unfertilised with undeveloped ovaries. Thirty females of *G. africana* dissected on 23 October were on average less developed than 70 dissected on 17 October;

in particular, 23% of the latter were classed as 'fully developed', none of the former. On 31 October reproductive condition resembled that on the 23rd, but the fat body index was much decreased, and this decrease in fat had continued even further in four females caught on 12 November.

Changes over a shorter period are shown by dissections of *A. agrestis*. Of 39 females dissected on 12 October, 87% had very small ovaries but the whole range of reproductive condition up to eggs ready for laying was present in the remainder. Two days later 30% of 20 females dissected had very small ovaries but a large proportion of the rest were at a stage compatible with two days' development from the very small ovaries of the 12th; again, the whole range of reproductive condition was present in other individuals.

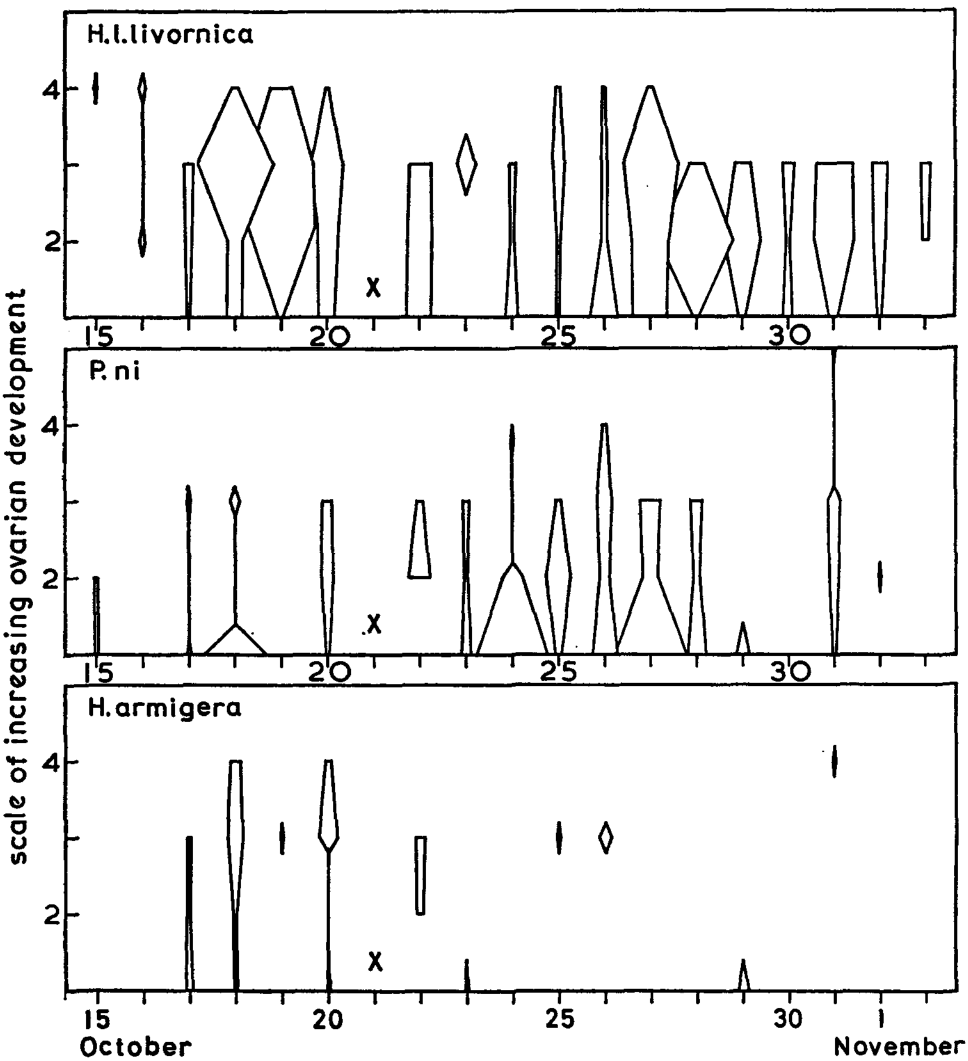

Fig. 7.—Ovarian development of moths in nightly light-trap catches. (Scale of 1–5 grades described on p. 589, grade 1 representing maximum reproductive potential; *X*, no data.)

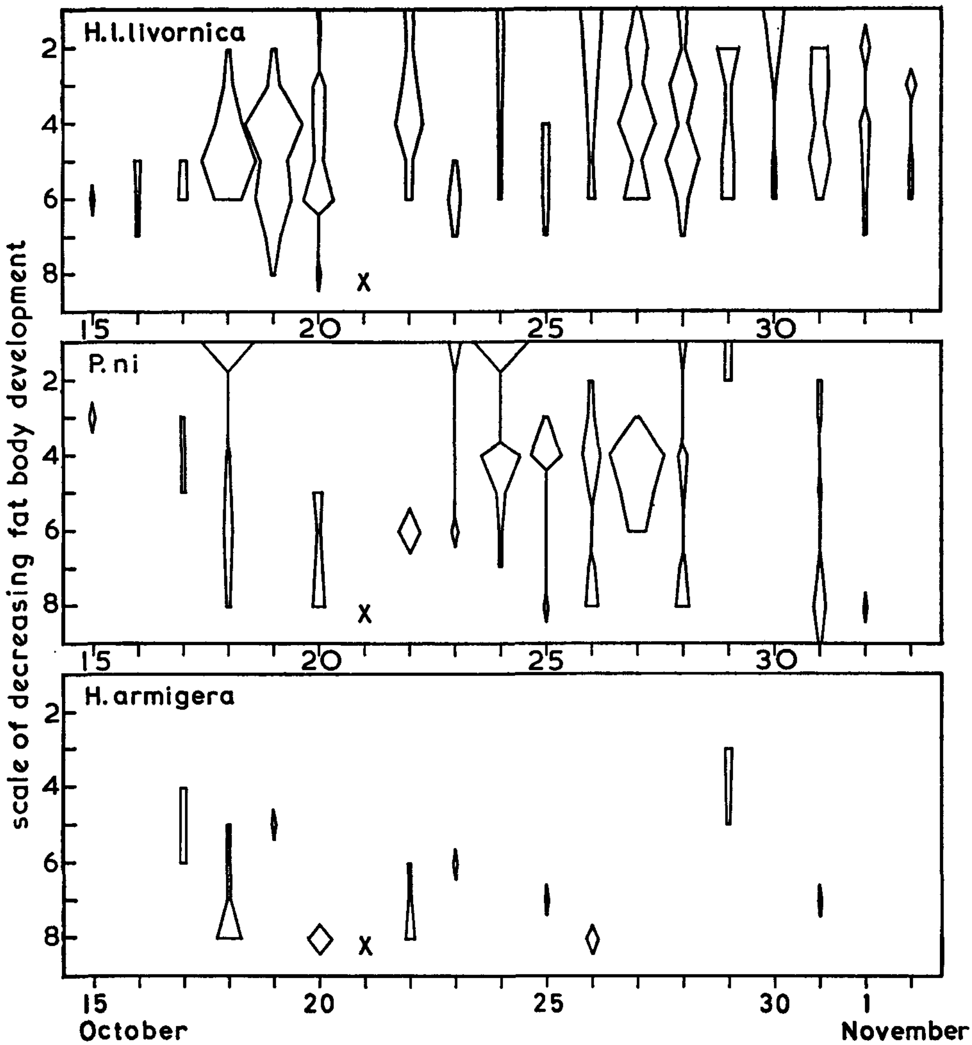

Fig. 8.—Fat body development of female moths in nightly light-trap catches. (Scale of 1–9 grades described on p. 589, grade 1 representing maximum reproductive potential; *X*, no data.)

Acridids differed from other taxa in that all individuals dissected throughout October were uniformly immature.

The main contrast shown by dissections is between reproductive condition before the start of the sustained increase in catch from about 16 October and in the period after the increase became established from 22 to 28 October; the earlier insects were more mature than the later ones. The regular increases that are clearly marked in some taxa from 22 to 28 October apparently involve the increasing availability of immature insects for trapping which supports the suggestion made earlier that the increases correspond with times when some aspect of development is synchronised in a large part of the population.

Change in sex ratio

Sex of all individuals was recorded for several species of Lepidoptera throughout the October and December sampling periods, for Gryllids in the October and part of the November periods, and for *U. pulchella* for a shorter period in October. The significance of departures from a 1 : 1 sex ratio was tested (Table I).

TABLE I. *Sex ratios, and significance of departure from 1:1 on days when sexes counted separately*

	H.l. livornica		*U. pulchella*		*S. cretica*		Gryllids	
	% ♀	*P*	% ♀	*P*	% ♀	*P*	% ♀	*P*
15 October							52	
16							60	
17					92	**	59	
18	56				93	**	55	
19							47	
20	57				94	**		
22	43				64	*	65	**
23			51		90	**	60	**
24			53		94	**	61	**
25			56		93	**	59	**
26	54		69	**	81	**	57	*
27	51		62	**	83	**	59	**
28	55		68	**	92	**	64	**
29	70	*			96	**	67	**
30					100	**		
31	47				86	**		
1 November	50				89	**		
10							43	
11							60	
12							71	*
13							45	
14							36	
15							40	
16							51	
17							49	
18							54	*

*$P<0.05$; **$P<0.001$.

In Gryllids the sexes were in equal or nearly equal proportions during the periods of rapid increase in catch from 15 to 19 October and from 14 to 18 November, but during the more gradual increase from 22 to 29 October females predominated on all days. Among the Lepidoptera *Sesamia cretica* catches comprised between 80% and 100% females on most days, but the proportion fell on the 22nd. *U. pulchella* had a roughly 1 : 1 ratio on 23 October but increase in catch from that day was accompanied by an increase in proportion of females. This increase in proportion of females caught appears to be a further characteristic of the regular increase in catch over the period 22–28 October, in addition to changing reproductive condition.

Some taxa showed a trend of changing sex ratio over the three months of sampling. In *H. l. livornica* the male to female ratio was 0.9 : 1 for October as a whole, and the only significant departure was a catch with 70% females on the 29th; the male to female ratio in December was 3.8 : 1. Similarly, both *P. ni* and *Heliothis armigera* had a male to female ratio of about 0.7 : 1 in October but a preponderance of males in December: four out of five *H. armigera* were male, and 10 out of 13 *P. ni* (sex of a further six *P. ni* in December was not recorded).

Hourly distribution within the sampling period

The proportion of insects in the nightly catch that arrived early or late in the five-hour sampling period from 18.00 to 23.00 h varied between months, between nights, and between taxa; percentage hourly distributions of four selected taxa during periods when their numbers were large are given in Fig. 9. In November, catches tended to be largest early in the five-hour sampling period; in October their distribution varied more between nights, and they were sometimes largest at the end of the sampling period. Some differences between nights were common to nearly all taxa, as on 26 and 27 October

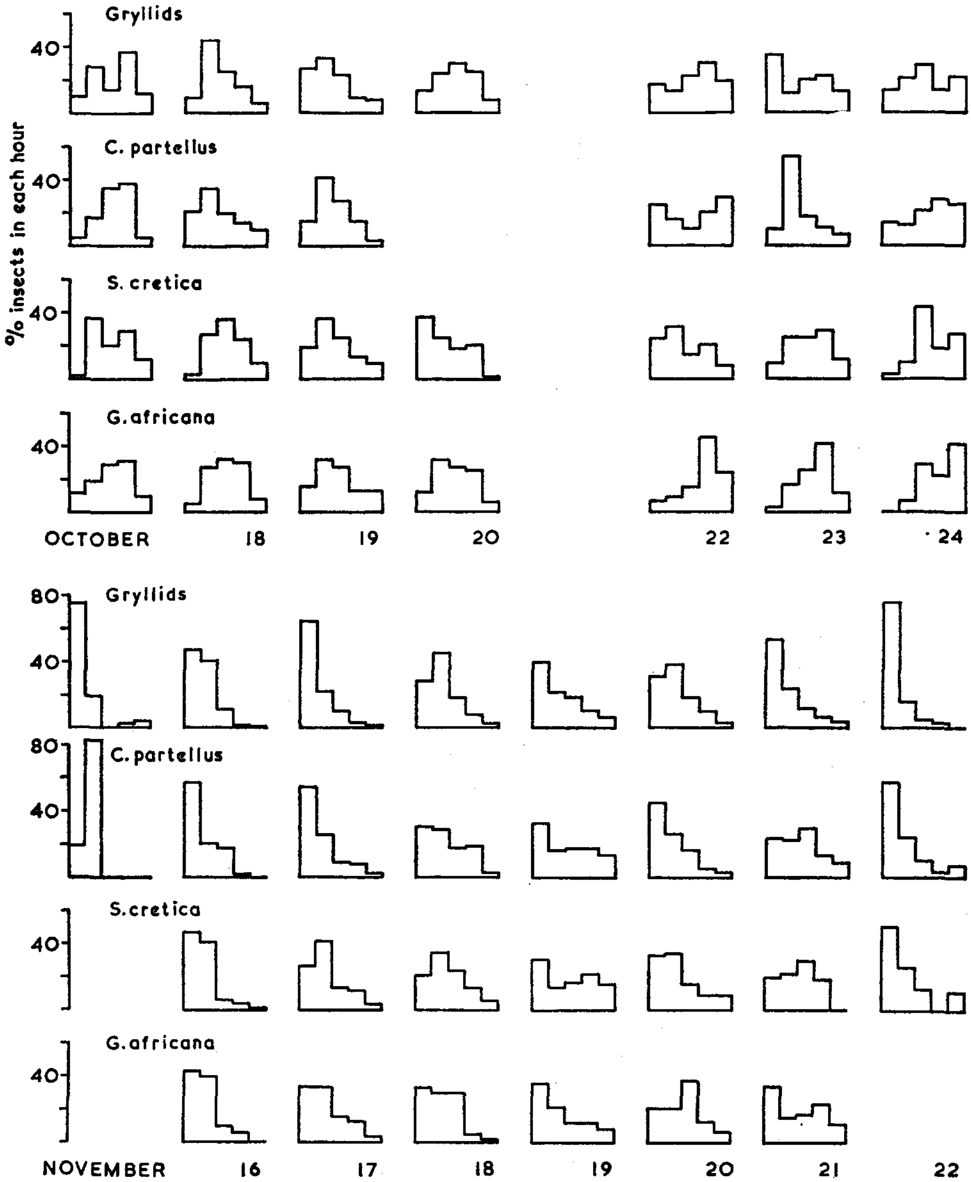

Fig. 9.—Distribution of light-trap catches of four taxa in the five hours of sampling (18.00 to 23.00 h). (The first day is of equivalent lunar phase in the two months, 2.3 days after full moon.)

when catches were concentrated at the end of the sampling period; hourly distributions of *U. pulchella* from 24 to 27 October are shown in Fig. 10. Arrival early in the night in November was characteristic of non-migrant species with breeding populations in the trap area, like all those in Fig. 9. Migrants like *Hyles l. livornica,* however, had a variable distribution closer to that shown by most taxa in October.

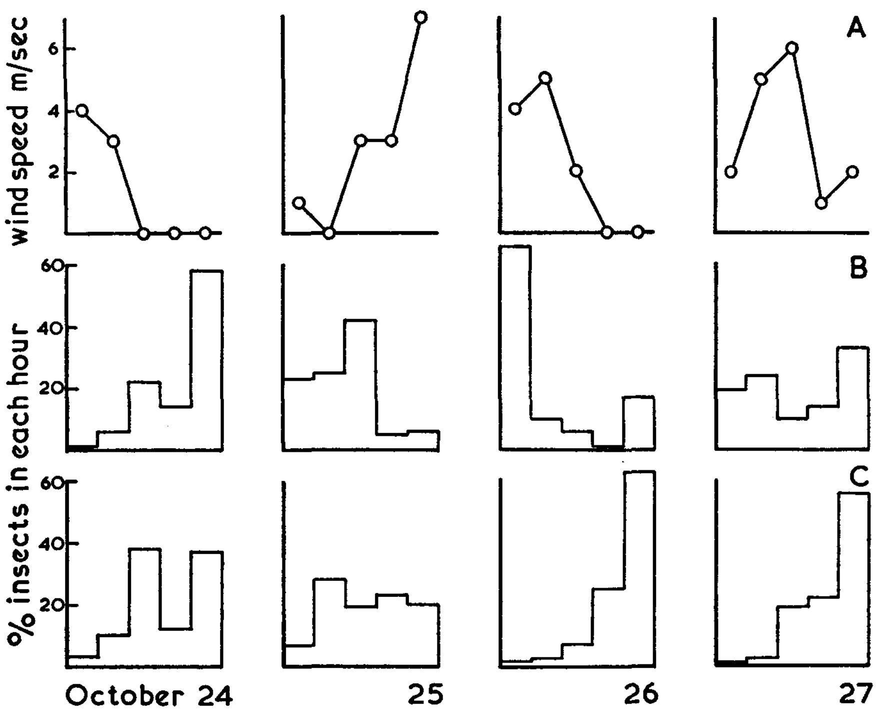

Fig. 10.—Distribution of catches between 18.00 and 23.00 h in relation to wind speed at 20 ft. (*A*, wind speed at the end of each hour; *B*, suction-trap catch of grass-feeding Homoptera; *C*, light-trap catches of *Utetheisa pulchella.*)

Several variables that might influence numbers of insects flying from hour to hour were compared with observed changes in hourly catch distribution.

Temperature.—More abrupt decrease in catch during the early part of the night, as observed in November, might be expected if the nightly fall in temperature was more pronounced than in October; therefore temperatures at Wad Medani during the time of large catches in each month were compared. Average temperatures for the periods 22–28 October and 16–21 November were 28.3°C and 26.7°C, respectively, at 20.00 h local time, 24.4°C and 24.5°C at 02.00 h. Temperature differences cannot, therefore, account for observed variation in catch.

Phase of moon.—Bright moonlight has commonly been found to suppress light-trap efficiency, for example by Siddorn & Brown (1971); when this occurs a greater proportion of a total night's catch is taken in that part of the night when the moon is below the horizon. On 13 November the moon rose at sunset (17.15 h) nearly an hour before the start of sampling (18.00 h), and by 20 November did not rise until after the end of the sampling period (23.00 h). No changes in hourly distribution of catch were associated with the increasing interval before the moon rose.

Wind direction.—Since changes in wind direction influence the time of large catches in suction traps (see pp. 574–576, 581), the possibility of a similar influence on the hourly distribution of light-trap catches was considered. Hourly light-trap catches from 24 to 25 October were compared with wind directions at 50 ft on the suction-trap tower, but timing of large catches within the sampling period was apparently independent of wind direction.

Wind speed.—Locally employed staff who emptied the light-trap sometimes predicted small catches on the grounds that wind was stronger than usual. Light winds are usual in large parts of tropical Africa (*e.g.*, Woodhead, 1969), except at times of squalls, but this does not exclude the possibility of adaptive responses to change in speed. Therefore wind speeds in each hour were compared with light-trap catches over four days that showed large differences in hourly distribution and also with suction-trap catches of grass-feeding Homoptera in the same period (Fig. 10). Large late catches of *U. pulchella* in the light-trap occurred on nights (26 and 27 October) when winds were stronger than four knots at the beginning of the sampling period and dropped later. Wind speed, therefore, may have had an influence. Suction-trap catches were not distributed in the same way as light-trap catches and showed no consistent correlation with wind speed. The large catch that coincided with winds of four knots on the 26th, however, was preceded by an hour in which the air was still and, as these insects become active in that hour (Fig. 3), they may already have been in the air by the time wind speed increased.

Discussion

Use of light-traps and suction traps

Much of the interpretation of the light-trap captures in this paper is necessarily speculative because changes in catch are the product of local abundance, immigration and amount and kind of local activity; information is not so far available on the respective influences of these on catches. Also traps at a single location were used to record events that involve changes in both horizontal and vertical distribution of insects. In a synoptic situation like that during suction-trap sampling in October, with repeated movements of the ITF over the trap site, parallel data from a second trap site at a few kilometres distance would probably resolve a large part of the ambiguity of interpretation (p. 581) due to inadequate knowledge of the spatial relations of the transport systems being intercepted. Clues might then be obtained to suggest whether periods of large catch were of short duration because airborne insects were concentrated in a specific zone relative to the ITF, or because dispersal was confined to narrow zones related in some way to the position of the ITF at the time of evening flight activity of local populations.

With both types of trap the kinds of event that emerge most clearly from a series of catches are probably much influenced by the latitude of sampling at a particular time of year. During the three months' sampling at Quweiz the ITF moved well to the north of the trap site on only one day, 20 October, and catches of some taxa were very large on that day. If the ITF had been so situated for a longer period it is possible that much of the pattern of change observed in the catches would have been obscured. Catches from situations well behind the front, or in its vicinity, or exposed to encroaching dry conditions after its passage south, will record a range of events connected with different aspects of the seasonal development of the insect, and some events might be clearly reflected in the catches at one time and be obscured by other events at another. Interpretation of a particular situation within the range of those intercepted by light-trap sampling at different times is, therefore, made difficult unless sampling covers the whole season of the insect's activity, or is done at more than one locality in relation to north-south movement of the ITF, or preferably both.

Catches in relation to synoptic weather

The weather factor most consistently associated with increased catches in both light-traps and suction traps is change between dry air to the north of the ITF and moist air to the south of it. Because winds tend to converge at the ITF, change from one air-mass to the other is almost invariably marked by shifts in wind direction.

During November the ITF moves south into Kenya, and the first seasonal appearances of the migratory Noctuid *Spodoptera exempta* regularly accompany wind shifts that mark passage of the front (Brown *et al.*, 1969). Wind shifts connected with the East African Convergence Zone, marking the eastward limit of moist Congo air, are also associated with increases in light-trap catches of *S. exempta* (Haggis, 1971). In West Africa light-trap catches of various Sphingids increase when northward passage of the ITF brings a change from dry to moist air in April to May (Bowden, 1964).

The above observations concern seasonal appearance of migrants. Light-trap sampling from local populations of non-migrant species, like Gryllids and Lepidopterous stem-borers from dura (Fig. 6), covered periods when the ITF was well to the north of the trap area (20 October), in the trap area (most of October), or well to the south of it (November). Different patterns of change in catch occur under these different circumstances, and aspects of behaviour and development other than transport of dispersing insects have to be considered where interpretation is much more dependent on knowledge of source populations, and this is not available. Whatever activities these catches reflect, the patterns of change of catch apparently depend closely on position of the trap area in relation to seasonal movement of the ITF. The fact that the northern Gezira is close to the northward limit of annual movement of the ITF makes it an area where changes associated with the ITF can be separated from other changes by studies over a period of a few months. It is therefore an area in which close study of life-cycles and phenology of populations that give rise to the changing patterns of trap catches would be particularly useful.

Catches in relation to the moon

Near the equator there is a short period in each month when the full moon, rising near the time of sunset, provides illumination throughout the night equal to that about 45 min after sunset on a moonless night. This illumination is above the threshold for photoperiodic response of some insects (de Wilde & Bonga, 1958). On nights immediately following full moon the moon rises successively later so that twilight is separated from bright moonlight by an increasing period in which illumination falls to that of starlight. It has been suggested (Bowden, 1973) that these events provide, every month, a potential photoperiodic timing stimulus by which aspects of insect development could be entrained.

The possibility that full moon provides a stimulus synchronising some aspect of development has been raised (p. 587) in attempting to interpret changes in light-trap catches. Regular logarithmic increase following soon after full moon was most marked in Gryllids, *C. partellus,* and *Sesamia cretica* in November, the last month before numbers declined with advance of the dry season. In October a spell of rapid increase after full moon was, in Gryllids, followed after several days by regular logarithmic increase that was slower than in November; this pattern was also shown clearly by catches of *U. pulchella.* Gradation between the two patterns is continuous as shown, for example, in comparison between catches of *S. cretica* in November and *U. pulchella* in October (Fig. 6). The patterns of increase shown in November were accompanied by a crepuscular pattern of nightly catch periodicity in the taxa concerned, those of October by a much more variable periodicity with largest catches at any time between the start of sampling near sunset and its end at 23.00 h (Fig. 9). Therefore it is in November that insect activity coincides most closely with the potential cue provided by the relations of sunset and moonrise. Also, activity in November is unlikely to be complicated by air movements conducive to displacement of insects.

These remarks, based on indirect methods of study, are offered in anticipation of studies to elucidate the little known phenological systems of the insects discussed. They merely point to a possible environmental cue, provided by the time of changing illumination at and in the days after full moon, that is followed by a regular pattern of change in light-trap catches. Functional relationships between lunar phase and insect behaviour or development may exist in addition to the known relationship between moon phase and light-trap efficiency (Williams, 1936), but remain to be demonstrated.

Summary

Catches in light-traps adjoining cotton were obtained at the time of seasonal southward movement of the Inter-Tropical Front (ITF) in October, and during most of the following two months. Taxa studied were mostly Orthoptera and moths, many associated with sorghum, others long-distance migrants. Suction-trap catches at three heights up to 50 ft were obtained for short periods in October and November, and aircraft catches at 250 ft were also available on two days. Suction-trap catches of grass-feeding Homoptera suggest that displacement of these insects was associated with changes in wind direction marking movement of the ITF in October. The exact form of the displacement system in relation to the front cannot be reconstructed from catches at a single place, but it seems likely that proximity of the front at or soon after the time of a brief period of crepuscular activity stimulates insects to take flight and rise to 50 ft or more so that they are displaced. In many taxa, light-trap catches showed a regular pattern of increase, with only slight nightly fluctuations from a logarithmic trend, following full moon. Other increases were superimposed on this pattern at times when the ITF passed north of the trap site, and in some taxa particularly when it was far north. The pattern of change after full moon, shown most clearly in taxa with source populations close to the trap, was related to the moon's influence on the range of trap effectiveness. But various qualitative variations suggest that, in addition, aspects of behaviour or development may have adaptive relationships to the lunar cycle; variations include differences between taxa, particularly in timing of catch changes, and increasing proportion and decreasing maturity of females of certain taxa at the time of the regular increases in catch.

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