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STATUS AND RELATIVE IMPORTANCE OF INSECTS INTRODUCED TO COMBAT LANTANA

A DISSERTATION SUBMITTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN ENTOMOLOGY JANUARY 1966

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STATUS AND RELATIVE IMPORTANCE OF INSECTS INTRODUCED TO COMBAT LANTANA

Abstract

Stem sections of the growing tip of the weed, Lantana camara var. aculeata (L.) Moldenke were taken in four sites in the Waianae Mts., Oahu, Hawaii, ten samples per site over a period of 65 weeks during 1963 and 1964. Damage by any of the purposely introduced insects for control of this weed was recorded along with species of insects present. Laboratory studies and observations on the three most abundant insects, Teleonemia scrupulosa Stål, Hypena strigata Fabr., and Cremastobombycia lantanella Busck were studied in detail.

There were significant positive correlations between the populations of insects and their respective damage and between the insects and the abundance of foliage. There were negative correlations between the leaf miner population and that of the tingid in site #2, and negative correlations between the leaf miner damage and the tingid population in sites #2 and #4. This implies an interaction between these two species of insects.

A relationship between the insect populations and the food material was indicated. T. scrupulosa and H. strigata populations followed the change in total foliage more closely than did the population of C. lantanella. However, there was an indication that the population of C. lantanella was related to leaves of a particular quality, the younger leaves, rather than the total foliage present.

Abiotic influences caused greater population fluctuations, however, in site #1, the abiotic influences were lessened by the surrounding forest, but lantana exhibited considerable defoliation here. This may be accounted for by the high tingid population in this site throughout the sampling period. In this site abiotic stress though possibly less than in the other three sites, was more severe on the plant than on the tingid.

The strongest biotic influence on the insect populations appeared to be food supply. Four species of eulophid parasites were found attacking C. lantanella larvae. However, the host population continued to increase in spite of their presence in the area. The other two lantana feeding species in question here seemed to have no parasites or predators of consequence.

The most effective of the three insects was probably Teleonemia, since it reached relatively high numbers in the field, and since its population was related to the abundance of foliage. In certain environments, such as a forest site, it can heavily defoliate lantana and possibly prevent flowering. Hypena may have been of less importance in this study due to its low numbers; Cremastobombycia may be of least importance since it probably causes little material damage to the plant, even though its population may be increasing.

INTRODUCTION

Lantana Introduction and Spread

Lantana camara var. aculeata (L.) Moldenke is a shrub of the family Verbenaceae. The stem is quadrangular in cross-section and bears thorns. The leaves are heart-shaped to oval with toothed edges, the teeth being bluntly rounded. Flowers (fig. 1) are in a pink, yellow, or lavender cluster borne on a stalk. This plant is found in almost all the major tropical and subtropical areas of the world, including, Hawaii, Australia, New Zealand, Indonesia, India, Fiji, Dutch East Indies, Madagascar and much of Africa, as well as its area of origin, tropical America (Mexico, Costa Rica, Cuba, Jamaica, Florida, California, and other areas) (Cleland, 1952; Dresner, 1958; Kenoyer, 1927; Simmonds, 1931; Atkinson, 1920; La Bathie, 1928; Doidge, 1926; Sanders, 1946; Perkins and Swezey, 1924; Krauss, 1953; Uhmann, 1934).

In about 1860 this plant was introduced into Hawaii as an ornamental by the distinguished botanist, Hillebrand. In tropical America, lantana was not a weed, but in Hawaii, with a favorable climate, ideal conditions for dissemination, and a lack of natural enemies, lantana could spread and thrive (fig. 2). By the 1890's the plant had become a serious weed in Hawaii, spreading over land formerly covered with grass. R.C.L. Perkins (1924) states that the major agents of spread of the plant were the recently introduced

Chinese turtle dove, Turtur chinensis (Scop.) and the Indian mynah, Acridotheres tristis (Linnaeus). These birds fed upon the berries and dropped the seeds in their feces, thereby efficiently disseminating the plant.

Economic Importance as a Weed

By 1902 large tracts of formerly valuable grazing land were thickly covered with lantana. Since ranching was a very important industry in Hawaii, the invasion of this weed was of great concern. Some ranchers cleared the land at great expense only to have the weed return in a short time as vigorous and thick as it was previously.

Besides the covering of rangeland, lantana foliage presented a hazard as a livestock poison. Reports from India (Lal et al., 1960), Australia (Brooks, 1961), Africa (Mettam, 1933), Florida, U.S.A. (Sanders, 1946) and Fiji (Turbet, 1931) described the occurrence of this malady.

Lantana was suspected of causing a disease "pink nose" of cattle as early as 1920 (Atkinson, 1920). Observations of a rapidly increasing disease of cattle in Fiji caused by their feeding on lantana foliage were reported (Turbet, 1931). Sanders (1946) summarized the symptoms caused by L. camara in Florida. These included photosensitization to ultra violet rays with icterus, exfoliate dermatitis, and conjunctivitis. Lesions, local or widespread, occurred, frequently affecting the nasolabial region. The amount necessary for poisoning is 3/4 to one pound of

dried leaves for a 400 pound animal. Brooks (1961) reported that in Queensland lantana poisoning is confined usually to hungry cattle introduced into lantana-infested areas. As little as two to three pounds of leaf material eaten in 12 hours will cause death. Symptoms listed were sunburning of light-pigmented areas of the skin, swelling of the eyes, cessation of feeding and cud-chewing, refusal to move from shade, and diarrhea, followed by severe constipation. Internally, the liver is jaundiced and the gall bladder is swollen. The disease may be treated by feeding sugar and eggs to relieve the liver damage and liquid paraffin as a laxative. Lal. et al. (1960) determined that of 40 species in the genus, only Lantana camara is poisonous to livestock. The principal leaf constituents are an essential oil and lantanin, present to the extent of 0.31 to 0.68 per cent in the leaves.

Lantana foliage is also poisonous to sheep (Louw, 1943) with the leaf extract, lantanin, a term later changed to lantadene A + B (Louw, 1948), fed at 2 gm per animal. Although this dosage of lantanin was composed of lantadene A and lantadene B, only lantadene A was found to produce toxic symptoms. Louw (1943, 1948, 1949a, 1949b) has done considerable work to discover the chemical nature of this compound.

Historical Account of Control Measures

Few insects present in the Hawaiian islands in 1902 were known to attack lantana. Among these were some polyphagous lepidoptera, including a common Plusia, one or two

tortricids, and one or two species of Scotorythra, and also a scale insect, Orthezia insignis (Douglas). The scale insect was found to be somewhat effective in suppressing the weed, although the lepidopterous insects had little permanent or widespread effect. The scale insect was a polyphagous species, but it had a "marked predilection" for lantana. Ranchers in Hawaii purposely spread this scale insect into various areas of the islands where lantana was a serious weed. In some areas the scale actually killed some plants. Entomologists in Hawaii at the time were opposed to the spread of this scale insect from island to island and from rangeland to rangeland, since the scale was known to feed on some valuable plants in the tropics, such as Liberian coffee. However, the success of this insect in weed control, although very limited, encouraged Hawaiian entomologists to take the big risk of introducing lantana insects into Hawaii from other areas of the world.

In 1902, Koebele, entomologist with the Hawaiian Sugar Planters' Association, was sent to Mexico to obtain insects which were found feeding on lantana. He sent these insects back to Perkins, who had just been appointed by the Commissioner of Agriculture to the post of entomologist in charge of inspecting imported plants.

Transporting the insects from Mexico to Hawaii using the slow methods of transport prevalent at the turn of the century was an added problem. Special storage containers

with fungus-inhibiting chemical, carbolic acid, had to be devised. Considerable trial and error took place, with political pressures of the time and slow communication between the two entomologists adding further frustration. Eventually, of 23 species of insects sent to the islands, eight were established (Table 1).

In 1953, the Board of Agriculture of the Territory of Hawaii renewed its program of lantana insect introduction, this time with the aid of modern, fast transportation with improved handling facilities, and with more rigorous feeding tests for the insects before their release. Davis and Krauss were chiefly involved in the later work (Krauss, 1953). The Queensland Department of Agriculture and Stock was involved in a co-operative study in this later program, since lantana had become a problem in Australia also (Wilson, 1960). Australia sent a representative to Hawaii to test the insects on the economically important plants of Australia before any of these insects were introduced there, and another representative was sent to Hawaii more recently to make additional investigations during the years 1965 and 1966.

Besides control by introduced insects, cultural and chemical control measures have been attempted. Mechanical removal of the weed by grubbing it out manually (Knott, 1953), or by clearing large tracts by bulldozer has been used in some areas. Continual inspection and removal of

developing lantana is possible in small cleared areas, but other methods of prevention of invasion have to be used for large tracts. In Queensland the areas are replanted in Kikuyu grass or guinea grass (Goodchild, 1951); these grasses compete well with lantana, and the latter grass, when it dries, provides a good fuel for burning over the area to destroy the weed. On banana plantations in Queensland lantana is considered useful because it quickly covers fallow banana fields and is easily removed when planting is to be done again. Spraying with sodium chlorate solution, 2-4-5-T, or 2-4-D (Griffith, 1941; Knott, 1955; Oosthuizen, 1964) will temporarily eliminate the weed, but the expense is too great for large scale application.

Lantana Feeding Species Introduced

Of the species of insects released, there are now possibly fifteen species established in Hawaii (Table 1). These insects include a berry-feeder, 4 flower feeders, 2 leaf miners, 4 leaf skeletonizers, a stem gall producer, 2 stem and root borers, and a sap sucker (Perkins and Swezey, 1924; Krauss, 1953; Fullaway, 1952; Davis and Krauss, 1962a; Davis and Krauss, 1962b; Krauss, 1962).

It was hoped that a concerted attack by these insects would cause lantana to die out and would halt its spread. Noteable decreases occurred in the abundance of lantana throughout the areas where the first eight insects were established, but still more widespread success could be

hoped for.

Scope of Present Study

Some studies conducted over a short period of time and involving only one particular species of lantana insect have been reported. However, the true effectiveness of these insects remained to be determined. This study is an attempt to indicate the relative abundance and effectiveness of the species at four different sampling sites.

Empirical data regarding population density, competition, available natural resources, climate, parasites, predators, and insect dispersal will be analyzed in order to determine the effective status of the insects of lantana. Several theories have been advanced regarding these factors as to how they influence animal populations. The manner in which populations of lantana insects conform to these population theories will be discussed.

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Acknowledgement is due the University of Hawaii Computer Center, which processed the field data on the IBM 7040 computer.

MATERIALS AND METHODS

Field Studies

Four sampling sites (fig. 3) were selected in the Waianae Mountains, Oahu, for study of the populations of various lantana insects. The sites were at different altitudes, and the ground distance between them varied considerably. The sampling sites were at the following altitudes:

Site No.	Altitude Above Sea Level
1	1,900
2	1,630
3	1,365
4	1,100

Site #2 and #3, which were on a steep slope, were exposed to sunlight. Site #4 was in a level area; some plants here were in the open, and a few plants were shaded by trees. Site #1 was in a forest area, with lantana plants growing on the side of the road at a bend in the road and on the side of a road cut. The plants in site #1 were openly exposed to sunlight several hours a day, but they were shaded by the tall trees behind them and on the other side of the road during the early and late hours of the day.

The weekly maximum and minimum temperatures in three of the four sites were recorded over a period of 52 weeks, April, 1963 through March, 1964, in site #2, and over a

period of 51 weeks, May, 1963 through June, 1964, in sites #1 and #4. Weekly rainfall records were taken in sites #1 and #2, December, 1963 through June, 1964, and sites #3 and #4, December, 1963 through March, 1964; this information on the relative rainfall in the four sites was supplemented by monthly rainfall records from the U.S. Weather Bureau Station in the Waianae Mountains. A hygrothermograph in area #2 recorded daily temperature and humidity fluctuations April, 1963 through March, 1964. Maximum-minimum thermometers and the hygrothermograph were housed in suitable shelters at the sampling sites. Maximum wind velocity was checked once a week from October, 1963 to June, 1964 in each of the four sampling sites by averaging three maximum wind velocity readings. Each reading consisted of the maximum wind velocity during a 10 second interval, and the readings were taken at least 10 seconds apart.

Several preliminary sampling techniques were employed over a period of several weeks in order to determine which sampling technique would be useful and practicable for studying populations of the lantana insects which were present and their effect on the plants. In each of the four sites, ten samples were taken weekly for a period of 54 weeks, after which five samples were taken bi-weekly through the 65th week of sampling. Each sample consisted of approximately the upper six inches of a growing stem of lantana. The stem sections were cut with shears, so that each fell

into a separate transparent plastic bag, in which it was stored until the time of examination. The sample plants were selected randomly by a plotless method. In this method, a plant in the site was chosen, and the first stem section was taken from the first plant three paces or more from this one. The direction of movement from the first plant was changed each week. The next sample was taken from a plant three paces or more in a different direction from this first sample plant. This sampling procedure was followed until a total of ten samples were collected at the site. Different plants were used for sampling each successive week. In addition to the random selection of plants in this manner, the location of each stem section on an individual plant was chosen so that each of the ten samples was cut from a different relative location on each plant.

Each stem section was examined separately in the laboratory as soon as possible after collection. The leaves were removed from the stem section and classed according to their lengths into one of seven classes. Leaves less than one centimeter in length were excluded from the classification, but damage was noted. The leaf length classes were 1-1.9 cm, 2-2.9 cm, 3-3.9 cm, 4-4.9 cm, 5-5.9 cm, 6-6.9 cm, and 7 cm or more, respectively. Each leaf and the stem were carefully examined under a dissecting microscope, and the species of insects present, the number present, their stage of development, and the damage caused to the plant by them were recorded.

The damage was assessed by various methods, depending on the insect involved. The damage by lepidopterous defoliators was recorded as average per cent of leaf material missing per leaf class per stem section. For each leaf removed from the stem section, the per cent of the leaf missing, i.e. that part required to form a whole leaf of the size indicated by the part which was present, was recorded. An average per cent missing in each leaf class for each stem section was then calculated by adding these percentages missing from the leaves of the class and dividing this sum by the number of leaves in the class. Damage by the stem gall fly was recorded as number and size of stem galls of any age present on each stem section; size was noted only as small, medium, or large. Damage by sap-sucking insects was indicated by a numerical scale, zero through five, indicating the relative severity of leaf injury, including drying, wilting, or burning of the leaves of each stem section. Damage by the leaf miners was recorded as number and size of leaf mines per leaf; the size was noted only as small, large, or medium. The class of leaf on which the mine or mines was found was also recorded. Damage by stem borers was recorded for each stem section. The presence of flowers or berries on a stem section was recorded along with any damage to them by insects.

Twenty-two of the recorded variables, including insect populations, insect damage, number of leaves in each

size class, and total leaves, were examined statistically for correlation.

Besides the insects introduced to feed on lantana, other arthropods, either feeding on lantana, feeding on the lantana insects, or transitory were recorded. These insects were preserved for later identification by specialists in some instances.

Laboratory Studies

Laboratory studies included rearing and observation of the three most prevalent species of lantana insects found in the field, Teleonemia scrupulosa Stål, Hypena strigata Fabricius, and Cremastobombycia lantanella Busck. The three insects were reared on bouquets, prepared by placing the cut green stem of a section of lantana in a vial of water, the stem being held in place with a wad of cotton. T. scrupulosa in various developmental stages, H. strigata in various larval instars, and C. lantanella as pupae within leaf mines were collected in the field. One or two specimens of H. strigata or T. scrupulosa were placed on each bouquet, and fresh bouquets were supplied to the insects as damage to the leaves of the former bouquet depleted the food supply. Leaves with swollen mines containing pupae of C. lantanella were placed in a metal cubical cage with a sliding glass front. Any parasites emerging from the leaf mines within the cage were immediately removed. When the adult insects began to emerge, a fresh bouquet of lantana was placed in

the cage each day in order to collect eggs deposited on a known day. Observations were made day and night on behavior. The bouquets exposed to ovipositing adults were placed in separate containers after removal from the cage of adults. Daily microscopic examinations of the leaves of the bouquet were made.

RESULTS[1]

Description and Habits of the Insects

Hypena strigata F.

The Hypena strigata adult (fig. 4) has a dull, mottled grayish-brown body and forewings. The labial palps extend prominently forward. The hind wings are a dull white color. At rest the forewings are folded rooflike over the body, giving the insect in side view the appearance of an elongate triangle. When the adult is at rest on a stem of lantana, the wings are folded downward, concealing the portion of the stem on which the insect is resting and resulting in an effective camouflage.

A single egg is placed on a leaf of lantana. The egg is oval and pearly opalescent with a number of sculptured ridges running from the top of the egg to its point of attachment.

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1 Each point in all graphs, except in figure 20 and in the monthly rainfall average of figure 18 represent a three-week average of weekly data.

The first instar larva is pale and almost colorless. Later instar larvae (fig 5) are pale green with prominent primary setae. The larva in feeding allows the epidermis of the leaf to remain (fig 5 and 6). As the larva feeds it twitches the posterior fourth of its body, throwing its fecal pellets. This insect is commonly called the lantana looper, due to the characteristic semi-looping manner of locomotion of the larva. When disturbed by an object brushing against the leaf on which the larva is feeding, the larva immediately wriggles and drops from the leaf, hanging by a silken strand from its head or falling completely to the ground. This is true of all instars. Pupation occurs in the soil.

Teleonemia scrupulosa Stål

The adult lantana leaf bug (fig. 7) is a dull grayish brown color. With a long, sharp ovipositor, the female (fig. 8) inserts the eggs into the peduncle and the veins on the underside of leaves, mostly the younger leaves, those around 2-2.9 cm in length. The presence of a large quantity of eggs may be detected by the deformation of the leaves, which bear numerous wart-like protuberances on the underside.

The first instar nymphs as they emerge from the eggs cluster in a group under the leaves and on the stem. The early instars (fig. 9) are pale brown with prominent lateral spines along the thorax and abdomen. Numerous cast exuviae (fig. 10) may be seen clinging clustered to leaves and stem.

Complete defoliation may be caused by a heavy tingid attack (fig. 11). Tingid damage in the field is easily recognized by the stippled or burnt condition of leaves (fig. 12); numerous fecal spots can be seen on the underside of the leaves.

Cremastobombycia lantanella Busck

The shiny light reddish-brown adult (fig. 13) has relatively long antennae and long legs. The color becomes dull and gray with age. The insect rests at an angle with the abdomen held high and the wings folded rooflike over the body.

The egg is oval and opaque white in appearance. It is placed on the underside of a leaf. The larva upon eclosion immediately enters into the leaf, mining between the outer leaf surfaces. The leaf mine at first is visible only as a small light spot on the underside of the leaf. As the larva feeds and grows, the mine enlarges, becoming a light green blotch. The larva (fig. 14) is opaque white in color. The head is dorso-ventrally flattened and partly concealed by the thorax. The thoracic legs are well-developed, and the prolegs are very short, hardly protruding at all from the abdomen. The thoracic area is large, and the abdomen tapers slightly toward the tip. Just before pupation, the larva becomes yellow and more opaque; the mine is lined with silk and becomes swollen and light brown at this time. Pupation occurs in a longitudinally-ridged

silken coccoon (fig. 15) suspended by silken strands at each end within the leaf mine. A number of leaf mines can be found on a single leaf.

Parasites of C. lantanella. There were four species of eulophid parasites found attacking the leaf miner larvae inside the leaf mines. These were Hemiptarsenus semialbiclavus Girault, Pnigalio externa Timberlake, Sympeisis vagans Timberlake, and Zagrammosoma flaviolineata Crawford. All have been recorded as external parasites of leaf-mining larvae. A banana-shaped parasite egg was found inside the leaf mine beside a medium-sized larva. The parasite larva (fig. 16) was observed to feed externally on the later instar larvae. The parasite pupated within the leaf mine immediately after consuming the entire host. The pupa (fig. 17) was shiny black.

Weather Conditions in Sampling Sites

Figure 18 indicates the average monthly rainfall for the entire sampling period in the Waianae Mountains (U.S. Weather Bureau data) and average weekly rainfall as measured in each of the four sampling sites between December, 1963 and June, 1964. The monthly rainfall was greatest, 19 inches, at the beginning of the sampling period, with peaks occurring in August and December, 1963 and March, 1964. The weekly rainfall data taken in the four sampling sites also indicated greater rainfall in December, 1963 and late March, 1964 in all four sampling sites. Sites #1 and #2 had the highest rainfall; sites

#3 and #4 had considerably less rainfall. The period of least rainfall occurred during the period of highest temperatures.

Figure 19 indicates the average maximum wind velocity in each of the four sampling sites between November, 1963 and June, 1964. The wind was consistently higher in site #3. The highest average maximum wind velocity indicated is 15 mph, however gusts up to 25 mph were recorded. Sites #2 and #4 followed with lower maximum wind velocities. Site #1, in which surrounding trees blocked the wind, had the lowest maximum wind velocity of all.

Figure 20 indicates the maximum and minimum temperatures in site #2 between April, 1963 and May, 1964 and in site #1 and site #4 between May, 1963 and June, 1964. As would be expected, site #1 had the lowest maximum temperatures and site #4 had the highest maximum temperatures. The warmest period occurred between August and November, 1963 and the coolest during March and April, 1964.

Lantana Samples

Variation in the numbers of leaves per stem section in three leaf size categories, 1-2.9 cm in length, 3-4.9 cm in length, and 5 cm or more in length during the sampling period is indicated in figure 21. These three categories represent combinations of results from examination of smaller leaves in the leaf size categories mentioned earlier. Site #3 had the most small leaves, site #2 had the most

intermediate leaves, and site #4 had the most large leaves. Site #1 had the least small leaves, site #4 had the least intermediate leaves, and site #3 had the least large leaves. The number of leaves decreased during the summer months of 1963. This decrease occurred at all sites in the intermediate and large sized leaves, and at site #3 in the small leaves. The most numerous leaves were the small leaves in all sites throughout the sampling period.

The average per cent of leaf material missing is presented in figure 22. Site #1 indicates a far greater percentage of leaf material missing from leaves of all sizes until early December, 1963. The percentage of leaf material missing decreased sharply at this time. In sites #2, #3, and #4 there is a noticeable decrease in percentage of leaf material missing. This decrease began during the summer months of 1963. The percentage of leaf material missing increased noticeably again in sites #1, #3, and #4 beginning in February, 1964.

The presence of flowers and berries in each site between September, 1963 and June, 1964 is indicated in table 2. In site #1 there were no flowers or berries. The peak of flower and berry production in the other three sampling sites occurred in October, 1963, and the period of little or no flower and berry production in these sites occurred during January and February, 1964 in site #2 and during September, 1963 in sites #3 and #4.

Insect Populations and Correlations

H. strigata. Correlations of *H. strigata* populations with abundance of leaf material and with the populations of *T. scrupulosa* and of *C. lantanella* are presented in table 3. Most of the correlations were at the 99% confidence level. All correlations except one were positive. In sites #1, #3, and #4 the populations correlate with the total number of leaves per stem section. The population correlates in all four sites with the number of leaves of this total which have part missing and with the number of leaf classes present on each stem section. In the four sites there is correlation between the *H. strigata* populations and the number of leaves in almost all the leaf size categories and with the per cent of leaf material missing from leaves of almost all size categories. There is negative correlation of the *H. strigata* population with tingid damage in site #1 and with the leaf miner population in site #2. No other correlations between the population of *H. strigata* and that of *T. scrupulosa* or that of *C. lantanella* occurred.

The population of *H. strigata* in the four sites during the sampling period is represented in figure 23. The population was highest in sites #1 and #3 during the population peak of late April, 1963, but was highest in sites #2 and #4 during the somewhat lower population increase which occurred between November, 1963 and March,

1964. The periods of low population in site #1 occurred between September and late November, 1963 and from late March, 1964 through the end of the sampling period. Site #3 had a low population of Hypena between May and October, 1963 and from April through June, 1964. Sites #2 and #4 maintained a higher population of Hypena during the lower population period than the other two sites. The population of Hypena during the sampling period never reached the density of the populations of the tingid and the leaf miner.

T. scrupulosa. Correlations between population of T. scrupulosa in the four sites, and the abundance of plant material and the populations of H. strigata and C. lantanella are presented in table 4. Most correlations were at the 99% confidence level. As would be expected, the tingid population correlates positively with the recorded damage by this insect in all four sites. It correlates positively with the number of leaves per stem section and with the number of leaves with part missing in sites #1, #2, and #4 and with the number of leaf classes present in all four sites. It correlates positively with the small to intermediate leaves in sites #1 and #2 and positively with the intermediate to large leaves in sites #3 and #4. The tingid population correlates negatively with the number of large leaves in site #2. There is no correlation between the tingid populations and those of

H. strigata in the four sites. There is negative correlation between the tingid population and that of C. lantanella in site #2 and that of the damage by C. lantanella in sites #2 and #4, the sites where the leaf miner populations were highest.

Figures 24 and 25 indicate the populations of tingids of different age groups, based on size and stage of development, in the four sampling sites.

In sites #2, #3, and #4 there is a low tingid population in August, 1963 and between December, 1963 and February, 1964. In site #1 the population never remained at a low level for any appreciable period of time. The number of early instars always outnumbered the adults and the later instars in all sites except site #1, where the adults predominated. Site #3 had a very noticeably higher number of early instar nymphs as compared with the number of later instar nymphs and adults. The tingid population was lowest in site #3 and highest in site #1. The sex ratio of field-collected adults was 1:1.

C. lantanella. Correlations between the population of C. lantanella and the abundance of leaf material and between populations of the two other abundant lantana insects are presented in table 5. Most correlations are at the 99% confidence level. The number of leaf mines present correlates positively with the insect population, as would be expected. There is a positive correlation between the C.

lantanella population and the number of leaves of intermediate size in sites #1, and #2, the number of leaves of small size in site #3, and the number of leaves of intermediate to large size in site #4. Positive correlation between the population of this insect and the per cent of leaf material missing from leaves 2-2.9 cm in length is found in site #1, and there is positive correlation between the H. strigata population and that of this insect in site #2. In site #2 there is negative correlation between the C. lantanella population and (1) the tingid population, (2) tingid damage, and (3) per cent of leaf material missing from leaves 1 to 4.9 cm in length. Positive correlation between the insect population and the total number of leaves present per stem section occurred in sites #3 and #4. Correlation between the C. lantanella population and number of leaves with part missing and the number of leaf classes present occurred only in site #4.

Figure 26 represents the population of C. lantanella during the period of sampling. The population began its increase in late May, 1963 and reached its peak population near the end of the sampling period between February and June, 1964. In sites #3 and #4 a decrease in the population occurred in September, 1963. The population was lowest in site #1 and highest in sites #2 and #4.

The number of leaf mines present is indicated by a logarithmic scale in figure 27. Damage was present prior to the period of observed increase in population of the

insect. The amount of damage decreased sharply to a low level in May and June, 1963 followed by an increase beginning in June, 1963 as the insect population increased. The decrease in the number of leaf mines in all four sites during September corresponds with the decrease in population of the leaf miner at that time. This decrease in both leaf miner population and damage is less noticeable in sites #1 and #2, but both the leaf miner population and its damage decreased noticeably in sites #3 and #4. In sites #2 and #4 the amount of damage after this decrease increased through the termination of sampling, but in sites #1 and #3 the amount of damage decreased somewhat beginning in April, 1964.

The combined population of all the eulophid parasites, based on the number found within mines of C. lantanella, is represented in figure 28. The parasite population began its increase in site #4 during late May, 1963. The parasite population began to increase in site #2 in August, 1963, in site #3 in January, 1964, and in site #1 in February, 1964. Table 6 represents the number of parasites, unattacked hosts, and the per cent parasitization in sampling sites #2 and #4 during the latter part of the sampling period. The per cent parasitization in sites #2 and #4 was highest January to April, 1964. The per cent parasitization was highest in site #4, although the host population was highest in site #2. For the overall period the per cent parasitization was almost twice as high in site #4 as in site #2.

Since the parasites were only observed attacking the medium or large-sized larvae, the small larvae were excluded from the numbers of unattacked hosts. Pupae were included, since they had been potential hosts while larvae. Adults were excluded naturally due to difficulty in sampling adults on an equal basis with sampling of the immatures.

Table 1.-Established species of lantana insects, the year of release in Hawaii, the order and family of the insect, and the area in which each was obtained.

Year of Release	Species	Order	Family	Procurement Area
1902	Strymon echion Linnaeus	Lepidoptera	Lycaenidae	Mexico
1902	Strymon bazochii gundlachianus Bates	Lepidoptera	Lycaenidae	Mexico
1902	Teleonemia scrupulosa Stål	Hemiptera	Tingidae	Mexico
1902	Epinotia lantana Busck	Lepidoptera	Tortricidae	Mexico
1902	Platyptilia pusillidactyla Walker	Lepidoptera	Pterophoridae	Mexico
1902	Cremastobombycia lantanella Busck	Lepidoptera	Tineidae	Mexico
1902	Eutreta xanthochaeta Aldrich	Diptera	Tephritidae	Mexico
1902	Ophiomyia lantanae Froggatt	Diptera	Agromyzidae	Mexico
1953	Octotoma scabripennis* Guerin	Coleoptera	Chrysomelidae	Cuernavaca, Morelos, Mexico
1955	Catabena esula Druce	Lepidoptera	Noctuidae	Los Angeles, California, USA
1955	Aerenicopsis championi* Bates	Coleoptera	Cerambycidae	Veracruz, Veracruz, Mexico
1956	Syngamia haemorrhoidalis Guenee	Lepidoptera	Pyralidae	Havana & Santiago de las Vegas, Cuba; Coral Gables, Florida, USA
1957	Hypena strigata Fabricius	Lepidoptera	Noctuidae	Umtali, So. Rhodesia; Diani Beach, Kenya, Africa
1960	Plagiohammus spinipennis Thomson	Coleoptera	Cerambycidae	Jalapa, Veracruz, Mexico
1961	Uroplata girardi Pic	Coleoptera	Chrysomelidae	Vitoria, Espirito Santo, Brazil

* These species are not definitely known to be established.

Table 2.-Reproductive condition of lantana at 4 sites in the Waianae Mountains between September, 1963 and June, 1964.

	Site 1	Site 2	Site 3	Site 4
1963:				
Sept.	none	flowers and berries	none	none
Oct.	none	flowers and berries	flowers and berries	flowers and berries
Nov.	none	flowers and berries	dried berries	dried berries
Dec.	none	dried berries	few dried berries	few dried berries
1964:				
Jan.	none	none	few dried berries	dried berries
Feb.	none	none	few berries	few dried berries
Mar.	none	few dried berries	few dried berries	few dried berries
Apr.	none	none	few dried berries	few dried berries
May	none	flowers	few dried berries	few flowers and few dried berries
June	none	flowers	few dried berries	few dried berries

Table 3.-Correlation of population of *H. strigata* in 4 sampling sites with populations of *T. scrupulosa* and *C. lantanella* and with abundance of plant material. Degrees of freedom = 568.

Variable	Positive or Negative Correlation	Confidence Level
Site 1:		
No. leaves per stem section	+	99%
No. leaves with part missing (fed upon)	+	99%
Tingid damage	-	99%
No. leaf classes present	+	99%
No. leaves 1-4.9 cm in length	+	99%
No. leaves 5-5.9 cm in length	+	95%
No. leaves 6-6.9 cm in length	+	99%
Per cent leaf material missing from leaves 1-5.9 cm in length	+	99%
Site 2:		
No. leaves with part missing (fed upon)	+	99%
Leaf miner population	+	95%
No. leaf classes present	+	99%
No. leaves 3-5.9 cm in length	+	99%
No. leaves 6 cm or more in length	+	95%
Per cent leaf material missing from leaves 1-1.9 cm in length	+	95%
Per cent leaf material missing from leaves 2-2.9 cm in length	+	99%
Per cent leaf material missing from leaves 3-3.9 cm in length	+	95%
Per cent leaf material missing from leaves 5-6.9 cm in length	+	99%
Site 3:		
No. leaves per stem section	+	99%
No. leaves with part missing (fed upon)	+	99%
No. leaf classes present	+	99%
No. leaves 2-2.9 cm in length	+	95%
No. leaves 3-6.9 cm in length	+	99%
Per cent leaf material missing from leaves 2-6.9 cm in length	+	99%
Site 4:		
No. leaves per stem section	+	99%
No. leaves with part missing (fed upon)	+	99%
No. leaf classes present	+	99%
No. leaves 2-4.9 cm in length	+	99%
No. leaves 7 cm or more in length	+	95%
Per cent leaf material missing from leaves of all sizes	+	99%

Table 4.-Correlation of population of *L. scrupulosa* in 4 sampling sites with populations of *A. striata* and *P. lantanella* and with abundance of plant material. [illegible] of freedom = 568.

Variable	Positive or Negative Correlation	[illegible]
Site 1:		
Tingid damage	+	
No. leaves per stem section	+	
No. leaves with part missing (fed upon)	+	
No. leaf classes present	+	
No. leaves 1-3.9 cm in length	+	
Site 2:		
Tingid damage	+	
No. leaves per stem section	+	
No. leaves with part missing (fed upon)	+	
Leaf miner population	-	
No. leaf mines	-	
No. leaf classes present	+	
No. leaves 2-4.9 cm in length	+	
No. leaves 5 cm or more in length	-	
Site 3:		
Tingid damage	+	
No. leaf classes present	+	
No. leaves 3-3.9 cm in length	+	
No. leaves 5-5.9 cm in length	+	
No. leaves 6-6.9 cm in length	+	
Site 4:		
Tingid damage	+	
No. leaves per stem section	+	
No. leaves with part missing (fed upon)	+	
No. leaf mines	-	
No. leaf classes present	+	
No. leaves 3-6.9 cm in length	+	

Table 4.-Correlation of population of T. scrupulosa in 4 sampling sites with populations of H. strigata and C. lantanella and with abundance of plant material. Degrees of freedom = 568.

Variable	Positive or Negative Correlation	Confidence Level
Site 1:		
Tingid damage	+	99%
No. leaves per stem section	+	99%
No. leaves with part missing (fed upon)	+	99%
No. leaf classes present	+	99%
No. leaves 1-3.9 cm in length	+	99%
Site 2:		
Tingid damage	+	99%
No. leaves per stem section	+	99%
No. leaves with part missing (fed upon)	+	99%
Leaf miner population	-	99%
No. leaf mines	-	99%
No. leaf classes present	+	99%
No. leaves 2-4.9 cm in length	+	99%
No. leaves 5 cm or more in length	-	95%
Site 3:		
Tingid damage	+	99%
No. leaf classes present	+	99%
No. leaves 3-3.9 cm in length	+	99%
No. leaves 5-5.9 cm in length	+	99%
No. leaves 6-6.9 cm in length	+	95%
Site 4:		
Tingid damage	+	99%
No. leaves per stem section	+	99%
No. leaves with part missing (fed upon)	+	99%
No. leaf mines	-	95%
No. leaf classes present	+	99%
No. leaves 3-6.9 cm in length	+	99%

Table 5.-Correlation of population of C. lantanella in 4 sampling sites with populations of H. strigata and T. scrupulosa and with abundance of plant material. Degrees of freedom = 568.

Variable	Positive or Negative Correlation	Confidence Level
Site 1:		
No. leaf mines	+	99%
No. leaves 3-3.9 cm in length	+	99%
Per cent leaf material missing from leaves 2-2.9 cm in length	+	95%
Site 2:		
No. leaf mines	+	99%
Looper population	+	95%
Tingid population	-	99%
Tingid damage	-	95%
No. leaves 3-3.9 cm in length	+	99%
Per cent leaf material missing from leaves 1-1.9 cm in length	-	95%
Per cent leaf material missing from leaves 2-2.9 cm in length	-	99%
Per cent leaf material missing from leaves 3-3.9 cm in length	-	95%
Per cent leaf material missing from leaves 4-4.9 cm in length	-	99%
Site 3:		
No. leaf mines	+	99%
No. leaves per stem section	+	99%
No. leaves 1-1.9 cm in length	+	99%
No. leaves 2-2.9 cm in length	+	95%
Site 4:		
No. leaf mines	+	99%
No. leaves per stem section	+	99%
No. leaves with part missing (fed upon)	+	99%
No. leaf classes present	+	99%
No. leaves 3-3.9 cm in length	+	99%
No. leaves 4-4.9 cm in length	+	95%
No. leaves 6-6.9 cm in length	+	99%

Table 6.-Number of parasites and unattacked hosts* and the per cent parasitization in sites #2 and #4 from November, 1963 to June, 1964.

Site No.		1963			1964							Total
		Nov.		Dec.	Jan.	Feb.	Mar.	Apr.	May	June		
	Sampling week no.	36	39	42	45	48	51	54	57	60	63	66	
2	Parasites	5	4	3	3	5	4	2	4	1	1	0	32
	Unattacked hosts	33	21	13	18	14	15	3	14	2	19	5	157
	Per cent parasitization	13	16	18	14	26	21	40	22	33	5	-	17
4	Parasites	4	3	1	8	8	12	12	2	3	1	4	58
	Unattacked hosts	12	12	9	10	18	18	24	9	4	7	5	118
	Per cent parasitization	25	20	10	44	30	40	33	18	42	12	44	33

* Only medium and large larvae and pupae are included.

Figure 1.-Flower of *Lantana camara* var. *aculeata* (L.) Moldenke with visiting honey bee.

Figure 2.-Thick lantana growth.

Figure 3.-Area of Oahu indicating location of sampling sites. This area is shown stippled on the inset map of Oahu.

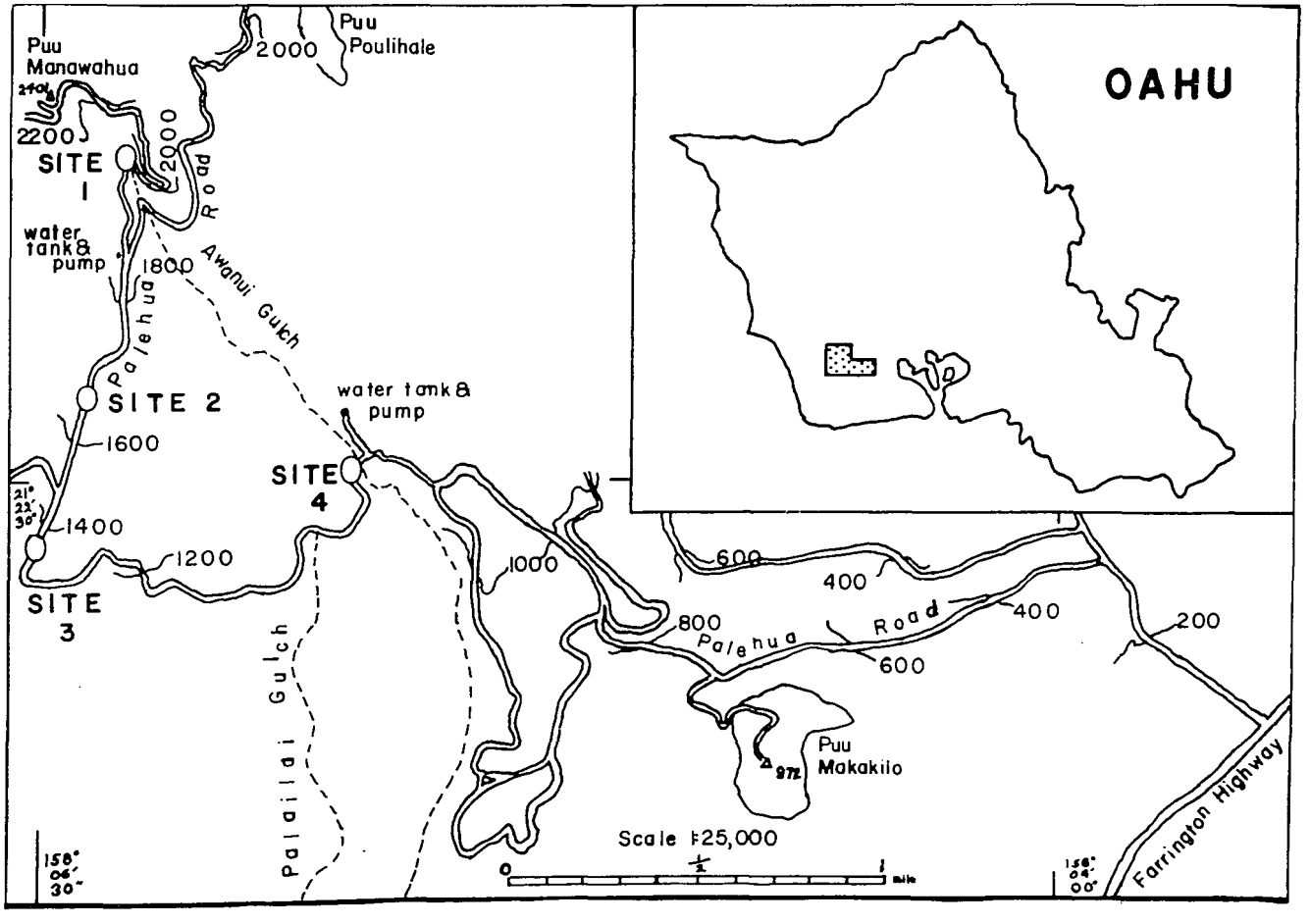

OAHU
Puu Manawahua
2701
2200
SITE 1
2000
Puu Poulihale
2000
Road
water tank & pump
1800
Awanui Gulch
Palehua
SITE 2
1600
water tank & pump
SITE 4
21° 22' 30"
1400
1200
SITE 3
1000
600
400
800
Palehua Road
400
200
600
Puu Makakilo
972
Palailai Gulch
Scale 1:25,000
0
1 mile
158° 06' 30"
158° 04' 00"
Farrington Highway

Figure 4.-*Hypena strigata* Fabricius adult.

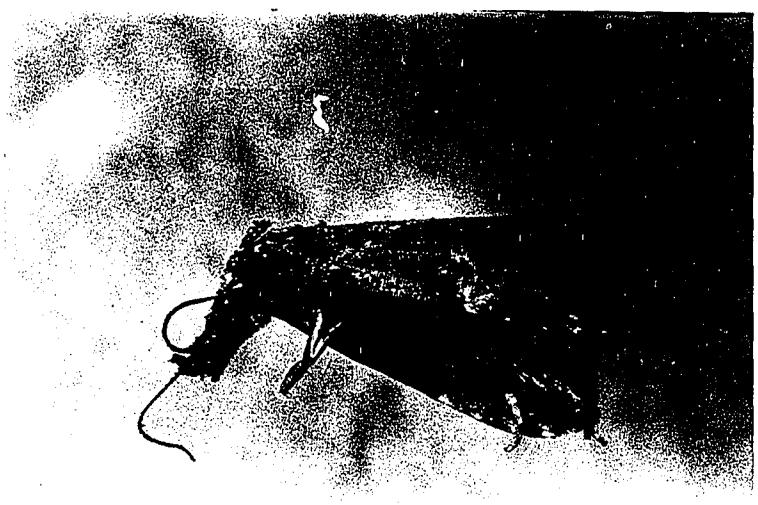


Figure 5.-Last instar larva of Hypena strigata Fabricius feeding on leaf of lantana.

Figure 6.-Damage to lantana leaves by Hypena strigata Fabricius.

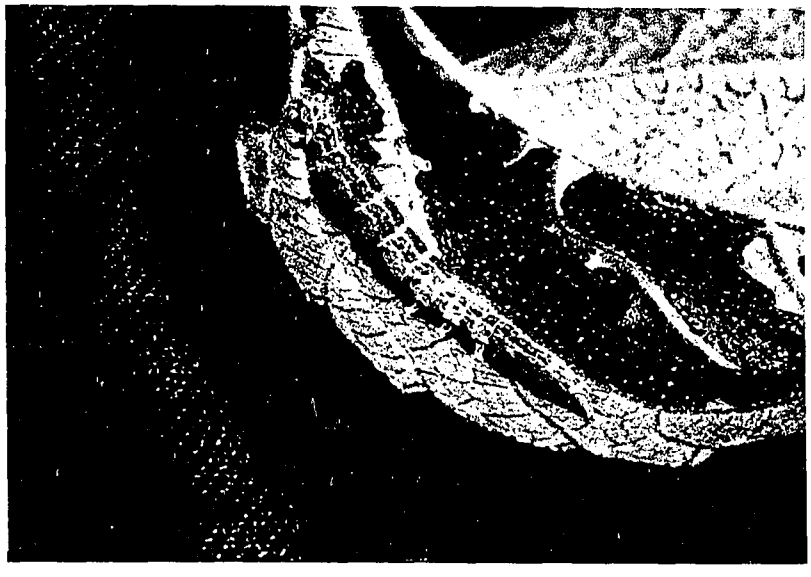


Figure 7.-Adult of Teleonemia scrupulosa Stål in dorsal view.

Figure 8.-Adult female of Teleonemia scrupulosa Stål, showing ovipositor and beak.

Figure 9.-Small nymphs of Teleonemia scrupulosa Stål feeding on leaf.

Figure 10.-Exuvia of last instar nymph of Teleonemia scrupulosa Stål, fastened to leaf of lantana.

Figure 11.-Leafless branches of lantana in site #1.

Figure 12.-Burning and crinkling of lantana leaves due to attack by Teleonemia scrupulosa Stål.

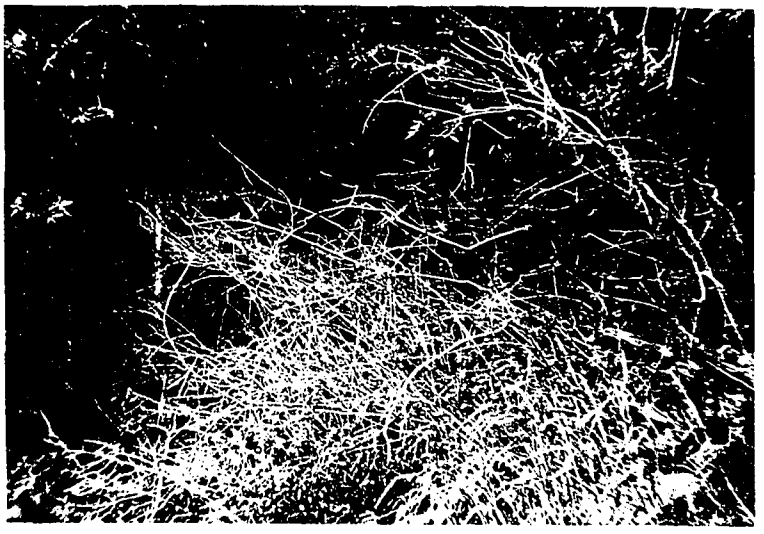


Figure 13.-Adult and pupal case of Cremastobombycia lantanella Busck.

Figure 14.-Larva of Cremastobombycia lantanella Busck feeding inside opened mine on lantana leaf.

Figure 15.-Silken coccoon of Cremastobombycia lantanella Busck suspended inside silk-lined leaf mine.

Figure 16.-Parasitic eulophid larva inside leaf mine of Cremastobombycia lantanella Busck after having eaten its host.

Figure 17.-Pupa of parasitic eulophid inside leaf mine of Cremastobombycia lantanella Busck.

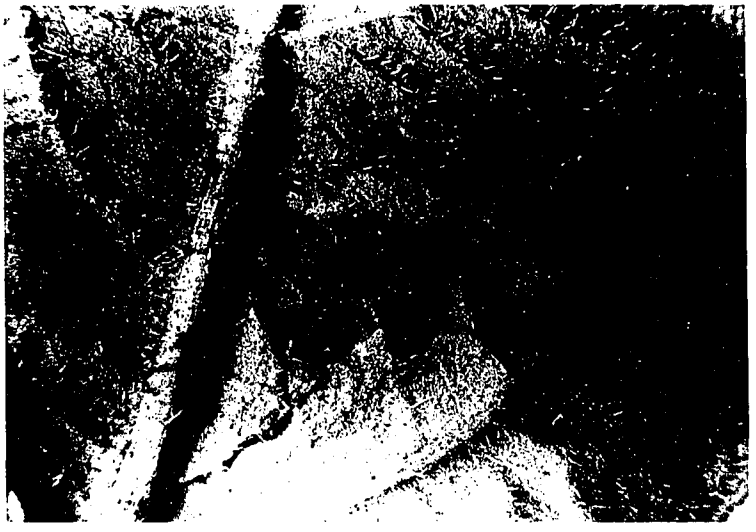


Figure 18.-Monthly rainfall in Waianae Mountains April, 1963 through June, 1964, and average weekly rainfall in each of 4 sampling sites between December, 1963 and June, 1964.

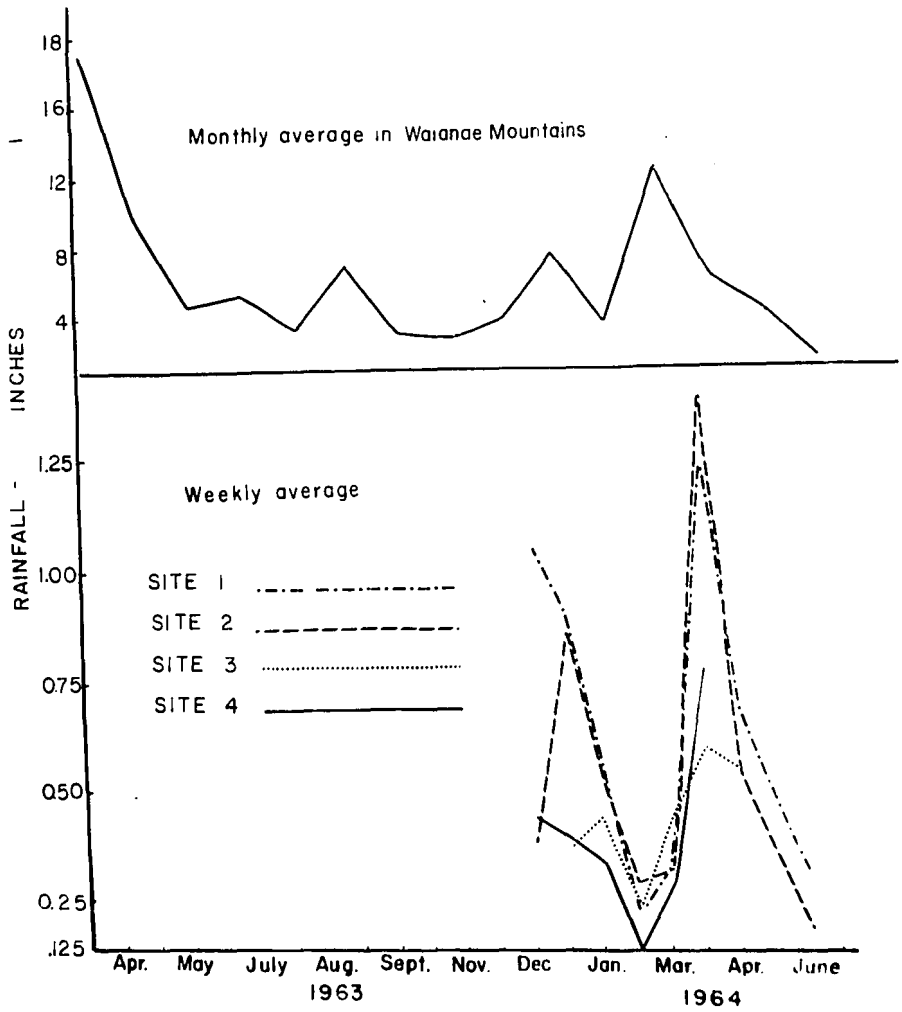

RAINFALL - INCHES
18
16
12
8
4
Monthly average in Waianae Mountains
1.25
1.00
0.75
0.50
0.25
.125
Weekly average
SITE 1
SITE 2
SITE 3
SITE 4
Apr.
May
July
Aug.
Sept.
Nov.
Dec
Jan.
Mar.
Apr.
June
1963
1964

Figure 19.-Average maximum wind velocity in each of the 4 sampling sites between November, 1963 and June, 1964.

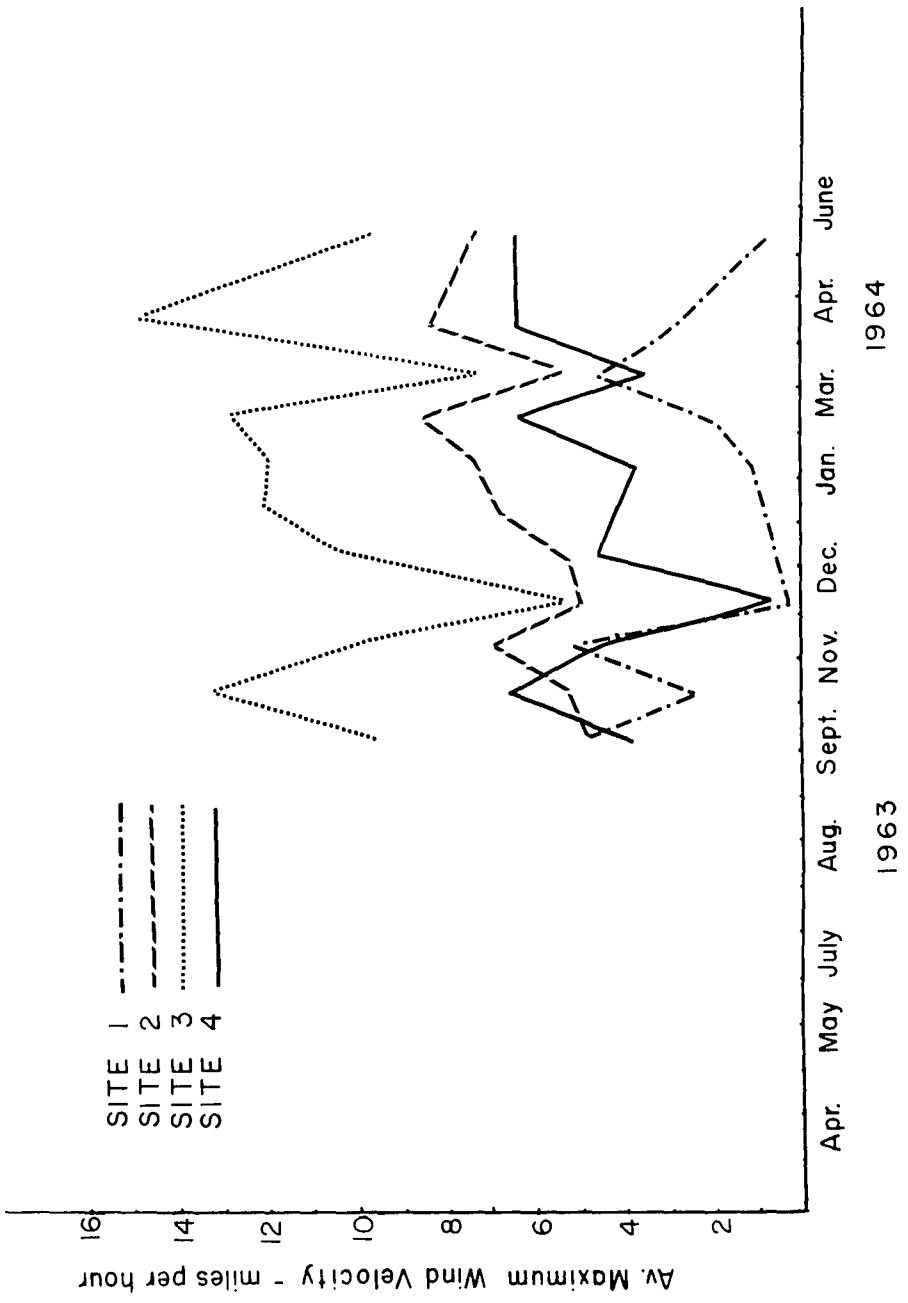

Av. Maximum Wind Velocity - miles per hour
16
14
12
10
8
6
4
2
SITE 1
SITE 2
SITE 3
SITE 4
Apr. May July Aug. Sept. Nov. Dec. Jan. Mar. Apr. June
1963
1964

Figure 20.-Weekly maximum and minimum temperatures at 3 sampling areas April, 1963 through May, 1964.

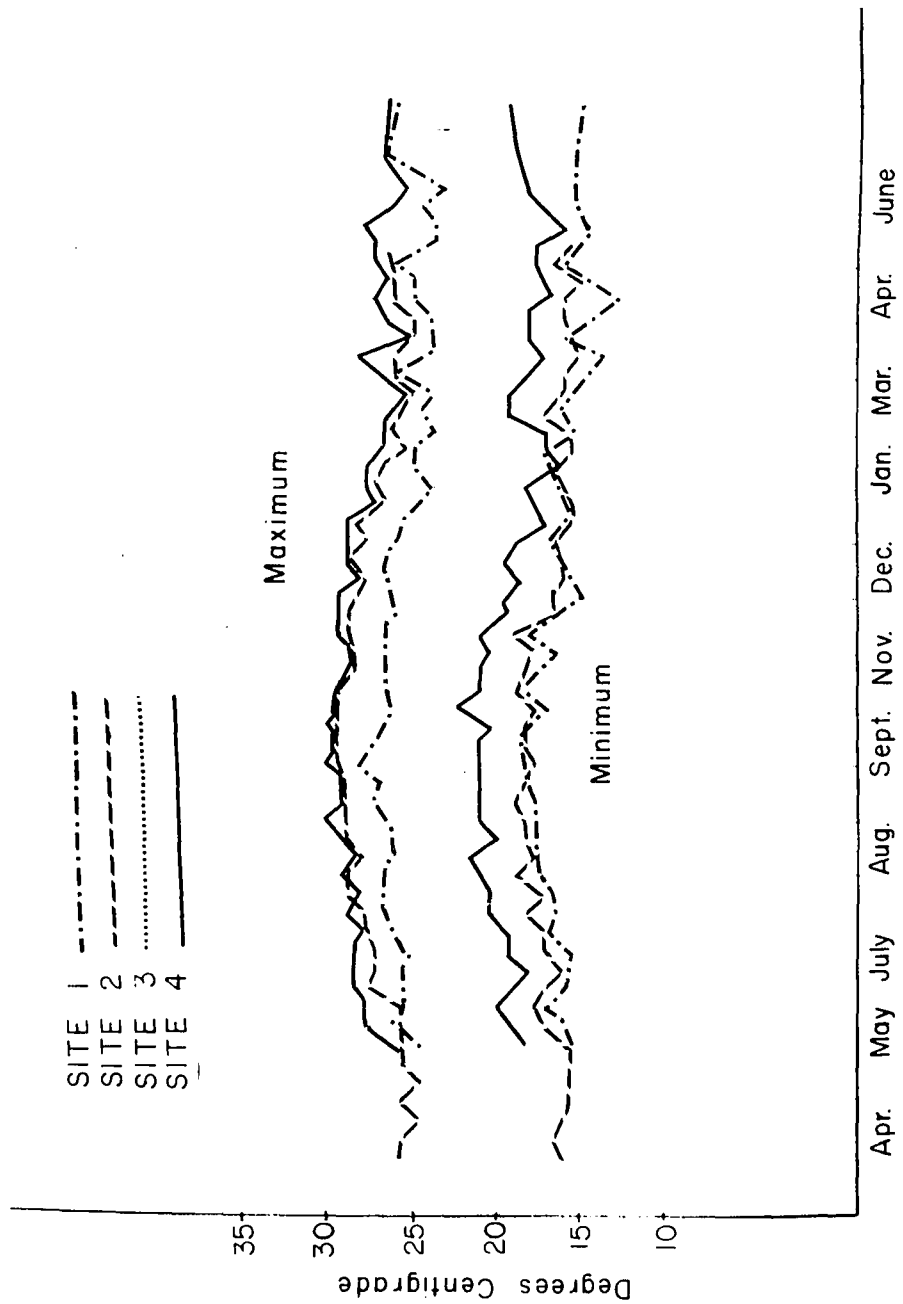

SITE 1
SITE 2
SITE 3
SITE 4
Maximum
Minimum
Degrees Centigrade
35
30
25
20
15
10
Apr. May July Aug. Sept. Nov. Dec. Jan. Mar. Apr. June
1963
1964

Figure 21.-Average number of leaves 1-2.9 cm, 3-4.9 cm, and 5 cm or more in length per stem section of L. camara var. aculeata (L.) Moldenke in 4 sampling sites April, 1963 through June, 1964.

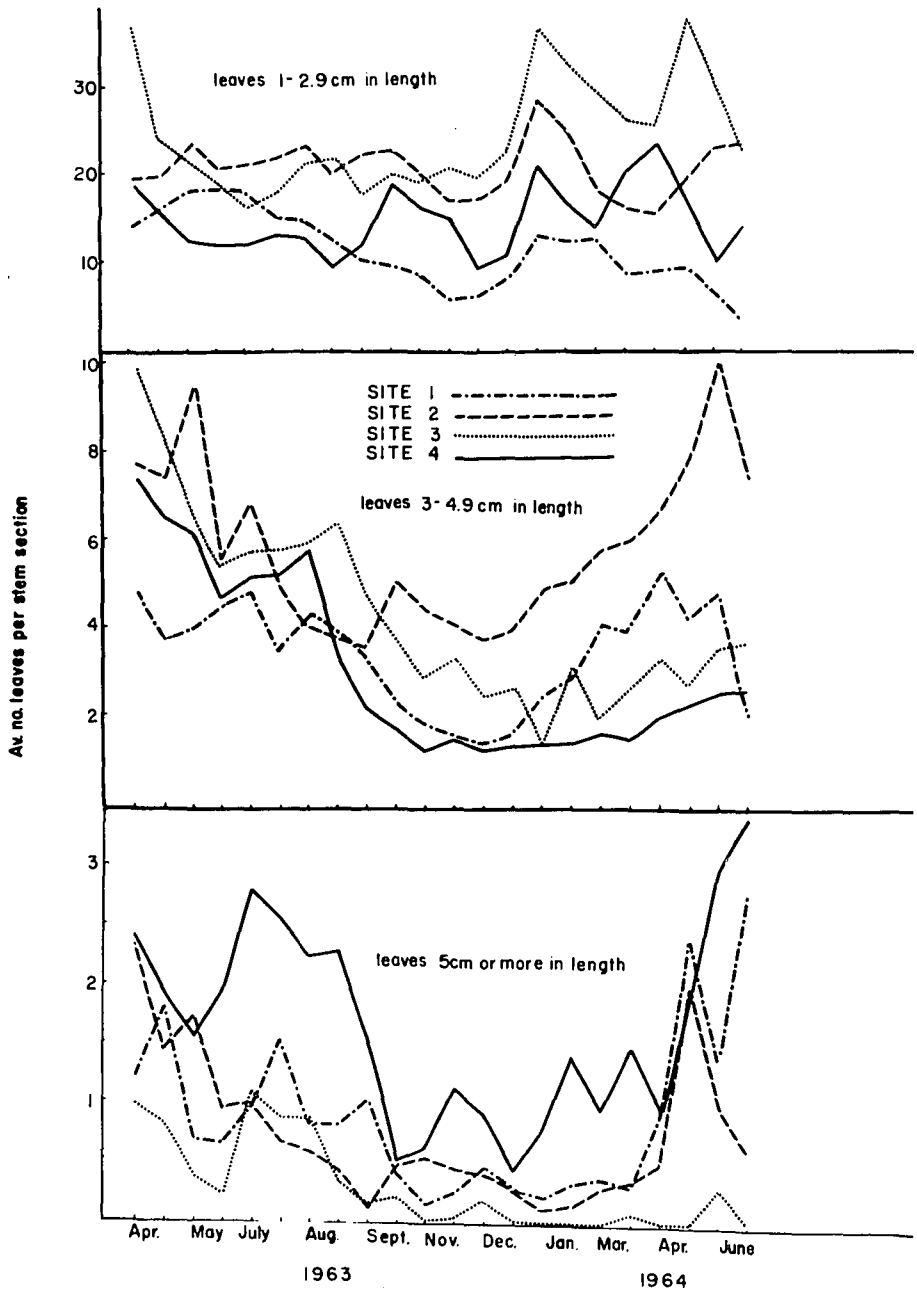

leaves 1-2.9 cm in length
leaves 3-4.9 cm in length
leaves 5cm or more in length
SITE 1
SITE 2
SITE 3
SITE 4
Av. no. leaves per stem section
30
20
10
10
8
6
4
2
3
2
1
Apr.
May
July
Aug.
Sept.
Nov.
Dec.
Jan.
Mar.
Apr.
June
1963
1964

Figure 22.-Average per cent of leaf material missing from lantana leaves 1-2.9 cm, 3-4.9 cm, and 5 cm or more in length April, 1963 through June, 1964.

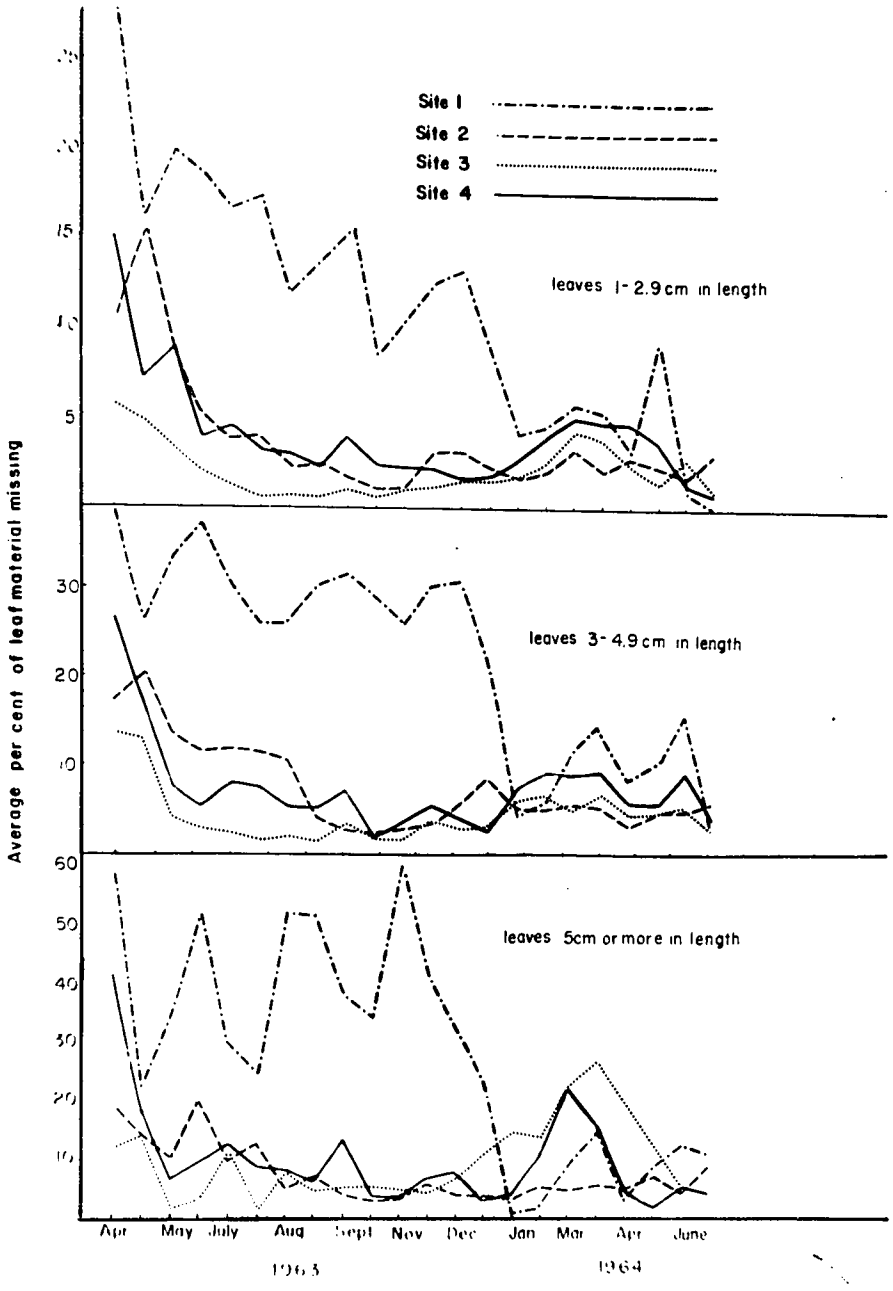

Site 1
Site 2
Site 3
Site 4
leaves 1-2.9 cm in length
leaves 3-4.9 cm in length
leaves 5cm or more in length
Average per cent of leaf material missing
Apr
May
July
Aug
Sept
Nov
Dec
Jan
Mar
Apr
June
1963
1964

Figure 23.-Populations of Hypena strigata Fabricius on lantana, April, 1963 through June, 1964, represented by average number of larvae per stem section in each of 4 sampling sites.

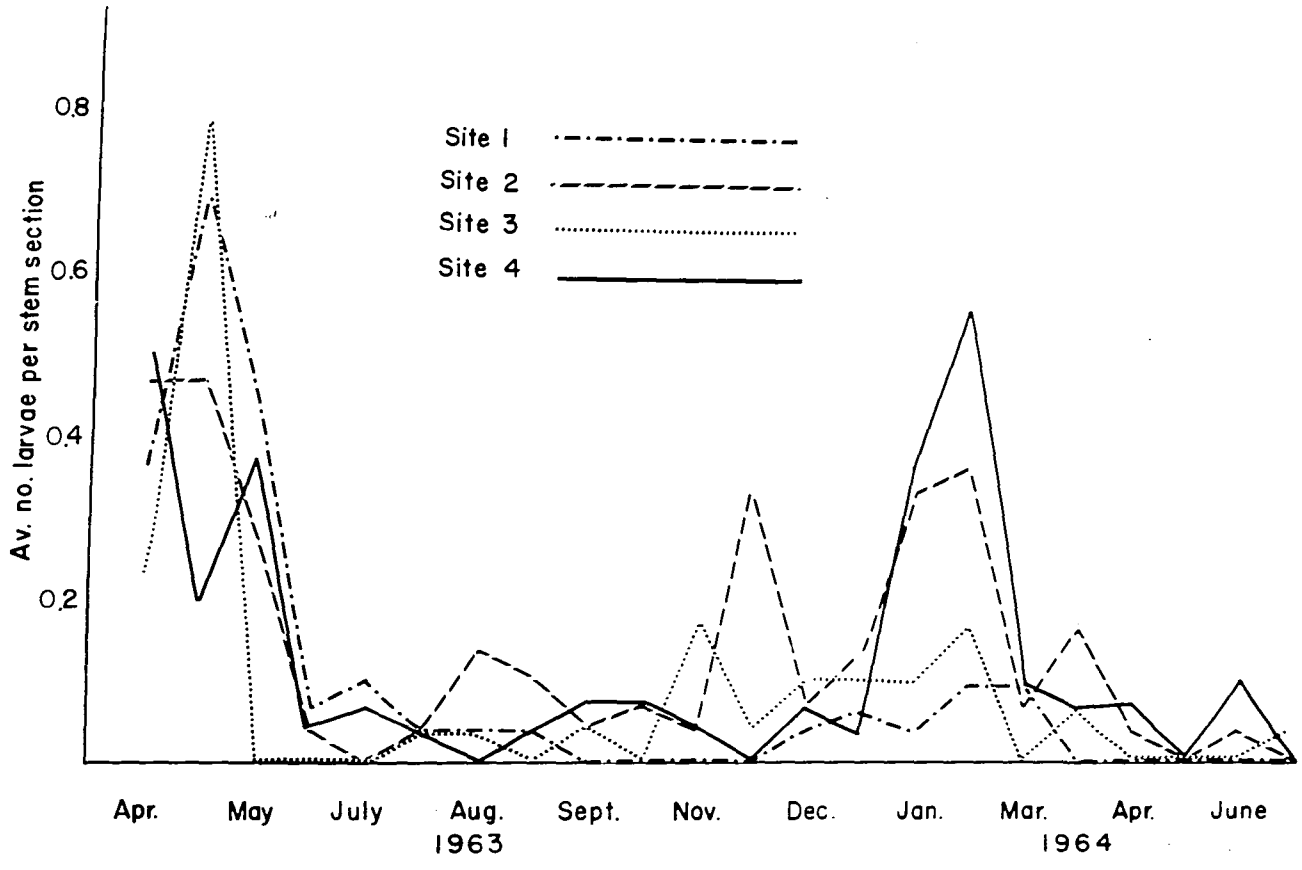

0.8
0.6
0.4
0.2
Av. no. larvae per stem section
Site 1
Site 2
Site 3
Site 4
Apr.
May
July
Aug.
Sept.
Nov.
Dec.
Jan.
Mar.
Apr.
June
1963
1964

Figure 24.-Populations of Teleonemia scrupulosa Stål on lantana, April, 1963 through June, 1964, represented by average number per stem section in weekly samples from sites #1 and #2.

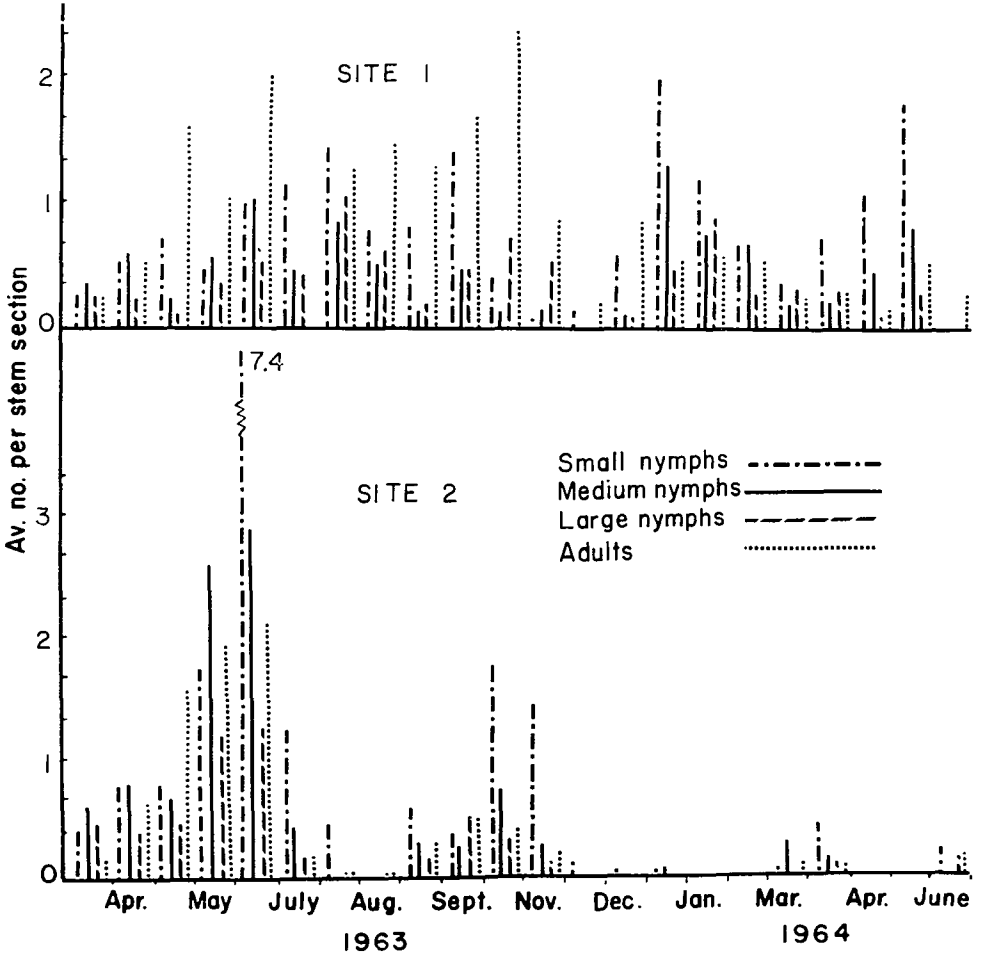

SITE 1
SITE 2
17.4
Av. no. per stem section
Small nymphs
Medium nymphs
Large nymphs
Adults
0
1
2
3
Apr.
May
July
Aug.
Sept.
Nov.
Dec.
Jan.
Mar.
Apr.
June
1963
1964

Figure 25.-Populations of Teleonemia scrupulosa Stål on lantana, April, 1963 through June, 1964, represented by average number per stem section in weekly samples from sites #3 and #4.

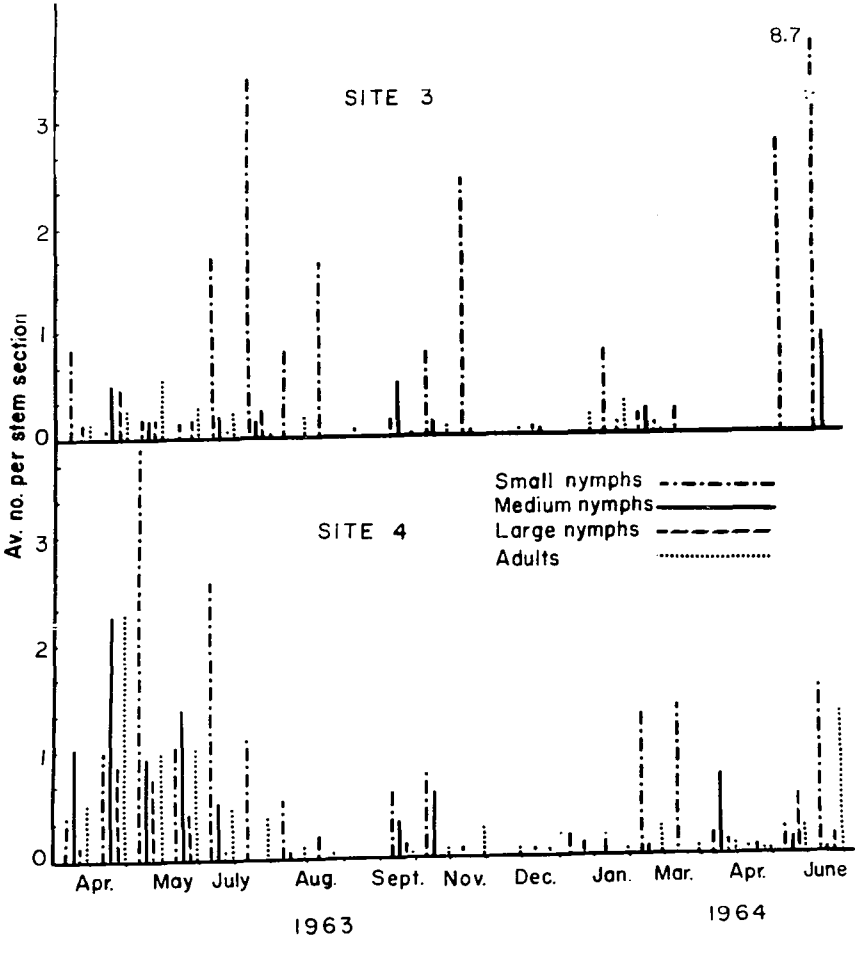

8.7
SITE 3
SITE 4
Av. no. per stem section
0
1
2
3
Small nymphs
Medium nymphs
Large nymphs
Adults
Apr.
May
July
Aug.
Sept.
Nov.
Dec.
Jan.
Mar.
Apr.
June
1963
1964

Figure 26.-Populations of Cremastobombycia lantanella Busck on lantana, April, 1963 through June, 1964, represented by average number per stem section in each of 4 sampling sites.

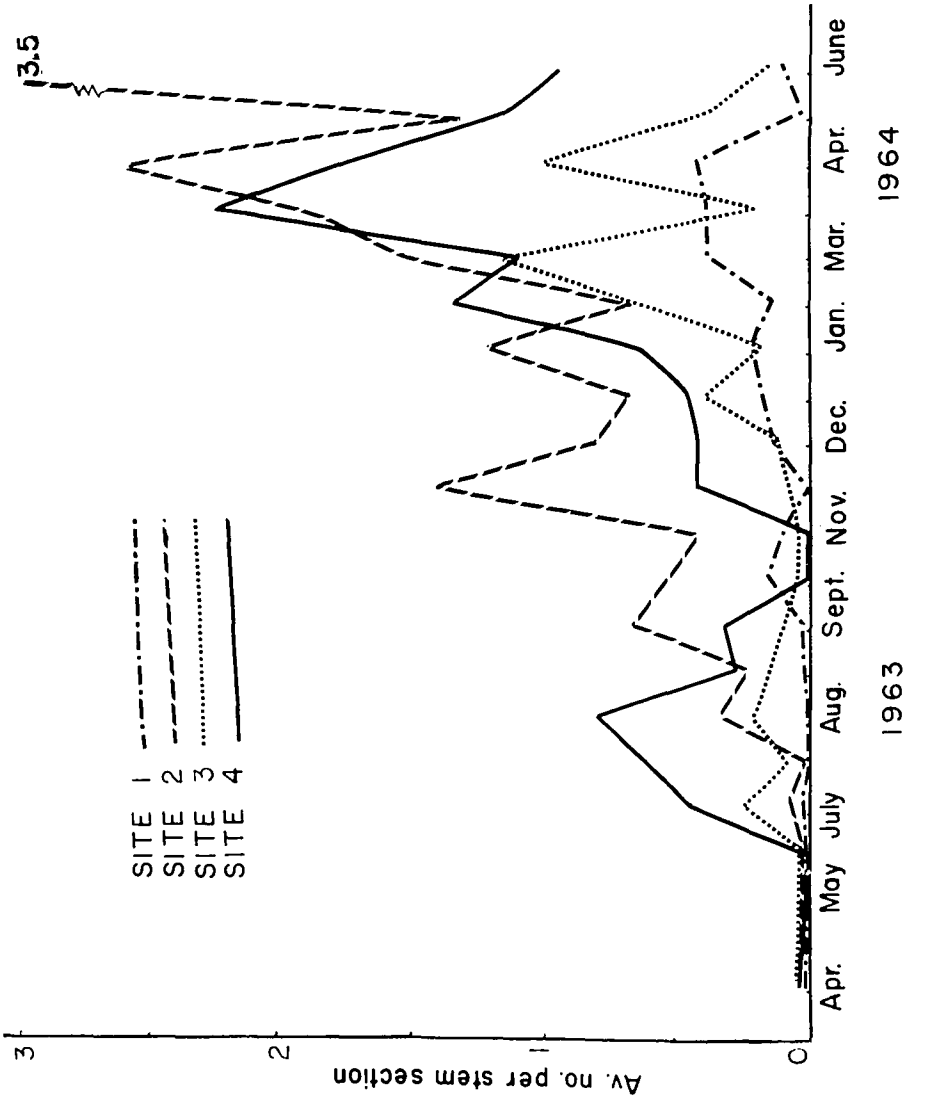

13.5
SITE 1
SITE 2
SITE 3
SITE 4
Av. no. per stem section
0
1
2
3
Apr.
May
July
Aug.
Sept.
Nov.
Dec.
Jan.
Mar.
Apr.
June
1963
1964

Figure 27.-Damage as number of leaf mines per stem section in weekly samples of leaves of lantana in 4 sampling sites due to the leaf miner, Cremastobombycia lantanella Busck.

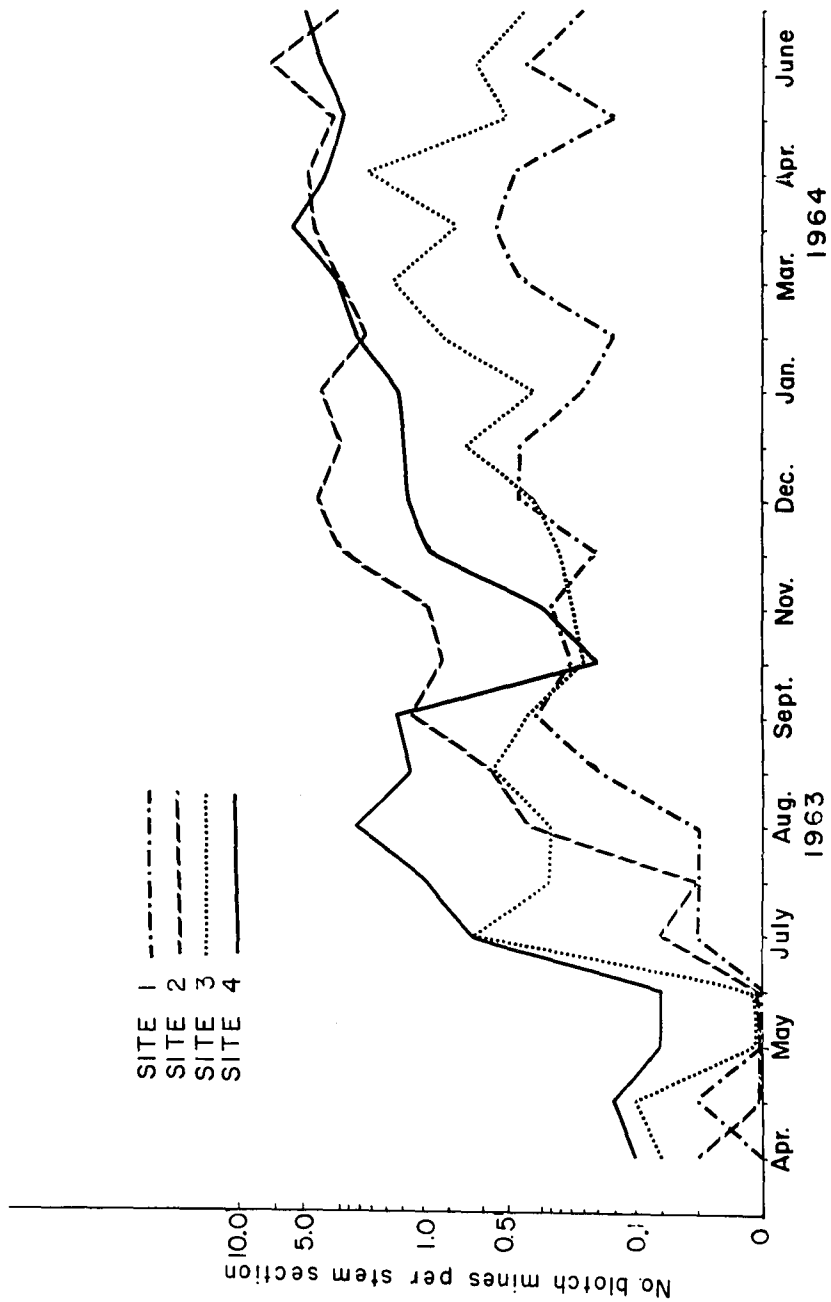
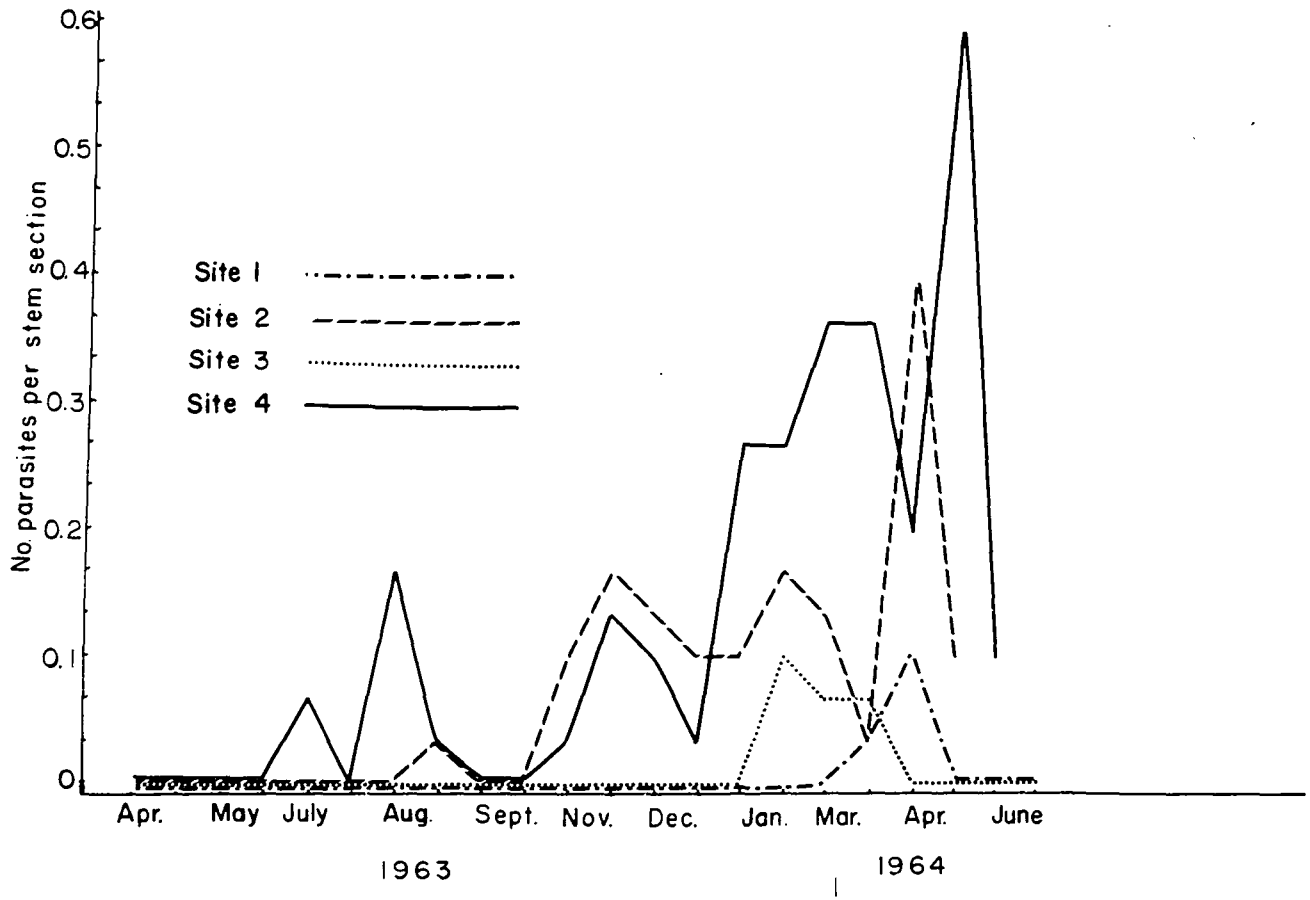

No. blotch mines per stem section
10.0
5.0
1.0
0.5
0.1
0
SITE 1
SITE 2
SITE 3
SITE 4
Apr.
May
July
Aug.
1963
Sept.
Nov.
Dec.
Jan.
Mar.
Apr.
June
1964

Figure 28.-Populations of eulophid parasites of lantana leaf miner, Cremastobombycia lantanella Busck based on average number per stem section in each of 4 sampling sites, April, 1963 through June, 1964.


0.6
0.5
0.4
0.3
0.2
0.1
0
No. parasites per stem section
Site 1
Site 2
Site 3
Site 4
Apr.
May
July
Aug.
Sept.
Nov.
Dec.
Jan.
Mar.
Apr.
June
1963
1964

DISCUSSION

Insect Populations and Abiotic Influences

Generally, abiotic influences were severe on the populations of *H. strigata* and *T. scrupulosa*. Abiotic stress on *C. lantanella*, however, seemed relatively low; the population increased through hot, dry weather and through cooler, wetter weather in all sampling sites. The *C. lantanella* population was considerably higher in April 1, 1964 than during this month of 1963. Abiotic stress on *T. scrupulosa* and on *H. strigata* may have been partly indirect by limiting the quantity and quality of the food supply.

A comparison of *T. scrupulosa* populations in the four sampling sites in figures 24 and 25 would indicate that abiotic stress is acting directly on the insect populations. In the three open field sites, the populations reached very low population levels and fluctuated greatly, especially in the sporadic, high production of early instar nymphs. The mortality rate must have been very high in the open sites, as evidenced by the production of numerous progeny, but the survival of relatively few later instar nymphs and adults. This difference in populations and age distribution was likely due to the effect of the surrounding forest area in site #1, acting as a baffle to limit the action of wind and sun on the *Teleonemia* population. Adult survival seemed higher in site #1.

Insect Populations and Biotic Influences

In this study relatively few species of parasites and predators of insects attacking lantana were found. Besides general predators in the field, such as spiders and praying mantises, the egg sucking bug, Tytthus mundulus (Bredd.), which was purposely introduced for control of the sugarcane leafhopper, was present in areas where tingid populations were high. These predators feed on eggs of a few other species, such as the corn planthopper, and it is likely that tingid eggs, which are inserted into plant tissue in a similar manner, could be fed upon by them also. However, the populations of these predaceous bugs in the lantana field were too sparse to be of much consequence as an effective agent of reduction of populations of T. scrupulosa.

In rearing field-collected H. strigata larvae, it was anticipated that parasites would emerge from some of them. However, none were obtained. Associated with high Hypena populations in the field, pupal cases of the braconid, Apanteles trifasciatus Muesebeck, were found. Since it attacks lepidopterous larvae, it is likely that some Hypena may have been attacked by it. There were less than a dozen of these parasite pupal cases observed in the field throughout a two year period, however, so they were probably of little influence on the populations of H. strigata.

The four eulophid parasites of C. lantanella were numerous in mines of the leaf miners, but still the leaf

miner population continued its general trend of increase from June, 1963 through June, 1964. Generally, the per cent of parasitization and the actual number of parasites were higher in site #4, possibly because of physical conditions. The wind, which was of higher velocity in site #2, would be a definite disadvantage to an insect as small as a eulophid. The size of the host population alone thus did not determine the size of the parasite population; the parasites were the most numerous in site #4, where the host population was less than that in site #2.

Swezey (Perkins and Swezey, 1924) states that as many as 12 to 20 leaf mines per leaf could be found, with an average of 5.65 per leaf in leaves collected in the field. In the study here presented, this level was never reached. The difference could be due to his collection of the leaf mines in different areas of Oahu, but examinations of lantana plants on Oahu in areas other than the Waianae Mountains during this study period never revealed as high a population of leaf miners as that recorded by Swezey. Beardsley has seen recent populations of C. lantanella on the island of Molokai as high as that reported by Swezey.

It is highly possible that a high population of T. scrupulosa on leaves attacked also by C. lantanella could be deleterious to the latter insect. Since feeding by T. scrupulosa causes leaves to fall from the plant, an early instar leaf miner feeding inside a fallen leaf would die

when the leaf dried. Also, leaves remaining on a plant which had a high tingid population would be dried and brittle, thus not only killing the larvae feeding inside, if any, but also preventing any additional leaf miner feeding inside these leaves and thereby limiting C. lantanella population increase. This conclusion is supported by the negative correlations between populations of T. scrupulosa and C. lantanella in site #2 and negative correlation between T. scrupulosa populations and C. lantanella damage in sites #2 and #4 and between C. lantanella population and T. scrupulosa damage in site #2. The lower populations of C. lantanella in sites #1 and #3 may account for the lack of such correlation in these sites. The negative correlations between the C. lantanella population and the per cent of leaf material missing (table 5) indicate that H. strigata may also reduce the quality of food for the leaf miner. Again, the higher numbers of C. lantanella in site #2 may account for correlation here, although there was none in the other sites.

Lantana and Abiotic Influences

Generally, high temperature and low rainfall had an adverse effect on lantana. The highest temperatures were encountered between the 18th and 33rd weeks of sampling July 3, 1963 through November 6, 1963. Rainfall was relatively low during this period also. Between these sampling dates noticeable decreases occurred in the total number of leaves per stem section present in all four sampling sites.

This sampling period in which the number of leaves was relatively low was followed in December, 1963 by a period of increased leaf production, which lasted through the end of the period of sampling. The dip in the number of leaves present is evident in figure 21. This effect is less noticeable in the smallest leaves, possibly because adverse temperature and moisture conditions tend to prevent growth of these smaller leaves into larger leaves, thus maintaining a relatively steady number of small leaves on the plant. The low number of larger leaves in site #3 is probably due to the relatively high wind velocity in the area, which caused the leaves to become wind-hardened, i.e. brittle and less flexible. The total number of leaves per stem section of all sizes larger than 1 to 1.9 cm in length began to increase in all areas between the 36th and 42nd weeks of sampling, November 13, 1963 to December 25, 1963. This is attributable to lower temperatures and increased rainfall.

Lantana and Biotic Influences

Food quantity and quality as regulators of population are important biotic factors acting on insect populations. The insects may in turn act on the plant to regulate its abundance. This mutual dependence of plant and insect is the basic principle of the biological control of weeds as stated by Huffaker (1964). Based on this premise, the population of an insect which is effective as a control agent of the weed should fluctuate in accordance with the

fluctuation in weed abundance, or over a relatively short period, in accordance with the fluctuation in abundance of leaves, flowers, seeds, or other growing parts of the plant. These mutual fluctuations in population should occur no matter whether one is the cause or the effect of a fluctuation in the other, and no matter whether the fluctuation was caused by biotic or by abiotic factors.

The population of Hypena in the field more closely follows the fluctuation in the number of leaves of its food plant, than does the population of the other two abundant insects in this study. This is supported by the correlation data in table 3, which indicates a concurrent fluctuation in amount of leaf material and number of Hypena throughout the sampling period in all four sites. The lantana looper population changed as did the abundance of leaves, as indicated in figures 21 and 23, except during the period from April, 1963 to the termination of sampling. The lower number of samples and the low numbers of loopers overall may account for this.

The average per cent of leaf material missing also decreased and increased concurrently with the populations of Hypena as is indicated by the correlation of per cent of leaf material missing in most of the leaf size categories with the population of Hypena. The looper population shown in figure 23 again does not strictly follow the change in per cent of leaf material missing.

Uvarov (1931) states that a plant with foliage reduced by abiotic influences and attacked at that time by leaf-feeding insects will have damage disproportionately greater than the damage caused by the insect to a plant with lush foliage. In site #1, where leaves were relatively low in number, the amount of leaf material missing was considerably higher (fig. 22) during the first half of the entire sampling period than in the other three sites. This occurred even though the Hypena population here was similar to that of the other three sampling sites. Uvarov's theory may explain this greater damage. A possible explanation for the persistence of high leaf damage in site #1 after the Hypena population had subsided could be that damaged leaves would remain on the plant longer in the area protected by the surrounding forest. These leaves in turn would limit new leaf growth. Much of the recorded Hypena damage was noticeably old; the damage then must have remained even though the Hypena population had since decreased.

The tingid population fluctuated with the amount of leaf material in all four sites. This is indicated by the correlations between total number of leaves and the tingid population (table 4) in all sites except site #3. The wind-hardened condition of the leaves in site #3 and the low tingid population there may account for the lack of correlation. The continual presence of T. scrupulosa in site #1 may account in part for the lack of flower production there. A low degree of sunlight was probably also a factor.

The change in insect numbers with the change in quantity of food material supports the contentions of Nicholson (1933, 1954), Uvarov (1931) and Brues (1946) that food quantity can regulate insect populations. However, the factor of food quantity was not operating alone in this study, and would probably seldom be found operating alone in natural outdoor situations. In most situations abiotic influences would also be present.

The population of C. lantanella larvae feeding in the leaves increased, beginning in June, just when the total number of leaves and the populations of the other two insects were beginning to decrease, up to a peak population in April, 1964. The population in site #2 seemed to be on the increase even through the termination of sampling.

The C. lantanella population in all sites did not seem to fluctuate seasonally, and any long term change in temperature, rainfall, or wind velocity seemed to affect the leaf miner population little. The belief that food material is seldom limiting to populations, as expressed by Muir (1914), Thompson (1929), Smith (1935), and Imms (1937) at first seems to be supported in this instance, however, even though the leaf miner population is not related to total number of leaves, the necessary presence of a number of leaves of particular quality indicates a dependency of population on food material. The smaller and intermediate-sized young leaves, which were affected less as the tingid

and Hypena populations decreased, did correlate with the population of C. lantanella; therefore, there must be a relationship between the insect and these leaves. The correlation extending to the larger leaves in site #4 may be accounted for by the high population in that area overflowing onto these leaves, which were more numerous in site #4 than in the other three sites. Although the population in site #2 was also high, there is an indication that the leaf quality may have been reduced here, as indicated by the negative correlations between the C. lantanella population and damage by tingids and the looper. Also, there were fewer large leaves here.

Difficulty arises in attempting to evaluate a biotic stress on lantana in the presence of an abiotic stress on lantana. The abiotic stress may induce the biotic change which may in turn bring about a change in insect population or food material. The greatest fluctuation in leaf material and insects present in this study is abiotically induced. In site #1, where there was some protection from physical stress, the population of tingids fluctuated relatively little, and there was less oscillation in the amount of leaf material present. This would indicate the attainment of a balance between insect and plant in this instance. This term balance as expressed by Smith (1935) depends on the inherent capacity of a species to exist at an equilibrium density in a given environment. Over a several year period

there would possibly be an indication of balance between tingids and plant material in sites #2, #3, and #4 also. The density of lantana was lowest in site #1. The plant density can be lowered by changing its environment, and this change may be brought about by the introduction of insects which feed on the plant.

In this study the introduced tingid, looper, and leaf miner were correlated with the abundance of lantana foliage. This correlation is less apparent in the leaf miner, since the relationship does not extend to all leaf sizes in all sites. Hypena would be considered of importance, since its feeding was producing stress in all sites. Its low numbers in this study, however, would not indicate that it is of prime importance as a control agent. Teleonemia would be considered of importance in some areas because it was present in relatively high numbers, and in some instances where extreme abiotic influences on the insect were reduced, such as in the forest area, it can possibly maintain a high population and defoliate some of the plants. The seasonal high temperatures and lower rainfall would still be affecting the plant in this site also, but to a lesser extent than in the open sites. Figure 8 illustrates bare branches of lantana at site #1 at a time when the tingid is abundant and abiotic stress on the plant, due to the period of lower rainfall and higher temperatures, is greatest.

The population of Cremastobombycia also is related to

the abundance of lantana foliage when the necessary quality of plant material is present. Quality is considered important by Smith (1935), Nicholson (1954), and Huffaker (1964). The period when there was a sufficient quantity of food of necessary quality might have allowed time for the insect population to increase to a high level and favor its population for an extended period of time. Andrewartha and Birch (1954) consider the availability of material resources (food quality and quantity, and a place in which to live), dispersal and searching capacity of the species, and the time during which the rate of increase of the species is positive, of prime importance in population regulation.

The value of the leaf miner is questionable, since the presence of a mine on the leaf may produce little stress. The leaf was not destroyed by the presence of the leaf miner, and if it had been destroyed this could have affected its own survival. Old leaf mines could dry out and cause dead spots on the leaves, but whether this would inhibit the plant materially is doubtful. On the contrary, there is evidence of interaction between the population of this insect and those of the tingid and the looper. In this instance, it seems that the interaction is unfavorable for the leaf miner. However, this would indicate a need for caution in the introduction of all species of beneficial insects available, since they could possibly inflict only slight damage to the weed, but could inhibit another

beneficial insect of greater potential importance.

Evaluation of Control of Lantana Based on this Study

Generally, lantana was omnipresent in the area which was sampled, however, the presence of the insects on the plant definitely inflicted stress. This stress seemed effective, however, only when abiotic factors were producing a stress on the plant and less stress on the insect, such as is evidenced by the defoliation, and lack of flowering in site #1, which was likely due to the abundant tingid population. Continuous attack by lantana insects at stress periods can defoliate the plant and prevent seed production, thus limiting the spread of lantana and actually causing die-back in some cases. However, in the exposed sites where abiotic stress was periodically heavy, lantana was thickly abundant when the abiotic stress lessened and thus was not under control in these sites, even though numerous lantana insects were present. The judicious introduction of more species of lantana insects should be of value in lowering the density of the plant, since the stress applied by them possibly lowers the plant density, though only slightly. A concerted attack by a number of species of these stress-producers could bring about control.

SUMMARY AND CONCLUSIONS

In four sites, each at a different altitude in the Waianae Mountains, Oahu, Hawaii, stem sections of lantana, each consisting of approximately six inches of the growing tip, were collected. Ten of these stem sections, each from a separate plant, were collected weekly in each site for a period of 54 weeks, after which five stem sections were collected bi-weekly through the 65th week of sampling. These stem sections were examined throughly in the laboratory for introduced insects of lantana and their damage. Laboratory rearing and observation were conducted on the three most abundant species found in the field, Hypena strigata F., Teleonemia scrupulosa Stål, and Cremastobombycia lantanella Busck, in order to supplement the field data.

The positive correlations of populations of these insects with their specific type of damage was expected and occurred in all sites. The populations of H. strigata and T. scrupulosa changed more noticeably as the total abundance of leaf material changed than did the population of C. lantanella. This may have been due to the apparent interaction of T. scrupulosa and H. strigata populations with that of C. lantanella and due to the abundance of food and shelter material which was unaffected by the looper and the tingid. Potentially higher populations of C. lantanella than that found in this study are possible, according to separate reports by two other entomologists. The parasitization of

C. lantanella in this study as well as interaction between C. lantanella and the insects attacking lantana may account for this difference. The parasite population followed the change in host population very closely. The higher wind in site #2 may have had an adverse effect on the population of the eulophid parasites, and could account for the difference in per cent parasitization between sites #2 and #4.

There was a definite difference in the populations of insects, their damage, and the abundance of lantana leaf material and fruiting structures present. This was probably due to the differing conditions in the sampling sites. Site #1 was coolest and was surrounded by a forest area, site #4 was warmest, and was partially in the open and partially shaded. Sites #2 and #3 were openly exposed to sun and wind and had the highest wind velocities, the highest of all being in site #3. The highest rainfall was in sites #1 and #2, and the lowest in site #4.

Lantana was in worst condition in site #1, with many plants often being defoliated completely. The tingid population was relatively high here throughout the sampling period. Although greater fluctuations in the tingid populations and in the abundance of plant material occurred in the other sites, the lantana plants still produced lush foliage and fruiting structures. The tingid is probably the most important of the three insects present in the sites sampled here during the sampling period. The population of

Hypena was too low to be of very much consequence, although much damage could be inflicted by a single larva. It appeared that much of the leaf-feeding damage present, especially in site #1, was old damage, as evidenced by the per cent of damage present on lantana leaves when the Hypena population was so low that almost no larvae were collected. Although the population of C. lantanella was relatively high near the termination of sampling, there was little evidence of a suppression of plant material abundance by this insect, therefore its value is questionable.

Although abiotic stress produced the greatest fluctuations in leaf material and insect populations, site #1 in which abiotic stress was least evident, that is, the site with highest rainfall, lowest temperatures, lowest wind velocity, and least direct sunlight, was the site in which lantana control seemed most effective. Abiotic stress was no doubt affecting the plant during this period of defoliation, since defoliation was most evident in site #1 during the period of adverse conditions. Based on this, it would seem that biological control of lantana is most effective where stress on the plant is present, but stress on the insect population during this period is relatively low. The insect population seemed of more importance in effecting control here than did the abiotic influences.

APPENDIX

The insects attacking lantana but not exceptionally abundant during the sampling period are listed in table 7. The seed fly, Ophiomyia (Agromyza) lantanae is not listed here, but studies on it were conducted. The two lantana butterflies are included under the genus Strymon, since only the larvae were collected; they were present only during the period of flowering and fruiting. Others present only during flowering and fruiting were Platyptilia pusillidactyla, Epinotia lantana, and Ophiomyia lantanae. Of the insects feeding on the flowers and the flower and berry receptacles Epinotia was the most abundant, and probably the most effective. This insect was found to attack the flowers, the flower receptacles, the berry receptacles, and even the young green stem. Larvae of Epinotia were often found boring within the stem, hollowing it out, so that only the outer shell remained. Platyptilia and Strymon generally fed only on the flowers and were therefore probably less effective than Epinotia since they were present only during the periods of flowering.

Ophiomyia lantanae was present whenever newly developed and ripe berries were present. Ripe berries were collected in the field and kept in the laboratory for emergence of adult flies. The numbers emerging are presented in table 8. The greatest destruction of berries indicated was 25 per cent. The average per cent of the berries collected which were destroyed, based on one berry

or seed destroyed per emerging adult, was 8 per cent. One species of parasite, Zaischnopsis sp., emerged from the berries which were collected. With about 92 per cent of the berries surviving the attack of Ophiomyia, it is probable that it has little controlling influence on the production of new plants through seeds.

The leaf skeletonizer, Syngamia, was present in lower numbers than Hypena, but it is possible that some of the per cent of leaf material missing was attributable to this insect. Damage by Syngamia is rather characteristic, however, and relatively little of it was found in the field samples. Syngamia feeds by forming an enclosed shelter of the leaf and feeding inside it. Syngamia forms this shelter by tying a leaf margin to the central area of the leaf. Two species of parasites, Trathala flavo-orbitalis Cameron and Casinaria infesta Cresson, emerged from last instar Syngamia larvae.

The population of the other leaf skeletonizer Catabena esula was at such a low ebb that only two larvae were collected during the study presented here. At the time of this writing, however, this insect is more numerous, and it has been reported feeding on plants in the sampling area.

The stem gall fly, Eutreta xanthochaeta was more numerous during the first part of the sampling period. Galls of this insect have readily attracted the attention of visitors to lantana areas, and many of these people have

given credit to this insect for a severe attack on the plant. However, many of the galls which they saw were old galls, which probably affected the growing condition of lantana little. In fact, even the galls which contained living larvae seemed to produce no deleterious effect upon the plant. One species of parasite, Opius tryoni Cameron, which was originally introduced for biological control of fruit flies, and which also attacks the pamakani gall fly, emerged from a large gall on a stem section of lantana. All of these hosts of this parasite are in the same family, Tephritidae.

The other insects of lantana listed in table 7 are not yet established on Oahu, but may be found attacking lantana on some of the other Hawaiian Islands. The establishment of two of them, Octotoma scabripennis and Aerenicopsis championi, is still questionable.

Table 9 indicates insects found associated with lantana, other than the ones purposely introduced for control of the weed. Some of these feed on lantana, and others are merely present in the area and are temporarily resting on the plant.

Table 7.-Number of lantana insects besides three most abundant species in combined samples.

	Apr.-Aug. 1963	Sept.-Jan. 1964	Feb.-June 1964	Total
Syngamia haemorrhoidalis	45	22	19	86
Eutreta xanthochaeta	39	7	18	64
Strymon sp.	9	22	0	31
Epinotia lantana	45	42	27	114
Pltyptilia pusillidactyla	27	27	23	77
Catabena esula	1	0	0	1

Table 8.-Number of berries and emerging lantana seed fly, Ophiomyia lantanae, adults from field collected samples July - September, 1963.

Date	No. berries	No. seed flies	Per cent berries destroyed*	Emerging parasites**
July, 1963	61	2	3	0
	69	15	22	0
	117	28	24	0
	152	12	8	0
	195	11	6	0
	154	18	12	1
	84	1	1	0
Aug., 1963	46	0	0	0
	21	0	0	0
	49	1	2	3
	87	1	1	0
	68	2	3	1
Sept., 1963	70	5	7	1
	40	6	15	0
	120	7	6	0
	12	3	25	0
Total	1345	112	8***	6

* Based on destruction of one berry per fly.

** Zaischnopsis sp.

*** Average per cent berries destroyed.

Table 9.-List of arthropods besides those introduced for lantana control found associated with lantana in four sites in the Waianae Mountains, Oahu.

INSECTA

Order	Species	Remarks
Collembola	Salina maculata Folsom	Occasionally found on lantana leaves.
	Several other unidentified species also collected.	
Orthoptera	Conocephalus saltator Sauss.	
Psocoptera	Unidentified species.	
Thysanoptera	Haplothrips gowdeyi (Franklin)	In lantana flowers.
	Several unidentified species.	
Dermaptera	Unidentified species.	
Hemiptera (Heteroptera)	Tytthus mundulus Bredd.	Possibly feeding on eggs of Teleonemia.
	Nezara viridula var. smaragdula Fabr.	Pair collected in copula on lantana leaf. Others seen resting on lantana at a lower elevation.
Hemiptera (Homoptera)	Orthezia insignis Douglas	Feeding heavily on lantana during some periods.
	Phenacoccus gossypii Towns and Ckll.	On stem of lantana and within empty mines of C. lantanella.
	Hemiberlesia lataniae Signoret	Feeding on stem of lantana.
	Trialeurodes vaporariorum (Westw.)	Feeding on lantana; all stages found on leaves.
	Aphis gossypii Glov.	Aphids feeding on leaves and often found within empty mines of C. lantanella.
	Other unidentified species of aphids collected also.	
	Siphanta acuta (Walk.)	Probably transitory in area.
	Stictocephala festina Say	Probably transitory in area.
	Unidentified Cicadellidae	Probably transitory in area.

Table 9 (continued)

INSECTA

Order	Species	Remarks
Coleoptera	Pantomorus godmani (Crotch)	Probably transitory in area.
	Hyperaspis jocosa Muls.	Predaceous ladybug of Orthezia.
	Coelophora inaequalis	Adults
	Cryptolaemus montrouzieri Muls.	Adults and larvae found on lantana.
	Orcus chalybeus (Boisd.)	Adults on lantanae.
	Bruchus pruininus Horn	Transitory
	Unidentified weevil	
	Unidentified nitidulid	
Neuroptera	Chrysopa macrophya McLachlan	Larvae found on lantana.
Lepidoptera	Plusia chalcites Esp.	Feeding on lantana leaves.
	Unidentified geometrid larva	Feeding on lantana leaves.
Diptera	Chrysomyia sp.	Transitory
	Unidentified Sarcophagidae	Transitory
Hymenoptera	Apis mellifera (L.)	Visiting lantana flowers
	Trathala flavo-orbitalis Cameron	Emerged from last instar larva of Syngamia haemorrhoidalis
	Casinaria infesta Cresson	Emerged from last instar larva of Syngamia haemorrhoidalis
	Apanteles margineventris Cresson	Pupa collected on lantana leaf in area of high Syngamia population.
	Apanteles trifasciatus Muesebeck	Found associated with high populations of Syngamia and Hypena.
	Opius tryoni Cameron	Adult parasite emerged from gall of Eutreta xanthochaeta.
	Agathis hawaiicola Ashmead	Adult on stem section of lantana, associated with high populations of Syngamia and Hypena.
	Zaischnopsis sp.	Adults emerged from berries containing lantana seed fly.
	Hemiptarsenus semialbiclavus Girault	Parasite of C. lantanella.

Table 9. (continued)

Order	Species	Remarks
	INSECTA	
	Pnigalio externa Timberlake	Parasite of *C. lantanella*.
	Sympeisis vagans Timberlake	Parasite of *C. lantanella*.
	Zagrammosoma flaviolineata Crawford	Parasite of *C. lantanella*.
	Several unidentified species of ants	
	CRUSTACEA	
Isopoda	Unidentified pillbug	Collected with stem sections of lantana.
	ARACHNIDA	
Acarina	*Brevipalpis phoenicis* (Geijskes)	Feeding on lantana leaves.
	Amblyscius sp.	Predaceous mite.
	Tetranychus telarius (L.)	Feeding on lantana leaves.
	Tuckerella pavoniformis (Ewing)	Feeding on lantana stem.
	Anystis baccarum (L.)	Predaceous mite.
	Flower mites	In flower heads of lantana.
Araneida	Orb-web weaving, and jumping spiders (several species) were noted, but as yet unidentified	

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