RELATIVE ABUNDANCE AND DISTRIBUTION OF INSECT PESTS, ANTS AND OTHER COMPONENTS OF THE COCOA ECOSYSTEM IN PAPUA NEW GUINEA

BY P. M. ROOM* AND E. S. C. SMITH

Department of Agriculture, Stock and Fisheries, Popondetta, Papua New Guinea

INTRODUCTION

This paper describes an investigation carried out in the cocoa-growing area around Popondetta in the Northern District of Papua New Guinea. The aim of the study was to obtain information on the components of the cocoa ecosystem which might affect the abundance and distribution of the major insect pests of cocoa.

The environment

Climate

Popondetta has an average annual rainfall of 2425 mm, and monthly means for rainfall and sunshine are shown in Fig. 1. June, July and August are relatively dry months, but receive sufficient rainfall not to limit plant growth. (Charter (1941) and Beard (1944) suggest 100 mm per month as the lower limit for effective rainfall in the tropics.) However, during the present study an exceptionally prolonged drought occurred between June and October 1972 causing water stress in cocoa and shedding of leaves. Mean monthly maximum and minimum temperatures are 32°C and 22°C respectively, ±2°C.

Land form

The cocoa near Popondetta is grown on the volcanic outwash plain to the north-east of Mt Lamington. The gently sloping plain is dissected by numerous steep-sided stream valleys, and the black, sandy volcanic soil is well drained. A C.S.I.R.O. land form survey (Haantjens 1964) describes the Popondetta and surrounding land systems.

Vegetation

Subjective estimates of the proportions of the cocoa-growing area covered by various types of vegetation were as follows:

secondary forest/food garden clearing patchwork 30%
Saccharum spontaneum L./Imperata cylindrica(L.)Beauv grassland 30%
cocoa plantings 15%
coffee plantings 10%
rubber plantings 5%
Pometia pinnata Forst.F./Alstonia scholaris (L.) R.Br. primary forest 5%
roads and clearings 5%

* Present address: C.S.I.R.O. Cotton Research Unit, PMB Myallvale Mail Run, Narrabri, N.S.W. 2390, Australia.
Cocoa ecosystem

Cocoa was first planted in the Northern District in the early 1900s. In 1926 there were eleven 'plantations', having a total area of 20·2 ha, but these were soon abandoned (Crocombe 1964). Minor plantings were carried out in the mid-1930s, reaching in excess of 25 ha by the early 1950s (W. Searle, personal communication). By 1955 there were about 80 ha of cocoa in production. Between 1958 and 1961 large-scale plantings were made as an ex-soldier settlement scheme developed, and at the time of the present study about 4100 ha were in production while another 1200 ha of cocoa, badly damaged by pests, had been abandoned but still carried some trees.

![Graph showing monthly mean rainfall and hours of daily sunshine at Popondetta.]

**Fig. 1.** Monthly mean rainfall (mm) (—) and hours of daily sunshine (— — —) at Popondetta.

With the exception of several blocks of thinned forest, each of about 25 ha, all the post-1950 plantings have been on clear felled land on which a single species of shade tree has been established. *Leucaena leucocephala* (Lam.) de Wit was the most commonly used shade species, but in places *Erythrina* sp., rubber or coconut trees had been planted.

Insect pests

The earliest reports of pests attacking cocoa near Popondetta were made in 1955 when *Pantorhytes szevinanyi* Marshall (Coleoptera:Curculionidae), *Helopeltis clavifer* Walk. (Hemiptera:Miridae) and *Pseudodoniella laensis* Mill. (Hemiptera:Miridae) caused serious economic damage, and in 1958 *Amblypelta theobromae* Brown (Hemiptera: Coreidae) became important (Szent-Ivany 1961). In 1960 the first outbreak of *Tiracola plagiata* Walk. (Lepidoptera:Noctuidae) occurred (Catley 1962).

At present, *Pantorhytes szevinanyi* and *Helopeltis clavifer* still cause extensive economic damage, whereas *Amblypelta theobromae* and *Tiracola plagiata* have declined in importance and *Pseudodoniella laensis* is almost absent from the cocoa plantings.

*Pantorhytes szevinanyi* adults are flightless and they feed on the bark of young shoots and pod husks leaving broad scars. The eggs are laid in crevices on the bark, particularly around the jorquette, and the larvae bore into the trunk and branches. *Helopeltis clavifer,*
Amblypetta theobromae and Pseudodoniella laensis adults and nymphs feed on pods and young shoots, and are known colloquially as ‘podsuckers’. The thorax of Helopeltis clavifer adult males and females is either red or black. D. Leston (personal communication) has examined the male genitalia of both colour forms and found no evidence that there is more than one species present. Tiracola plagiata is highly polyphagous with over seventy known species of foodplant. On cocoa it feeds particularly on newly opened ‘flush’ leaves and soft growing points. Entwistle (1972) has described the biology of the above insect pest species.

MATERIALS AND METHODS

In addition to the pests mentioned above, the cocoa flush defoliating caterpillars Achaea janata L. (Lepidoptera:Noctuidae), Ectropis sabulosa Warr. (Lepidoptera:Geometridae) and Hyposidra talaca Walk. (Lepidoptera:Geometridae) were also sampled. Individually, these species rarely cause significant damage, but when their populations increase synchronously, particularly during Tiracola plagiata outbreaks, their combined effects can be important.

Other components of the cocoa ecosystem which might affect the abundance and distribution of pests fall into five categories (Table 2). Ants have long been recognized as the dominant predators of terrestrial insects in the tropics (McCook 1882), and Anoplolepis longipes (Jerdon) and Oecophylla smaragdina F. were recognized by Szent-Ivany (1961) as having a controlling effect on certain pests of cocoa in the Northern District of Papua. The other four species of ant and the three Hemiptera in Table 2 were chosen because they appeared to be the other most abundant predators in the cocoa canopy.

The only parasite studied was Nephrotoma spp. (Diptera:Tipulidae), larvae of which are ectoparasitic on Pantorhytes szentivanyi larvae.

The non-faunal components chosen gave the best description of the conditions under which each sample was taken in the time available. Several of the components were recorded as being in one of two possible states. For example, the cocoa canopy was good (continuous) in 122 of the 200 samples and bad (discontinuous) in the other 78 samples.

Sampling was stratified with respect to time and cocoa block location, but random within blocks. Four samples were taken in the morning and four in the afternoon on one day every two weeks from December 1971 to January 1973. Morning and afternoon samples were taken in two different blocks well separated from each other. Towards the end of the study specific blocks were sampled for a second time. Sampling sites within a block were chosen by walking from the centre of the block a random number of paces towards each of the four points of the compass.

At each sampling site the various non-faunal components shown in Table 2 were scored for presence or absence, and the three nearest cocoa trees were searched to head height for the bore holes of Pantorhyteš szentivanyi larvae. These bore holes were excavated and the average number of occupied channels per tree and the presence of Nephrotoma spp. larvae recorded. A ‘pyrethrum knockdown’ treatment was then carried out (Gibbs, Pickett & Leston 1968; Booker 1968). A 9 m² white collecting sheet was spread out on the ground; in alternate samples the sheet (which had been cut from the middle of one side to the centre) was either placed symmetrically around the base of a cocoa trunk, or in the middle of the space between four trunks. A 0·2% pyrethrum extract was applied to the cocoa above the sheet with a ‘Solo Mistblower’, and the pests and
selected predator species which fell onto the sheet during the following 30 min were
collected, identified and recorded.

Significant distributional associations for all the components recorded were detected
using a multiple $2 \times 2 \chi^2$ analysis computer programme (Room 1971) to process
the presence/absence data. The distributions of all components with respect to each of
the twelve months of the year, and then to each of four three-monthly periods, were
analysed using a CSIRO $2 \times n \chi^2$ programme.

RESULTS

Table 1 shows the abundance of pests in 200 samples taken between December 1971 and
January 1973 in terms of presence or absence, and the numbers of individuals. Pan-
torhytes szentivanyi was by far the most abundant pest in terms of both criteria, followed

<table>
<thead>
<tr>
<th>Pest</th>
<th>Frequency of occurrence</th>
<th>Total no. of individuals</th>
<th>Mean no. individuals per occurrence</th>
<th>Mean no. individuals per sample</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pantorhytes szentivanyi</em></td>
<td>adult 130</td>
<td>1064</td>
<td>8·2</td>
<td>5·3</td>
</tr>
<tr>
<td></td>
<td>larva 88</td>
<td>262</td>
<td>3·0</td>
<td>1·3</td>
</tr>
<tr>
<td><em>Helopeltis claviger</em></td>
<td>male 57</td>
<td>204</td>
<td>3·6</td>
<td>2·0</td>
</tr>
<tr>
<td></td>
<td>female 68</td>
<td>141</td>
<td>2·1</td>
<td>0·7</td>
</tr>
<tr>
<td></td>
<td>nymph 48</td>
<td>167</td>
<td>5·8</td>
<td>2·5</td>
</tr>
<tr>
<td><em>Amblypelta theobromae</em></td>
<td>male 14</td>
<td>14</td>
<td>1·0</td>
<td>0·07</td>
</tr>
<tr>
<td></td>
<td>female 14</td>
<td>15</td>
<td>1·0</td>
<td>0·07</td>
</tr>
<tr>
<td></td>
<td>nymph 46</td>
<td>90</td>
<td>2·0</td>
<td>0·45</td>
</tr>
<tr>
<td><em>Pseudodioniella laensis</em></td>
<td>larva 2</td>
<td>2</td>
<td>1·0</td>
<td>0·01</td>
</tr>
<tr>
<td><em>Tiracola plagiata</em></td>
<td>larva 40</td>
<td>667</td>
<td>16·7</td>
<td>3·3</td>
</tr>
<tr>
<td><em>Achaea janata</em></td>
<td>larva 17</td>
<td>46</td>
<td>2·7</td>
<td>0·2</td>
</tr>
<tr>
<td><em>Ectopis sabulosa</em></td>
<td>larva 60</td>
<td>454</td>
<td>7·6</td>
<td>2·3</td>
</tr>
<tr>
<td><em>Hyposidra talaco</em></td>
<td>larva 30</td>
<td>163</td>
<td>5·4</td>
<td>0·8</td>
</tr>
<tr>
<td><em>Aconthotyla sp.</em></td>
<td>larva 102</td>
<td>758</td>
<td>14·9</td>
<td>3·8</td>
</tr>
</tbody>
</table>

by *Helopeltis claviger*, *Tiracola plagiata* (highly aggregated) and *Ectopis sabulosa*.
*Amblypelta theobromae* occurred in a relatively large number of samples, but usually
only as a few individuals. *Hyposidra talaco* was less common and moderately aggregated,
while *Achaea janata* was scarce and *Pseudodioniella laensis* was very scarce.

The numbers of samples in which the other cocoa ecosystem components were present
are shown in Table 2. *Technomyrmex albipes* and *Anoplolepis longipes* were much the
most abundant predators, and *Leucaena leucocephala* the most commonly used shade
tree.

Results of the inter-component association analysis are shown in Figs 2, 3, 4 and 5.
Figs 2 and 4 could have been combined but have been kept separate for clarity. In each
figure a line joining two components indicates that the components were significantly
associated at the probability level indicated. Components included in the analysis not found to have any significant associations are listed (Figs 2 and 3).
There were no significant associations of components with month and only a few with quarter. Therefore the effects of changing seasons were slight compared with the effects of the other variables. This was apparent during sampling as the variance between

<table>
<thead>
<tr>
<th>Pest predator</th>
<th>Frequency of occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technomyrmex albipes (F.Sm.) (Hymenoptera: Formicidae)</td>
<td>114</td>
</tr>
<tr>
<td>Anoplolepis longipes (Jerdon)</td>
<td>80</td>
</tr>
<tr>
<td>Oecophylla smaragdina F.</td>
<td>28</td>
</tr>
<tr>
<td>Odontomachus similimus F.Sm.</td>
<td>18</td>
</tr>
<tr>
<td>Rhytidoponera araneoides (Le Gillou)</td>
<td>22</td>
</tr>
<tr>
<td>Monomorium floricola (Jerdon)</td>
<td>38</td>
</tr>
<tr>
<td>Dindymus pyrrhocorus (Boisd) (Hemiptera: Pyrrhocoridae)</td>
<td>11</td>
</tr>
<tr>
<td>Pristhecanthus sp. Reduviidae</td>
<td>31</td>
</tr>
<tr>
<td>Euagrus sp.</td>
<td>22</td>
</tr>
<tr>
<td>Pest parasite Nephrotoma spp. larva (Diptera:Tipulidae)</td>
<td>43</td>
</tr>
<tr>
<td>Shade tree species (&gt; 1 present in some samples) Leucaena leucocephala (Lam.) de Wit</td>
<td>136</td>
</tr>
<tr>
<td>Cocos nucifera L.</td>
<td>19</td>
</tr>
<tr>
<td>Thinned forest</td>
<td>16</td>
</tr>
<tr>
<td>No shade</td>
<td>52</td>
</tr>
<tr>
<td>Cocoa condition</td>
<td></td>
</tr>
<tr>
<td>Canopy good (continuous)</td>
<td>122</td>
</tr>
<tr>
<td>Flush present</td>
<td>89</td>
</tr>
<tr>
<td>Pod sucker damage heavy</td>
<td>14</td>
</tr>
<tr>
<td>Non-biotic</td>
<td></td>
</tr>
<tr>
<td>Month (January–December) (for most) 16 each</td>
<td></td>
</tr>
<tr>
<td>Sample taken before noon</td>
<td>105</td>
</tr>
<tr>
<td>Sample taken when sun was shining</td>
<td>124</td>
</tr>
<tr>
<td>Top shade heavy</td>
<td>52</td>
</tr>
<tr>
<td>Knockdown sheet placed around trunk</td>
<td>100</td>
</tr>
</tbody>
</table>

samples taken in any one month was always high. This could be overcome by sampling more intensively and extensively in each month, or by choosing a single block of cocoa having a combination of components for which phenological data are required and by taking monthly samples. The few meaningful associations with quarter are given in Fig. 6. The proportion of samples with sunshine, pod sucker damage, Tiracola plagiata, Achaea janata and Pristhecanthus sp. increased in the first three quarters and then decreased in the final quarter of the year. Cocoa flush was present in 38% of samples in the first three quarters, and increased in the last.

DISCUSSION

Stratified random samples were taken over the whole cocoa-growing area near Popodetta over a full seasonal cycle. Because of this the data in Tables 1 and 2 probably
Fig. 2. Faunal associations shown to be positively significant at <5% level by \( \chi^2 \) analysis of 200 cocoa insect knockdown samples. Species listed were not associated.
Odontomachus simillimus
Amblypelta theobromae ♀
Amblypelta theobromae nymph

Fig. 3. Faunal associations shown to be significantly negative at <5% and 10% levels by $\chi^2$ analysis of 200 cocoa insect knockdown samples (dotted lines = 5–10% level). Species listed were not associated.
Fig. 4. Positive associations between faunal elements and other environmental components shown to be significant at <5% level by \( \chi^2 \) analysis of 200 samples from cocoa plantings.
Fig. 5. Negative associations between shade tree species and other environmental components shown to be significant at <5 and 10% levels by $\chi^2$ analysis (dotted lines = 5–10% level).
give an accurate assessment of the relative abundance of most of the selected cocoa ecosystem components during 1972. However, figures for adult *Amblypelta theobromae* are too low because they tended to take flight as soon as spraying was started, and figures for *Pantorhytes szentivanyi* larvae were low because the first three instars could not be detected.

In addition to being the most abundant pest, *P. szentivanyi* also causes more damage per individual than any of the other pests. This is because larvae boring into a trunk,

![Graph](image)

**Fig. 6.** Percentage frequencies of occurrence of six cocoa ecosystem components shown to vary significantly at <5% level with quarter.

jorquette or branch permanently weaken a tree and often kill it, whereas the effects of podsuckers and flush defoliating caterpillars are more ephemeral and probably only kill very young trees. Thus, control of *P. szentivanyi* is of first priority to ensure survival of trees while control of the other pests is secondary, though essential to ensure economic production over any particular period.

When considering the relative importance of *Helopeltis clavifer* and *Amblypelta theobromae* as agents of pod and shoot damage, although the former is more abundant, an individual of *A. theobromae* probably causes more damage than an individual of *Helopeltis clavifer*. Brown (1958) attributes extensive damage caused by small *Amblypelta*
theobromae populations to the injection of toxins accentuating the physical effects of feeding.

In Figs 2-5, lines connecting components represent distributional relationships and do not necessarily imply direct biological relationships. For example, in Fig. 2 Pantorhytes szentivanyi larva is linked to Nephrotheta spp. and this is known to represent a direct biological relationship because the latter parasitizes the former. In the case of Pantorhytes szentivanyi adult linked to Rhytidoponera araneoides, however, the relationship is probably indirect because both are shown to be negatively associated with Anoplolepis longipes (Fig. 3). These negative associations are known to represent direct biological relationships: competition for foraging area between the two ants, and harassment of Pantorhytes szentivanyi adults by Anoplolepis longipes causing the former to move out of the ant’s foraging territory (Baker 1972).

In Fig. 4 several associations are shown which can only represent biases which developed during the sampling programme because it is already known that the distributions of the components involved are not dependent on each other. These associations are

\[ \text{Technomyrmex albipes} \]
\[ \text{Leucaena leucocephala} \]
\[ \text{Podsucker damage heavy—P.M.} \]
\[ \text{Cloudy—no shade} \]
\[ \text{Cocoa canopy good—A.M.} \]
\[ \text{Anoplolepis longipes} \]
\[ \text{Thinned forest shade} \]
\[ \text{Pantorhytes szentivanyi larva—canopy sample} \]

and must be taken into account when interpreting other results of the association analysis.

Fig. 2 shows two groups of four faunal components in which each member of a group is linked together. These groups are circled in the figure, and were used as a starting point for the interpretation of the association analysis results. Achaeta janata is common to both groups, one of which consists of the four flush defoliating caterpillars, while the other group contains Pantorhytes szentivanyi adult, larva and larval parasite.

Fig. 4 shows that all the flush defoliating caterpillars were positively associated with Leucaena leucocephala shade and afternoon sampling. It has already been pointed out that the p.m.—L. leucocephala association must represent a sampling bias, so it is likely that the caterpillar group has a direct relationship with L. leucocephala only. This is acceptable since Tiracola plagiata, Hyposidra talaca and Ectropis sabulosa are known to feed on Leucaena leucocephala (Dun 1967; Smee 1963), and Dun (1967) noticed that in areas where cocoa under L. leucocephala was adjacent to cocoa under thinned forest shade, the former crop often suffered badly from defoliating caterpillars while the latter did not.

None of the caterpillars was positively associated with cocoa flush, and Tiracola plagiata was negatively associated with it (positive with no cocoa flush in Fig. 4). It is probable that Leucaena leucocephala is preferred to cocoa by all the caterpillars, and during the study there was an abundant supply of the preferred host because caterpillar populations were low. Caterpillars knocked down by the pyrethrum treatment had
probably been feeding on the shade tree and not on the cocoa, and were not associated with the flushing state of the cocoa. The negative association between Tiracola plagiata and flush was probably caused by another factor not studied which depressed T. plagiata populations at the end of the long dry season when the cocoa experienced an increase in flushing (see Fig. 6).

Positive association between Pantorhytes szentivanyi adult, larva and Nephrotoma spp. was to be expected on empirical grounds, but no clear reason for the inclusion of Achaea janata in the Pantorhytes szentivanyi group is indicated by Figs 3, 4 or 5. Again, a factor not included in the study may have caused P. szentivanyi and Achaea janata to have been similarly distributed.

The next best-defined group in Fig. 2 comprises Helopeltis clavifer male, female, nymph and Amblypelta theobromae nymph. This group has four links with the caterpillar group dealt with above. Fig. 4 shows that every member of this pod sucker group is positively associated with Leucaena leucocephala shade. It is likely that the relationship with L. leucocephala is indirect because the tree is not known as a pod sucker host; some factor conducive to pod sucker survival presumably being present more often under L. leucocephala than other shade trees. The association between the pod sucker and caterpillar groups thus appears to reflect the association of both groups with L. leucocephala shade rather than any direct relationships.

Helopeltis clavifer male, female and nymph and Amblypelta theobromae male are linked to heavy pod sucker damage which in turn is linked to Leucaena leucocephala shade (Fig. 4). This relationship has not been reported before, and constitutes additional evidence of the unsuitability of L. leucocephala as a shade tree for cocoa.

Anoplolepis longipes, Oecophylla smaragdina and Technomyrmex albipes are the only common dominant (higher density of individuals per unit area than other species present) ants in the cocoa studied, Oecophylla smaragdina being significantly less abundant than the other two species. Earlier work on cocoa in Ghana (Leston 1971; Room 1971; Strickland 1951), and on coconuts in Zanzibar (Way 1953) and in the Solomon Islands (Brown 1959), has shown that the foraging territories of dominant ants are distributed in a mutually exclusive way with respect to one another. Hence, the negative associations shown in Fig. 3 between Anoplolepis longipes and the other two dominant ants were expected, while the lack of a negative association between Technomyrmex albipes and Oecophylla smaragdina was surprising.

Fig. 3 also shows that Technomyrmex albipes has no negative association with pests, while Oecophylla smaragdina is negatively associated with Helopeltis clavifer, Tiracola plagiata and Achaea janata. Baker (1972) has already demonstrated that Anoplolepis longipes controls Pantorhytes szentivanyi by displacing it from foraging territories, so it is apparent why Anoplolepis longipes is linked to good cocoa canopy and Technomyrmex albipes is linked to bad cocoa canopy (Fig. 4). Pantorhytes szentivanyi is the single most important cause of cocoa degeneration and it is distributed in the same way as Technomyrmex albipes with respect to Anoplolepis longipes. In addition, it can be seen that Pantorhytes szentivanyi adult and larva are linked to no cocoa flush, presumably because of their debilitating effect on cocoa.

The positive association between Anoplolepis longipes and Acanthotyta sp. (Fig. 2) cannot be explained. Though Acanthotyta sp. is abundant on cocoa (Table 1) its biology and ecology have not been studied because it causes no economic damage.

Odontomachus simillimus has no significant associations (Figs 2–5) which was not unexpected because this ant nests in the ground and only occasionally forages on the
lower parts of tree trunks. It has a very wide tolerance of environmental conditions, being found in forest as well as savanna, which might explain the absence of associations with non-faunal components.

Two main points emerge from Fig. 5. First, the positive association between *Leucaena leucocephala*, pod suckers and caterpillars is mirrored by the negative associations of no shade to pod suckers and caterpillars, and of thinned forest shade to pod suckers. Secondly, *Cocos nucifera* shade is strongly negatively associated with *Pantarhytes szentivanyi*. The reasons for this are not known.

The proportion of samples taken with the sun shining was highest in the middle of the dry season from June to October, and the proportion of cocoa trees flushing remained constant until wet weather returned in the final quarter, when it increased by 25% (Fig. 6). Hurd & Cunningham (1961) showed that cocoa in Ghana experienced a flushing cycle with a periodicity of approximately eleven weeks, and J. D. Majer (personal communication) has recently confirmed this periodicity providing that no inhibitory factor such as excessive top shade is present. Thus the apparently constant level of flush over the first three quarters shown in Fig. 6 probably reflects a constant mean of three flushing cycles. MacDonald (1932, 1933) in Trinidad, and Hurd & Cunningham (1961), point out that increased flushing often coincides with the arrival of rain after a dry spell as appears to be the case in the final quarter shown in Fig. 6.

The incidence of heavy pod sucker damage, *Tiracola plagiata*, *Achaea janata*, and *Pristhecanthus* sp. all reached a maximum towards the end of the dry season and then dropped rapidly in the final quarter. Smith (1972) reported a continuous increase in *Helopeltis clavifer* numbers until the end of the dry season, when a rapid decline in population size took place. He suggested that meteorological factors were more directly responsible for controlling population size than biotic factors. The nature of the relationship between seasons and population size in *Tiracola plagiata*, *Achaea janata* and *Pristhecanthus* sp. is not known. *Tiracola plagiata* is attacked by the parasites *Exorista falloxy* Meig. (Diptera: Tachinidae) and *Echthromorpha insidiator* Smith (Hymenoptera: Ichneumonidae) and by the fungus *Spicaria rileyi* (Farlow) (Catley 1962) and it is possible that higher rainfall favours one of these.

**IMPLICATIONS FOR COCOA GROWING IN THE NORTHERN DISTRICT OF PAPUA NEW GUINEA**

Recommendation of insecticides to control cocoa pests in the Northern District of Papua New Guinea has been a failure. In particular the recommendation of trichlorphon against *Pantarhytes szentivanyi* has not made cocoa growing economically feasible for a number of expatriate soldier settlers in the area. The reasons for this seem to be largely socio-economic, but the inefficiency of this insecticide treatment must take part of the blame. Some of the factors which appear to have affected both indigenous and expatriate growers are as follows.

(1) Lack of motivation to apply chemicals according to recommendations partly because of:

(a) lack of knowledge about pests and chemicals by growers;
(b) the occasional low value of cocoa making chemical application economically impossible at times for undercapitalized growers.
The need of the cocoa/Leucaena leucocephala ecosystem for continuous intensive management to prevent breakdown partly because of:

(a) the ecological instability of all agricultural systems which entail the artificial maintenance of a simplified ecosystem in a biotope which is normally occupied by a more complex climax;

(b) the occurrence of organisms in the Northern District which happen to be particularly devastating to cocoa grown under L. leucocephala.

It can be seen that the present situation is similar to that described for cocoa in West Africa by Clark et al. (1967) in that it is the outcome of events one could not 'anticipate, because what might appear in hindsight to be a consistent causal chain is in fact no more than a highly improbably, cumulative result of an infinite succession of random steps; recognize, before the situation had developed enough to reveal its full economic implications and biological complexity; or avoid'.

Problems of anticipation, recognition and avoidance are ever present, and it is the element of clairvoyance involved which makes the recommendation of specific agricultural practices such a hazardous undertaking. The problems of cocoa in the Northern District have now been recognized, in outline at least, and the present study has suggested some specific ecological approaches aimed at avoiding continuation of these problems.

(1) Stop the use of L. leucocephala as a shade tree as was recommended by the Department of Agriculture in 1965.

(2) Investigate the use of coconuts as shade for minimizing Pantorhytes szentivanyi populations. Coconuts have been used successfully as shade on the Gazelle Peninsula of New Britain in Papua New Guinea, and they have been recommended for use in Ghana (Leston 1973) because they tend to support large populations of Oecophylla which have a controlling effect on cocoa capsid populations.

(3) Develop the use of Anoplolepis longipes to control Pantorhytes szentivanyi. A number of growers have successfully used this method of control for some time; a few have been unable to maintain high ant populations and ways of overcoming this problem need to be found. Principles relating to the use of ants as pest control agents in tropical tree crops are described by Leston (1973) and Room (1974).

(4) Search for pod sucker control measures which are compatible with (2) and (3).

Even if the above proposals were found to be effective, the problem of anticipation would still remain. It could not be foreseen when, for example, the pod suckers would become resistant to insecticides which are relatively harmless to ants, or when an insect not presently a pest might attain pest status, or whether a plant virus might adapt to cocoa from some indigenous host.

Attempts should be made to use ecological principles to try to minimize the effects of present and future pests. One such principle suggests that the more heterogenous the ecosystem the more stable it is (Voute 1964; Odum 1970). Catley (1962) deplored the growing of cocoa as a monoculture under a shade monoculture around Ppseudetta because the lack of diversity allowed pest fluctuations to be catastrophically violent. Unfortunately, diversity in a crop system is frequently linked with reduced productivity of the crop per unit area and reduced efficiency of harvesting. Intercropping as part of the diversification programme could offset losses to some extent, as recommended by Leach, Shepherd & Turner (1971) for Malaysia, and Leston (1973) for Ghana. In general terms, however, a balance has to be sought between increased stability through diversity
on one hand, and increased productivity through decreased diversity on the other. The less diverse the ecosystem, the more intensive is the management (or the greater the energy input) needed to maintain it in its artificial state. Thus the position of the balance between diversity and productivity should be chosen to suit the socio-economic conditions under which the growers are expected to operate. In particular, indigenous smallholders should not be advised to grow cocoa in exactly the same way as expatriate owners of large plantations, and vice-versa.

ACKNOWLEDGMENTS

Field work and analysis were carried out while working for the Papua New Guinea Department of Agriculture, Stock and Fisheries. A grant from the Cocoa, Chocolate and Confectionery Alliance supported the senior author when writing this paper.

SUMMARY

(1) Cocoa has been grown on a large scale around Popondetta in the Northern District of Papua New Guinea since 1958. Cocoa pest problems were present in the area before that time, but while most of the pests continue to be damaging, the mirid _Pseudodoniella laensis_ is no longer important.

(2) A programme of eight, stratified random, pyrethrum knockdown samples taken every two weeks between December 1971 and January 1973 showed that the weevil _Pantorhytes szentivanyi_ was the most abundant pest present. It is also the most important because the larvae cause permanent damage and sometimes kill trees by boring into the trunk, jorquette and branches. The pod and shoot damaging bugs _Helopeltis clavifer_ and _Amblypelta theobromae_ were less abundant, but sufficient to cause economic loss. Larvae of the moth _Tiracola plagiata_ were more abundant than _Amblypelta theobromae_, but it was concluded that many of the specimens taken had been feeding on the shade tree _Leucaena leucocephala_ and not on cocoa. Control of _Pantorhytes szentivanyi_ was concluded to be the first priority.

(3) Analysis of the relative distributions of pests, ants and other components of the cocoa ecosystem confirmed earlier work which showed that the ant _Anoprolepis longipes_ controls _Pantorhytes szentivanyi_. A group of four cocoa flush feeding moth larvae _Tiracola plagiata, Achaea janata, Hyposidra talaca_ and _Ectropis sabulosae_, was found to be associated with the use of _Leucaena leucocephala_ as shade tree, as was damage by the bugs _Helopeltis clavifer_ and _Amblypelta theobromae_. Implications of the study for cocoa growing in the Popondetta area are discussed, and suggestions for future research include the use of _Anoprolepis longipes_ and coconut shade to minimize _Pantorhytes szentivanyi_ populations.

REFERENCES


_Booker, R. H. (1968)._ A list of insects and spiders associated with cacao (_Theobroma cacao_) in a plantation in Western Nigeria. _Niger. ent. Mag._ 1, 81–6.


(Received 26 April 1974; revision received 11 July 1974)