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ECOLOGICAL ASPECTS OF PEST CONTROL IN MALAYSIA

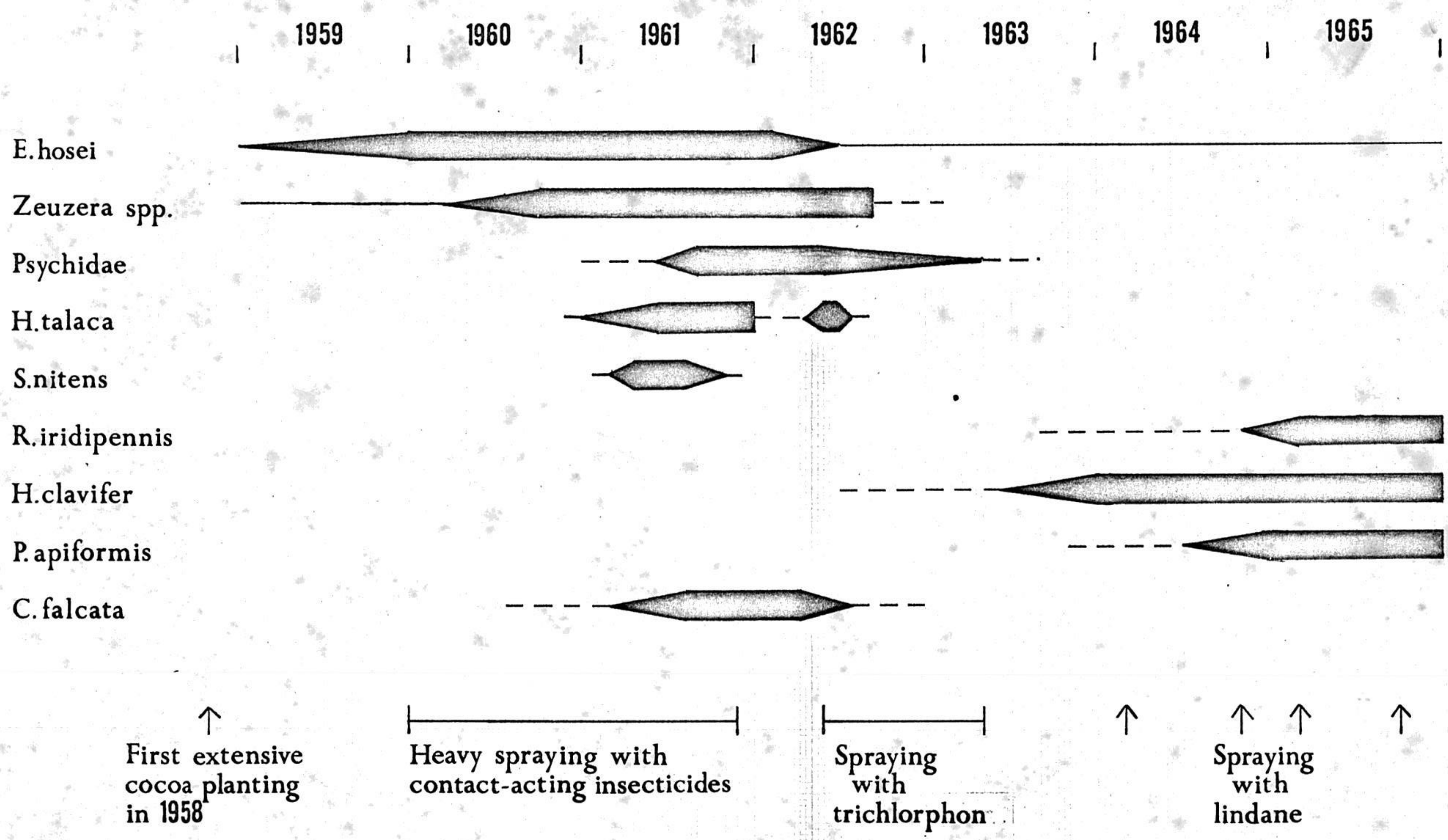
by

Gordon R. Conway

CAPTIONS

Figure 1. The sequence of pest outbreaks at the Cocoa Research Station, Quoin Hill, Sabah. Note that this is very schematic; the bars do not directly indicate the size of the population, only the periods during which the species was of economic importance as a pest.

Table 1. Spraying program of a representative field at the Cocoa Research Station, Quoin Hill, 1960-1965. (Detailed records are not available before November 1960, but the heavy spraying began some ten months earlier.)


1959
1960
1961
1962
1963
1964
1965
E. hosei
Zeuzera spp.
Psychidae
H. talaca
S. nitens
R. iridipennis
H. clavifer
P. apiformis
C. falcata
First extensive cocoa planting in 1958
Heavy spraying with contact-acting insecticides
Spraying with trichlorphon
Spraying with lindane

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Year	Month	Endrin	Dieldrin	DDT	BHC (Techn[illegible]	Lindan[illegible]	Lead Arsen[illegible]	Trichl[illegible] phon	[illegible]
1960	November			+	+				+
	December	(+)							
1961	January	+	(+)						
	February	+	+						
	March				+		+		
	April								
	May				+		+		
	June		+	+			+		
	July								
	August			+	+		+		+
	September								
	October								
	November				+				
	December			+					
1962	January			+					
	February		+	+			+		
	March								
	April								
	May							+	
	June							+	
	July							+	
	August								
	September							+	
	October							+	
	November							+	
	December							+	
1963	January								
	February							+	
	March							+	
	April							+	
	May						+		
	June								
	July								
	August								
	September								
	October								
	November								
	December								
1964	January								
	February				+				
	March					+			
	April								
	May								
	June								
	July								
	August								
	September								
	October								
	November					+			
	December								
1965	January								
	February								
	March					+			
	April								
	May					+			
	June								
	July					+			
	August								
	September								
	October								
	November								
	December								

+ = one application, (+) = two applications.

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Malaysia, comprising mainland Malaya and the Borneo states of Sabah and Sarawak, lies just north of the equator. It has a hot, humid climate with average daily temperatures varying from 70° to 90°F and, in most areas, an annual rainfall of over 100 inches without any very marked dry season. Tropical rainforest is the predominant natural climax vegetation, and it still covers over 70% of the land area. Wet rice, rubber, oil palms, and coconuts constitute the main crops grown; in certain localities there are also sizable acreages of cocoa, manila hemp (abaca), sago, and pepper. Vegetables and fruit are widely grown but rarely other than on a small scale. Shifting cultivation based on dry rice, tapioca, vegetables, and bananas is still commonly practiced, particularly in the Borneo States (20% of the area in Sarawak); in consequence secondary forest is widespread and in some areas, where the land has deteriorated seriously, extensive stands of lallang grass (*Imperata cylindrica*) are present.

Since the 1920's and apart from the period of the Second World War, there has been continuous research on Malaysian pests and their control. Before the war the country was served by a number of distinguished entomologists who were mainly concerned with the pest problems of rice, coconuts, vegetables, and fruit. Like that of their colleagues working in the then Dutch East Indies,

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their approach to these problems was dominated by ecological considerations (see, for example, the papers of Corbett [12, 13], Miller [22], and Pagden [23], and the books of Dammerman [14] and Kalshoven [19]). Much of their work was devoted to elucidating pest life histories and their relation to the crop and the season. They also spent considerable effort in discovering the natural enemies of these pests and in working out their habits and life cycles. Sound cultural practices, such as the careful timing of planting and the destruction of crop residues, commonly formed the basis of their control recommendations. They relied heavily on encouraging natural enemies wherever possible, and often quite elaborate steps were taken to ensure the presence in a crop of particular parasites or predators. Light trapping of moths was a common practice and larvae, beetles, and bugs were often collected by hand or with the aid of simple, but effective, devices. Simple pesticides such as the arsenicals, derris, and various soap and kerosene mixtures were also much used. It is difficult to judge, now, just how successful these control measures really were. Many outbreaks probably were prevented and certainly if they did develop they were brought to an end much sooner than would have occurred naturally. With many pests if the damage is not too prolonged, the crop can recover and compensate for much of the loss. But, for chronic pest problems, such as those on rice, the control measures seem to have been only marginally effective. Undoubtedly, the best results were obtained on small-holder vegetable and fruit crops, and here the patience and intensive care of the grower and his family were the decisive factors.

After the war the new synthetic insecticides, DDT, BHC, dieldrin, endrin, malathion, and others became available. Their use in Malaysia grew slowly at first but has accelerated in the last ten years with the establishment of several vigorous concerns specializing in the sale of agricultural chemicals. The benefits these pesticides have wrought have been considerable. BHC, DDT, and dieldrin have been particularly effective against rice pests (20); in Sabah dieldrin has provided a cheap and extremely effective means of combating the locust outbreaks which had previously been so serious; and DDT and dieldrin have been the main instruments of the successful malaria control campaigns. However, my experiences and those of other entomologists in Malaysia suggest that the increasing reliance on these pesticides has not been wholly beneficial. Used indiscriminantly and without regard to the ecological factors of the situation, they may aggravate existing pest problems or create new ones, and they can produce unwanted and far-reaching side-effects.

In the following I have attempted to summarize some of these experiences. Inevitably, much remains open to conjecture. Entomologists confronted with immediate pest problems have often not the time or resources to unravel all the complex relationships which might seem relevant or to obtain firm proof of deductions based on cursory observations. Frequently, the only proof lies in the success of control measures based on these deductions.

Cocoa Pests in Sabah

Cocoa is a new crop in Sabah; the first commercial plantings were made in 1956. Ten years later there were some 6,000 acres under the crop, mostly in the Southeast corner of the State at Quoin Hill and Tiger where there are large areas of volcanic soils. In 1958 a Cocoa Research Station was set up by the Department of Agriculture at Quoin Hill and as Entomologist in the Department from 1961 to 1966, I was concerned with cocoa pest problems there and through the country. Brief references to this work have appeared in a number of previous papers (7, 8, 10, 11) and a fully detailed account is to be published shortly (9).

The soils which were chosen for cocoa planting naturally support rich stands of primary dipterocarp forest. In the areas to be planted the forest species yielding commercial timber were first felled and extracted by levering on runways to prevent soil damage. Some second story trees and regenerating dominants were left as top shade for the cocoa and the remainder were felled, partially cut and left to decompose. Secondary forest trees such as Macaranga, Mellotus, and Acanthocephala were then allowed controlled growth to provide the main shade.

As the cocoa acreage has grown, the primary forest has been pushed back, but the cocoa remains essentially an island within it. Much of the cocoa is thus physically close to primary forest and, in some parts, at the forest edge, along roads, and where there are uncultivated clearings it also borders on uncontrolled secondary scrub or forest.

Early Pests, 1958-1960

The first serious insect pests at the Cocoa Research Station were borers--a Ring Bark Borer, Endoclita hosei, which is the larva of a hepialid or swift moth, and two Branch Borers, Zeuzera spp., the larvae of cossid moths. The former bores into the young cocoa tree, either at ground level or at the fork and from the shelter of the tunnel feeds on the bark, girdling the trunk and often causing the death of the tree. The Branch Borers, as their name implies, tunnel along the upper branches and shoots. During their life cycle, they usually make several borings, attacking larger branches as they grow. Attacked branches usually die above the boring site. Neither pest was initially present in large numbers but the extensive damage caused by individual Ring Bark Borer larvae made them immediately serious pests. During the first two years of growth, when the cocoa is at its most susceptible, deaths often amounted to 20% or more per field. The earliest attempts at control were by hand; laborers were employed to seek out fresh borings and destroy the larvae inside by inserting a wire or by introducing paradichlorbenzene crystals or a dieldrin mixture. This method, though, soon became too costly in labor and in 1959 spraying with high concentrations of insecticides was adopted. Dieldrin or DDT were applied as high volume sprays to the branches, fork and trunk (dieldrin at 15 to 25 ounces and DDT at 12 to 15 ounces active ingredient per acre). This did give some degree of control, but the inaccessibility of the borer larvae precluded very high kills.

In 1959 several other pests, including various leaf-eating caterpillars, aphids, and mealybugs became noticeable. Again, these were present in very low numbers, but they were felt to be a potential danger and in early 1960, in addition to the spraying for borer control, further general spraying was carried out as a prophylactic measure. Dieldrin, endrin, DDT, BHC, lead arsenate, and a white oil (Albolineum) were variously used, either in combination or alone. Applications were irregular but often very frequent so that during the two years 1960 and 1961 the cocoa received a very heavy insecticide coverage (Table 1).

Major Pest Outbreaks, 1961

The situation, however, gradually became worse (Fig. 1). First, the Branch Borers increased, becoming abundant by the beginning of 1961, the incidence of attack rising to one new boring per six trees per month. Then, not long afterwards, outbreaks also occurred of three other pests. Two were leaf-eating caterpillars--one a looper or geometrid, Hyposidra talaca; the other a nettle caterpillar or limacodid, Setora nitens, which was hitherto known in Sabah only as a major, periodic pest of coconuts. The third outbreak was of a flatid or plant-hopper, Colobesthes falcata. All of these became very abundant, the hopper so much so that on being disturbed the adults, which resembled moths, rose in large clouds from the branches. Both the leaf-eating caterpillars caused considerable damage to the young flush leaves, attacking particularly those leaves which were newly green. The plant-hopper nymphs fed by sucking the shoot tips, flower stalks, and young green pods, but the damage this caused was of lesser consequence.

In July of 1961 a fourth outbreak occurred which proved to be the most serious of all. This consisted of several species of bagworms (Psychidae), the principal ones being two species of Clania and an unidentified species of Mahasena. Bagworms are unusual insects with a number of characteristics which make them particularly important pests. As the name implies, the larval bagworm lives in a bag of silk which is skillfully covered with pieces of leaf or short lengths of twig. When moving or feeding, the head, thorax, and legs only are exposed and on being disturbed, the whole larva quickly retracts into the bag, closing up the open end. The bag is retained throughout the larval and pupal periods; as the larva grows, it is extended and new leaves or twigs are added. The adult male is a typical winged moth, but the female is wingless and "degenerate" being little more than a large, egg-producing sac which stays within the pupal case inside the bag. Numerous eggs are produced (from 3,000 to 4,000 in the case of the related Mahasena corbetti [35]), and they too are retained in the bag. On hatching the young larvae make their way onto the surface where they quickly proceed to spin their own bags covering them with material from that of the parent. They also produce copious silk threads and, with the help of these, are blown away, often over a considerable distance.

The bags give the insect considerable protection throughout its lifetime, not only from the weather but also, apparently, from insecticides. In a series of replicated trials with bagworms on sprayed cocoa seedlings, they showed almost complete resistance to DDT, BHC, dieldrin, diazinon, and dimethoate, all applied to run off at 0.25% active ingredient or more. Some feeding occurred in the trials, but apparently the amount of insecticide so ingested was not sufficient to cause mortality, while the bags prevented the insecticides from acting through contact. Removal of the larvae from their bags and dipping them in the same insecticides, at the previous concentrations, gave rapid and complete kills as compared with control larvae dipped in water.

The damage caused by bagworms is very great, since not only are they voracious feeders, but also large areas of leaf surface are chewed off to make the bags. As the defoliation progresses, extensive dieback of the branches occurs and the trees respond by proliferation of shoots from unaffected buds which are then in their turn eaten. With extreme defoliation, the bagworms turn to feeding on the bark of the branches and trunks. Because of the reproductive and dispersal characteristics, outbreaks are typically in the form of explosions which radiate out from a central focus. The outbreak of 1961 began in one field at the Cocoa Research Station and rapidly spread in this fashion. By late 1961 some 70 acres were affected, and repeated defoliation had produced large numbers of bare and dying trees.

Spraying with DDT, dieldrin, and the other insecticides continued throughout 1961, but the bagworm outbreak persisted unaffected. Some attempt at hand collection was made, but this proved ineffective and very costly. The other outbreaks also continued, with the exception of the nettle caterpillar, S. nitens, which died out in September.

Cessation of Spraying, End of 1961

Then, toward the end of 1961 with the pest situation extremely serious, a decision was made to stop the spraying. This was based upon a number of considerations. Firstly, although some pests had been present since the beginning of cocoa planting, it was only after the introduction of the heavy spraying program that the major outbreaks occurred. Secondly, nearly all the insecticides used hitherto were of the broad-spectrum, contact-acting type: that is they killed most insects which came in contact with them. Since parasitic and predatory insects tend to explore widely, they are more likely to contact insecticide deposits than are pest insects, particularly when these are relatively stationary, leaf-eating caterpillars. Differential mortality can thus occur, and the pest species are able to break out from the natural enemy control. It was felt that even if this was not the cause of the outbreaks on cocoa, the chances were that the spraying was preventing any possibility of natural enemies reestablishing control.

Natural Control Reestablished, 1962

The level of spraying was reduced in October and November and finally stopped in December, except for two fields which had exceptionally severe bagworm infestations and were sprayed twice more in January and February. The event which almost immediately followed was the appearance of a braconid parasite, a species of Apanteles, attacking the looper, H. talaca. Some twenty or more parasites developed in each looper larva and at maturity emerged to form dense clusters of whitish cocoons which were everywhere visible on the cocoa trees. The rapid increase in this parasite caused looper population to drop suddenly. It remained low until May when it flared back, only to be followed by another parasite buildup. Within three to four weeks, the population had again declined, this time to a level at which damage was negligible. In April and May it became evident that the plant-hopper, C. falcata, also was declining rapidly. In this case the cause was not obvious, although there was some evidence of predation and an entomophagous fungus was present. The decline continued, and by August the hoppers were present in only very small numbers.

The next pests to come under control were the Branch Borers. These had persisted in abundance through the first half of 1962, continuing to inflict severe damage. But in August a decline in new borings became noticeable, and when a sample of borings were opened and examined, it was found that over 50% of the Branch Borer larvae were parasitized by braconid wasps, mostly belonging to the genus Iphiaulax. The population continued to decrease rapidly so that at the end of September, few new borings were to be found and by the end of the year, the damage was infrequent.

Selective Control Measures, 1962

Following the cessation of spraying, it was felt that the damage caused by the looper and plant-hopper and to a lesser extent by the Branch Borer could be tolerated without taking any action other than waiting in the hope that natural control would be reestablished. However, the damage caused by the Ring Bark Borer and by the bagworms was too severe to be ignored for any length of time, and attention was turned to finding selective means of control for these pests which would not interfere with any natural control being reestablished over the other species.

As has been mentioned above, although the Ring Bark Borer damage was severe, the population present was not very high; and toward the end of 1961, it was decided to revert to inspection and eradication of individual borers. More labor was available for this form of control since the general spraying program was being stopped; small teams were organized to inspect the cocoa and treat new borings with a jet of 1% dieldrin from a hand sprayer. Since the life cycle of the Ring Bark Borer is very long, probably up to a year in duration, it was thought that an initial blitz of twice a month inspections followed by others at monthly intervals would serve to bring the population down to tolerable levels which could then be maintained by much more infrequent inspections. By applying the insecticide in this extremely localized fashion, there was also little possibility of affecting the natural enemies of the other pests. At about the same time, it was discovered that an important alternative host of the borer was a secondary forest tree, *Trema cannabina*, which was not only common in the cocoa fields but, along roadsides and in other areas, was present in nearly pure stands. Inspection revealed that many of these trees each supported considerable numbers of borers living in a complex of tunnels. In the fields the trees were acting as foci for the infestations in the cocoa and, therefore, as a complement to the inspection program, steps were taken to eradicate *Trema* from the cocoa and from much of the surrounding areas. Combining these two measures proved immediately effective, and borer damage dropped off rapidly. From 1962 onward mortality in new plantings during the first two years was usually well below 0.5%.

In the case of the bagworms an intensive search was carried out in the hope of finding a selective insecticide which would give control. Finally, in March of 1962 samples of trichlorphon (Dipterex) and of a preparation of the bacterium *Bacillus thuringiensis* (Thuricide) were obtained and in a series of trials with sprayed cocoa seedlings were found to give rapid and complete mortality. Trichlorphon had been shown elsewhere to have considerable selective properties (1); it is only of moderate toxicity to such insects as the parasitic wasps and it is a persistent stomach-acting insecticide with only short-lived contact action. Bacillus thuringiensis similarly is selective, causing mortality mostly to larvae of lepidopterous pests, such as the bagworms. Of the two, trichlorphon was the more readily available, and a high volume test spraying of an infested field with 0.25% spray appeared to give a very high kill. Regular monthly spraying of the infested 45 acres at the Cocoa Research Station was thus begun in May, the trichlorphon being applied at about 3/4 pound per acre active ingredient. The treatment brought about an immediate effect; the bagworm population dropped rapidly and the trees began to recover putting out new flushes of leaves which were able to survive. But, it became evident that kills were not as high as they had first appeared (probably not much more than 75 percent) and the hope of obtaining complete control with two or three applications was not realized. Regular spraying was continued, though, and gradually control was obtained, the population dropping lower each month with occasional mild resurgencies. By April of 1963 the population was very low, the damage insignificant, and the sprayings were stopped.

Thus, during 1962, most of the pests which had been so important in 1960 and 1961 had succumbed to natural control of one form or another or in the case of the Ring Bark Borer and the bagworms had come under effective and selective artificial control. In 1963 artificial control was no longer needed against the bagworms, and the high incidence of parasitic tachinid flies in the remaining individuals suggested that there were now responsible for keeping them in check. Significantly, in the subsequent five years, none of these pests have built up again.

The commercial cocoa estates nearby at Quoin Hill were urged to follow the example of the Cocoa Research Station and in early 1962 most of them abandoned the use of contact-acting insecticides. Their experience was the same: most of the outbreaks died out rapidly in 1962, and these pests have remained at low, insignificant levels ever since. They also adopted the control measures devised against bagworms and the Ring Bark Borer and experienced similar success. Only on one estate which persisted in the use of contact-acting insecticides has the situation been different; it has continued to be plagued by Branch Borer damage and by periodic outbreaks of bagworms and other leaf-eating caterpillars.

Later Problems, 1963 to Date

This does not quite complete the story since some other pest problems have arisen subsequently. In 1963 two mirid species, the mosquito bug, *Helopeltis clavifer*, and the bee bug, *Platyngomiriodes apiformis*, made their appearance in the cocoa at the research station and on other cocoa estates in the area. Both species slowly spread through the cocoa, but not uniformly, being for the most part present in small pockets. Their numbers have never been very high but the damage caused can be severe. The developing and the maturing pods are attacked primarily, the bugs feeding through their needle-like mouthparts and producing lesions which subsequently provide a ready entry point for pathogenic fungi. It has been estimated for a related mirid species that a single individual can produce 10 to 50 lesions a day (15), so that the potential damage of even a small population is great. In West Africa where the damage has been particularly severe, control has centered on the use of lindane (gamma BHC) sprays. No action was taken at first in Sabah when the mirids appeared, but as the level of damage increased, it was decided to spray with lindane; and the West African recommendation of applying

4 ounces of active ingredient per acre by low-volume mist blower was followed. Lindane was not an ideal choice; since it is a contact-acting insecticide, although with relatively low persistence, it could upset control by natural enemies, and there has been evidence of this in West Africa (16). But, no better alternative could be found at the time. In an endeavor to keep such possible effects to a minimum, spraying was restricted to twice a year, prior to the fruiting seasons, and where the infestation was localized, spot spraying only was carried out.

Lindane spraying in this manner has in fact continued to the time of writing and the mirids have been kept economically under control. With the exception of one pest, a eumolpid beetle, Rhyparida iridipennis, no other pest problems of any severity have arisen. The beetle was first noticed in a small pocket in 1963 but toward the end of 1964 it began to spread through the cocoa, pockets appearing mostly at the edges of fields. It has never become very abundant, but the damage caused by the adult beetles feeding along the veins of the young flush leaves has been important. The beetle is susceptible, to a degree, to trichlorphon and lead arsenate (a selective stomach-poison pesticide) and some spot spraying with these insecticides has been carried out; but a really effective form of control is still being sought. Possibly, if a more selective replacement for lindane, such as a systemic insecticide, were to be found, then some degree of natural control for the beetle might be reestablished.

There have been a few minor pest problems. The young cocoa in its first year is particularly susceptible to leaf damage caused by crickets and caterpillars and to mealybugs attacking the growing points. Often this can be ignored but if necessary it can be effectively curtailed by limited applications of trichlorphon or lead arsenate against the leaf-eating pests or a white oil against the mealybugs. The cocoa remains rich in fauna with many potential pests present including a number of species such as the noctuids, Spodoptera litura and Heliothis armigera, which are notorious for their damage to tropical crops. But, it would seem that a stable faunal balance has arisen over the past five or more years which in general keeps the pest potential well in check.

Review

All the insects on cocoa in Sabah, including the pest species, are indigenous. Originally, it was thought that they had come from the primary forest. But in 1961, as has been mentioned, the Ring Bark Borer was found in large numbers in the secondary forest tree, Trema. The evident tolerance of the borer shown by this tree strongly suggested that it was a primary and original host and raised the possibility that the other pests had similarly come from the secondary forest. On examination it was found that several secondary forest trees, such as Macaranga and Acanthocephala, were common hosts of the Ring Bark Borer and of the plant-hopper and that several of the other pests were also present on occasions. A search of the literature showed that in other countries where wild hosts of the Sabah pest species have been recorded these hosts were predominantly or exclusively secondary forest, or in some cases riverine, plants. None of this is, of course, very strong evidence. Secondary forest growth is widespread and easily inspected which may account for the predominance of records. Until more is known of the fauna of the primary forest and particularly of the canopy foliage, the question cannot definitely be resolved. However, this rather circumstantial evidence is also backed by certain theoretical considerations.

Most of the plants of the secondary forest and of such situations as river banks and road sides are essentially fugitive species. They have well-developed powers of dispersal and reproduction and grow vigorously so that they are able to rapidly colonize newly available sites. Inevitably they are destined to be replaced in time by other fugitives in the succession or destroyed by floods or other causes. They are also hosts to many insects which, as Southwood has argued (28), must be adapted in the same way as the plants to this special situation. An example of such an insect, which shows these fugitive characteristics to an extreme, is the plague caterpillar of South-east Asia, a noctuid Tiracola plagiata. This species has an enormous reproductive potential, the eggs being laid in batches of up to 1,200 each; the caterpillars feed on a wide variety of plants and both moths and caterpillars are very mobile (3). An outbreak of the caterpillar occurred in the east of Sabah in 1965, in an area of primary forest about 3/4 mile long by 1/4 mile wide which had been cleared and allowed to develop into low secondary forest, mostly consisting of Trema sp. The outbreak consisted of a vast army of the caterpillars, all approximately of the same age which moved slowly along the strip of secondary forest and finally pupated. This was in every sense a pest outbreak, except that no crop was involved. Fortunately, in Sabah very few adult moths emerged from the pupae and the outbreak died out as suddenly as it had arisen. But in New Guinea following such outbreaks on secondary vegetation the caterpillar has frequently moved onto nearby crops, such as cocoa, and has become an extremely serious pest (2, 3). Clearly, possession of these characteristics preadapts the species to the role of crop pest. Many of the cocoa pests in Sabah possess them to some degree and from this alone there is good reason to accept that these pests have come from the secondary forest habitat.

But, to see the secondary forest as a source of potential pests only is to see but part of the picture. For undoubtedly it also supports their natural enemies; on reflection it would seem logical that they, too, in their adaptation to this habitat will show the characteristic, fugitive features of well-developed powers of dispersal and habitat (host) finding, together with a high reproductive rate and some degree of polyphagy.

In nature, destruction of part of the primary forest may result from earthquake, lightning, whirlwinds or flood, or perhaps more commonly from the natural death of an emergent, which in falling brings down its neighbors. Whatever the cause, this destruction will create a habitat for fugitive species and initiate a secondary forest succession. First the bare area will become rapidly colonized by herbacious and spreading plants and then, after an interval, the first herbivorous insects will arrive. As the latter multiply, they will in turn be found by parasitic and predatory insects; the numbers of these will increase and those of the herbivores decrease. But, the flora of the area will also be changing; the first colonizers will become replaced by other secondary forest species, shrubbier in form and more competitive. Some of the first insects will be able to move onto these, but the new plants and the new microhabitats they create will also be favorable for a second wave of fugitive insects. In the hot, humid climate of Malaysia conditions will be almost continuously favorable for the growth and reproduction of these plants and insects. And so the succession will go on with new waves of colonizing plants, herbivorous insects, and their enemies, each exploding briefly and dying down.

Apparently, the clearing of the primary forest and the planting of cocoa in Sabah has resulted in a somewhat similar chain events. The bare areas following the felling of the forest have become colonized by secondary forest plants and by the transplanted cocoa seedlings. Fugitive insect species have moved in, attracted to the secondary growth plants, and because of their generally polyphagic habits to the cocoa as well. There, as a result of the damage they cause, some have become pests. But, at this point the picture is complicated by the intrusion of heavy applications of contact-acting insecticides. In effect these seem to have either prevented the expected natural enemies from entering the crop or destroyed those which were already present and exercising some degree of control. Many of the pests, in consequence, instead of exploding briefly and dying out, continued to multiply, producing major and prolonged outbreaks. It is significant that in the cocoa-growing area at Tiger in Sabah, where the use of this type of insecticide was very much less, although there has been damage from the Branch Borers and from such low density pests as the mirids and the Ring Bark Borer, the major pest outbreaks did not occur. At Quoin Hill cessation of the spraying at the end of 1961 appears to have corrected the situation, the major outbreaks coming under natural control leaving only a few pests, damaging at low densities, which required selective, artificial control measures. As the cocoa has grown older and the microhabitats have changed, other pests--as was to be expected--invaded the crop. But the absence of contact-acting insecticides has meant that, for the most part, these have come quickly under effective natural control leaving again only the low density pests in need of attention.

Of course, this is a hypothetical and simplified explanation of what occurred; undoubtedly other factors enter the picture. For example, in 1961 when the major outbreaks occurred it was drier than usual, and this may have triggered them off, although such dry periods have occurred subsequently and without outbreaks following them. It should also be noted that the outbreak of the nettle caterpillar S. nitens died out while the heavy contact-acting insecticide spraying was still being carried on, and this could perhaps also be said of the looper, H. talaca. The explanation does, however, appear to fit the facts better than any other; more importantly, in acting on it, effective economic control of the pest problems on cocoa in Sabah has been achieved.

Oil Palm Pests in Malaya

Perhaps more convincing evidence of the role of contact-acting insecticides in causing or aggravating pest problems can be derived from experience with oil palms in Malaya. B. J. Wood of the Chemara Research Station in Johore has described many instances of oil palm problems which can be explained in this way, and he has produced, in addition, some experimental evidence. Wood's findings have been referred to already in a number of publications (11, 32, 33, 34), and he is preparing a comprehensive oil palm pest handbook for publication in early 1969 (35).

Oil palms, like cocoa, are a relatively new crop in Malaysia. Although some commercial planting was carried out before the war, extensive planting (which now amounts to some 250,000 acres) has only occurred in the last 20 years. Most plantings are on a big scale, from several hundred to 20,000 acres or more. In some areas oil palms have been placed in cleared primary forest, but large plantings have also been made on old rubber land--the rubber trees being felled and burned prior to planting. Oil palm plantings, unlike cocoa, are almost pure monocultures; they do not require shade so that the only other vegetation present consists of various legumes which are planted as ground cover crops.

The crop originated in West Africa and damage by pests there has never been a major problem. This was also true, at first, of the Malaysian plantings, apart from the damage caused by the Rhinoceros Beetle, Oryctes rhinoceros, which had previously been a pest of coconuts and some minor damage by cockchafer beetles, bagworms, or nettle caterpillars.

Bagworm Outbreaks

But, from 1956 onward, a number of severe outbreaks, mostly of bagworms with some of nettle caterpillars, have occurred. Most of the outbreaks examined by Wood were found to have arisen following the use of contact-acting insecticides such as DDT, dieldrin, and endrin. These insecticides had begun to be used on a large scale at about that time, either as a general prophylactic measure or against minor damage caused by cockchafers or limited bagworm outbreaks. On one estate, for example, a contact-acting insecticide was combined with a fungicide, purely as a general prophylactic measure, and a serious increase in bagworm numbers occurred. On a second estate a severe outbreak of bagworms affecting several hundred acres commenced around an area which had been sprayed a number of times with DDT against cockchafers. The bagworms were in turn sprayed with DDT, but it was found that as each field was sprayed, successive increases of bagworms occurred in adjacent areas which then had to be sprayed in their turn. Apparently, the drift of DDT from the sprayed area to adjacent areas had resulted in the destruction of natural enemies and this had allowed the bagworms to increase. Gradually a very wide area was sprayed and resprayed as the outbreaks recurred. Finally, however, spraying was stopped and despite new outbreaks occurring around the most recently sprayed fields, these too were left untreated. Soon a high degree of parasitization was noted, mainly by ichneumon wasps, and the infestation declined. On other estates which began spraying against minor outbreaks of bagworms or the nettle caterpillar, S. nitens, these pests only increased further and became of permanent importance. Thus, on one estate in Perak which began applications of contact-acting insecticides in 1956, they found it necessary to treat, in nearly every subsequent year, between one and two-and-a-half thousand acres with endrin against bagworms. Spraying in this fashion was still being continued in 1964. As Wood points out, all these outbreaks occurred on estates in quite different localities in Malaya, and they commenced at different times; but, in each case, the sequence of events was very similar.

Damage by bagworms to oil palms is as severe as to cocoa. The larvae feed on the leaves, and there is a progressive necrosis of leaf tissue with eventual skeletonization. Crop losses, over hundreds of acres, of up to 40% in the first year after attack have been recorded following such defoliation (35).

Where bagworms were present initially as minor pests, they were usually of the species Cremastopsyche pendula, but in the major outbreaks which followed insecticide spraying, a different species, Metisa plana, was the more important. Prior to 1956 M. plana had not been recorded from oil palms at all. Wood has made a study of the biology of these bagworms and has identified a number of important natural enemies. The cocoons of both species are attacked by several hymenopterous parasites, while a braconid Apanteles is a very common parasite of the larvae of M. plana; there is also an important predator--the bug Sycanus dichotomus.

The Experimental Evidence

To test the hypothesis that the use of contact-acting insecticides was causing the bagworm outbreaks, Wood carried out a small-scale trial based on De Bach's insecticidal check technique. In an oil palm stand with a small population of bagworms of the species M. plana, an area of about two acres was given a number of very light mist sprays with an insecticide often recommended to control the pest. As he had expected, an explosive bagworm increase resulted over the sprayed and surrounding areas. Counts across the sprayed plot and for up to half a mile away in six different directions clearly showed that the sprayed central area was the point of heaviest buildup, with a gradual decline away from the center in all directions.

Selective Control

While it was perhaps possible to find alternative explanations for these bagworm outbreaks and for the results of the experiment, Wood was personally convinced that the hypothesis was correct and began a search for more selective forms of control which would allow the oil palm growers to abandon the use of contact-acting insecticides. Lead arsenate had been used before the war against bagworms and it was known to have little effect on natural enemies. Applied at about 4 pounds per acre, it did prove fairly effective, but the kill was not very rapid. To obtain a better kill, Wood turned to trichlorphon (Dipterex). Ground trials soon showed that it was more rapidly effective than lead arsenate and, in fact, was comparable to endrin in this respect.

Trichlorphon has been subsequently adopted on a large scale in Malaysia for bagworm control. Wood has developed an effective census technique which allows for the correct placing and timing of application; spraying is usually carried out when the census shows a level of bagworm infestation of ten or more larvae per frond and is timed to coincide with the maximum emergence of the young larvae. Much of the spraying, as was the case with the contact-acting insecticides before, is carried out from the air, trichlorphon being applied at a rate of about 1 to 2 pounds in 1 to 2 gallons per acre.

The results have been very encouraging. Widespread outbreaks of M. plana, affecting areas of up to 3,000 acres, have been dealt with remarkably effectively--populations averaging up to 50 bagworm larvae per frond being virtually eliminated after a single application of trichlorphon and with only mild resurgencies at the most. In general, where these selective measures of control have been used, the importance of bagworms as pests is declining.

Review

Wood in his forthcoming book (35) discusses the various possible causes of oil palm pest outbreaks in Malaysia. As with the cocoa pests in Sabah, the oil palm pests all appear to be indigenous. Many have come to the oil palm from coconuts or other cultivated palms; others have come from wild palms or other plants of the natural vegetation. The environmental changes brought about by oil palm cultivation have thus been one such set of causes. For example, the presence of rotting logs and stumps of wild palms or previously cultivated oil palms or rubber provide breeding sites for rhinoceros beetles. Similarly, the opening of the previously shaded area before planting and the consequent changes in ground vegetation contribute to the buildup of such pests as grasshoppers and cockchafers.

However Wood, like myself, considers that the key to understanding the causes of most of these outbreaks lies in the recognition of the importance of natural enemies in regulating potential pest species. Perennial tree crops in Malaysia, such as oil palms and cocoa, mostly support a rich herbivorous insect fauna. When mature, they provide a relatively stable habitat with almost continuously favorable climatic conditions and an abundance of potential food; yet these insects rarely become abundant. The only obvious explanation is that they are kept in check by their natural enemies. Casual observation suggests that high levels of parasitism and predation are the normal rule but, when outbreaks do occur, enemy species are conspicuous by their absence. A graphic example is furnished by the outbreaks of the leaf-roller caterpillar, Erionota thrax, on manila hemp (abaca) in Sabah (10). The population of this caterpillar usually begins to increase in August, reaching a peak at the beginning of the following year. It has a number of natural enemies--the two most important being the parasitic wasps Xanthopimpla sp. and Apanteles erionotae. During the growth of the outbreak, these are little in evidence, but in February and March they suddenly reappear in huge numbers, so that the manila hemp seems to be swarming with them, and the leaf-roller outbreak comes to a sudden end.

Thus, in looking for the cause of most outbreaks, we have to consider factors which could upset regulation by natural enemies. One such factor is the weather which, despite the lack of extremes, at certain times may favor the pest species rather than their enemies. There is, for example, some evidence of seasonality in that the numbers of leaf-eating caterpillars in Malaysia tend to be higher at the beginning of the year (35). Life cycles of enemy species may also grow out of phase with those of their hosts; possibly a combination of this and the weather was responsible for the leaf-roller outbreaks. There are also other, less natural factors. For example, Wood draws attention to the importance of road dust on oil palm estates. It has been observed that outbreaks of various caterpillars often commence at the side of busy roads, especially after a dry spell. Road dust can kill insects by abrasion, cutting through the cuticle which acts as a waterproof covering; it affects the natural enemies more than the pest species because they are usually more active with smaller, more delicate bodies. Nevertheless, whatever other factors may cause the breakdown of natural control, it seems evident from Wood's experiences that one major factor is the use of residual contact-acting insecticides.

Rubber Pests in Malaya

The severe pest problems which arose on cocoa and oil palms, apparently as a result of the use of contact-acting insecticides, led to rather hurried and piecemeal attempts to obtain better control through more selective measures. Ideally, though, pest problems should be countered with measures of this kind at the outset; these measures should be designed and executed with a thorough understanding of the biology of the pest and the ecology of the pest situation. Such an approach is now referred to as integrated pest control. As a concept, it draws much of its inspiration from the work of various Californian entomologists, in particular Dr. R. F. Smith who has written widely on the subject (26, 27). On rubber in Malaya, an integrated control program has been devised for the control of cockchafer beetles by Mr. B. S. Rao of the Rubber Research Institute at Kuala Lumpur (24, 25).

Rubber as a crop is rather unusual in that it is largely free from pest attack. Probably this is attributable to the heavy amounts of latex in the trunk and branches and to the presence of a cyanic acid compound in the leaves. However, the commercial exploitation of this crop has reached such a high level of efficiency that damage which would be considered trivial on another crop becomes of economic significance, and control measures have to be devised. Further, in young rubber, the ground between the trees is planted to a cover crop and this is very prone to damage, particularly by leaf-eating caterpillars. There has been some suggestion that outbreaks on these cover crops could be attributed to the use of contact-acting insecticides; so when control measures were being sought for the cockchafer damage, an attempt was made to keep such insecticide use to a minimum.

The Cockchafers and their Damage

Rao lists seven species of cockchafer (Melolonthidae) known to be pests of rubber plantations in Malaya (25). They were almost unknown until 1930, when their numbers started building up, in particular those of the species *Psilopholis vestita*. Each year more areas were attacked, and by 1938 about 3,400 acres were infested. The outbreaks diminished from then on, but not apparently because of any applied control measures. Following the war, attacks continued on a very small scale, but after 1955 there was a sudden increase in activity which had continued up to 1965, when Rao wrote his account. The outbreaks are not widespread through Malaya but are confined to two areas on the western side of the peninsula: one area overlapping the states of Johore, Malacca, and Negri Sembilan and the other in Kedah and central Perak. Although *P. vestita* is still an important cockchafer, the species responsible for most of the outbreaks has been *Leucopholis bidentata*.

The cockchafers have an annual life cycle. The eggs are laid during March and April and the young grubs, on hatching, feed in the soil, first on dead vegetable matter and then on roots. Pupation occurs deep in the soil and is usually completed by January or February. These, though, are dry months and the adult beetles remain in the soil until wet weather occurs. Then they emerge in large numbers and take to flight; they do not feed on rubber or on the cover crops, but fly to either primary or secondary forest or even grassland, to feed and mate.

The damage caused can be quite severe. Where rubber nurseries or field plantings are established on land in which the grubs have persisted from an old stand, many plants are quickly killed. In plantings on clean land, infestations begin in the second year as the leguminous cover crop becomes established in the inter-rows. L. bidentata in particular seems to be attracted to oviposit under the cover crop plants. The grubs begin by destroying the cover in extending patches and then proceed to feed on the rubber roots, killing many young trees. Mature rubber, though, has an extensive root system and infestations at this age have little affect at first; but successive reinfestations result in extensive damage. On rubber in hilly terrain, destruction of the cover and loosening of the soil by the movement of grubs can lead to soil erosion and the collapse of contour terraces.

Development of Selective Control

Before the war, hand digging was the only form of control against the grubs. It was laborious, only partially effective, and it added to the soil erosion. After the war several effective insecticides became available; in particular, it was found that control lasting for at least three years can be achieved with heptachlor applied at a 0.1% emulsion. Poured into holes placed 18 inches apart through the area, it will, for example, easily protect nurseries; while applied to the soil immediately around the root system, it will similarly protect the trees in first-year plantings. To obtain control in slightly older plantings, though, the insecticide would have to be injected both by the trees and under the cover crop, and this would mean the wide dispersal of a residual contact-acting insecticide; in any case, it would be prohibitively expensive.

Rao has found, however, that the adult beetles--at least in immature plantations--can be very effectively controlled by light trapping. Before the war light traps (usually built around kerosene lamps) were a common form of control against many pests. Despite the fact that large catches of insects were often obtained in this way, it has generally been considered a very inefficient form of pest control. The catches though large are often only a small proportion of the total population, particularly when the insect concerned does not have well-defined swarming periods. Further, the catches tend to comprise mostly males or females that have already laid their eggs. Often, too, traps have acted as a focus of subsequent infestation, attracting pests from all the neighboring areas; finally, the traps may catch a large number of beneficial insects. In the case of the rubber cockchafers, though, there is a well-defined swarming period: it occurs with the first rains, during the second half of February or the first half of March, and is further confined to mass flights for about an hour just after dusk. Rao tried a number of different traps and found the most effective was one with a 15 watt, blacklight, fluorescent tube suspended over a funnel. Only a total of 42 hours trapping time is required, the traps being operated for one hour a day, after dusk, during the six-week swarming period. A high proportion of the catch consists of females which have not yet laid their eggs and few of the smaller natural enemies are caught; if larger species, such as the scoliid wasps, are trapped, they can easily be set free. In a trial conducted in an area heavily infested with L. bidentata, light trapping resulted in a reinfestation in the following season of an average of 9 grubs per square yard as compared with 46 grubs per square yard in the control plots.

Unfortunately, neither light trapping against the adults nor chemical control against the grubs gives adequate protection to mature rubber. In this situation Rao has found that good control can be achieved by applying Heptachlor to the soil surface, directed not at the grubs, but at the emerging beetles. In the trial referred to above, this method of control resulted in a reinfestation of only two grubs per square yard in the succeeding season. The potential drawback to the method is that the widespread insecticide application could adversely affect natural enemies. The cockchafer grubs are mostly parasitized by scoliid wasps and by tachinid flies, but fortunately both of these natural enemies complete their life cycle and emerge from the soil before the cockchafer grubs pupate. Rao was thus able to obtain selective control by delaying the treatment until just a month before the flighting season of the beetles.

The Integrated Program

In summary Rao has devised three methods of control against the cockchafers. Depending on the pest situation and the condition of the plantation, these can be variously combined to give effective integrated control. In very young rubber localized application of insecticide against the grubs gives cheap, efficient control with only a limited possibility of interfering with the natural enemies. In older but still immature plantations, the same insecticide application can be combined with light trapping of the adults, again with little effect on natural enemies. Finally, in mature rubber overall chemical application against the beetles has to be resorted to but, if timed correctly, the enemy species are spared.

Obviously, there is still room for improvement in this control program in that it can probably be made yet more selective. Rao is, for example, considering the use of the "Green muscardine" fungus (*Metarrhizium* anisopliae) which is often encountered in the field. Nevertheless, this case history does show that given the right approach effective economic pest control can be achieved without the hazard of creating further problems. It also illustrates the fact that when applied with correct insight into the biology of the pest, the older traditional methods of pest control can compete efficiently and economically with modern pesticides.

Malaria Control in the Borneo States

So far I have only been concerned with the direct effects of the use of contact-acting insecticides in causing or aggravating pest problems. This final case history illustrates the kind of side-effects which can result.

In the Borneo states of Sabah, Sarawak, and Brunei, malaria used to be an important disease; in some areas over 90% of the population had enlarged spleens. In 1955 the World Health Organization (WHO), in cooperation with the local medical departments, embarked on a program of malaria control (5, 6). The program was aimed at chemical control of the mosquito vectors (Anopheles balabacensis in Sabah and A. leucosphyrus in Sarawak), together with treatment and administration of prophylactic drugs. DDT and dieldrin have been the insecticides used (DDT at 2 g and dieldrin at 0.6 g per square meter, applied to the inside of dwellings) and, apart from some mosquito resistance to dieldrin (2, 9), they have been extremely effective in their primary objective. The campaign as a whole has been regarded as a model one and used in training for later campaigns in other countries. In 1957 the original aim of control was changed to one of eradication and today this has been all but achieved. But, there have been some undesirable side-effects of the mosquito control spraying and these are worth considering.

Thatch-eating Larvae

Dr. F. Y. Cheng, the WHO entomologist in Borneo, referred to one of the side-effects in a note published in 1963 (4). At about this time a number of complaints were received from villagers who maintained that the DDT spraying was causing the thatch (attap) roofs of their houses to rot. On examination, it was found that the damage was being caused by heavy infestations of the larvae of a pyralid moth, Herculia nigrivitta. A survey carried out in sample unsprayed and sprayed areas revealed that the number of live thatch-eating larvae per square foot of infested root was 4.2 in the unsprayed area, 6.6 in the DDT-sprayed area, and 0.2 in the dieldrin-sprayed area. Although the density was highest in the DDT-sprayed area, the presence of a high density and rotten thatched roofs in the unsprayed area suggested that the damage could not be due to DDT spraying alone; in fact it has been suggested that part of the problem was due to the poor preparation of the attap before thatching.

In a test on the susceptibility to DDT of these larvae, Cheng found that they have the ability to distinguish the presence of the insecticide and refuse to feed on DDT-sprayed thatch, even if they have been starved for 24 hours previously. In the case of dieldrin, though, they are very susceptible, with a mortality rate of up to 92%.

A sample of full-grown larvae was collected and bred out, and from a number of the pupae, small chalcid parasites, Antrocephalus sp., appeared. Altogether 16% of the pupae were parasitized in this way. In a preliminary test with the parasites, Cheng discovered that enclosing them with a piece of DDT-sprayed thatch caused a complete knockdown. The high incidence of thatch destruction in the DDT-sprayed areas could thus be attributed to the avoidance reaction of the thatch larvae and the susceptibility of their natural enemies to the insecticides.

Of course the problem that was created was insignificant as compared with the benefits in malaria control to be attained from the continuation of DDT spraying; and there was some evidence that it could be large avoided through better preparation of the attap thatch. However, the second side-effect, while in practice producing an equally minor problem, carried the potential of something much more serious.

Rat Outbreaks

In Sarawak (18) following the spraying of the houses, the insecticide deposits were not only picked up by the mosquitoes but also by the many other insects normally present, including the frequently large populations of cockroaches. During the actual spray operation, domestic animals such as cats were kept outside; afterwards, they returned and, in feeding on the dead or affected cockroaches, the cats picked up the insecticide. On accummulation the insecticide was frequently lethal, and before long many areas (particularly in the uplands) were almost completely denuded of their cats. The result was an explosion in rat populations in the treated villages. In Sabah the story was the same except that a more likely route for the chain reaction was through the house lizards, small geckos known locally as "chi-chaks." Normally, a score or more of these live in each house and are commonly seen running on the roofs and walls and feeding on all manner of insects. Like the cockroaches, they, too, are frequently eaten by cats and can similarly pass on the accummulated DDT.

There are many species of rats in the Borneo states, but only a few (mostly non-indigenous species) can live in houses (17, 21). In the port areas and large coastal settlements, the Brown Rat (*Rattus norvegicus*) and the Black Rat (*R. rattus diardii*) are the common species; but inland, they are replaced by the Little Rat (R. exulans) and the Malaysian Field Rat (R. tiomanicus sabae). This latter species is equally at home in plantations, scrub, and secondary forest, and there is thus a permanent reservoir for house infestations to spring from. More important, though, is the fact that many of these rats are carriers of leptospirosis and various rickettsial diseases, such as typhus, and are of course potential carriers of plague. When attention was drawn to the extensive death of cats and consequent rat explosions, attempts were made by the authorities to replace the cat population. In Sabah cat owners in the towns were encouraged to donate surplus cats and litters of young kittens, and these were transported to the upland areas. In Sarawak, where the interior is much more inaccessible, a quite remarkable operation known as "Operation Cat Drop" was undertaken by WHO in cooperation with the Royal Air Force in Singapore (18). The donated cats were packed in special containers and dropped by parachute over the upland villages.

Luckily, these rat outbreaks did not, in fact, produce any outbreaks of disease. The major consequence was the creation of resistance from the villagers to having their houses resprayed at a later date. Nevertheless, the case history is important, since it does illustrate graphically how far-reaching the effects of the use of such contact-acting insecticides as DDT could be.

Discussion

The basic ecological problem in natural resource development can be described fairly concisely. In a natural climax ecosystem the energy received from the sun and the available minerals, gases, and water are converted into a maximal production of living materials; because of the way in which the system has evolved and is structured, this productivity is stable and long-lasting. Only a part of the material produced, though, is directly of use to man, and the natural ecosystem becomes replaced by an artificial one where the productivity, measured as yield, comes in a more utilizable form. Experience has shown, however, that artificial ecosystems tend to be unstable, with long- or short-term deterioration.* The ecological problem thus becomes: How can the stable characteristics of the one system be combined with the high-yielding qualities of the other?

Pest control is but a special case. In attempting to obtain a high crop yield or a human population in excellent health, we create artificial ecosystems. Nevertheless, elements (pests) from the remaining natural ecosystems continue to intrude. These can in turn be controlled by additional artificial measures, such as the use of contact-acting insecticides, but as we are finding out, such control tends to create further instability--either in the target pest or in other features of the ecosystem. The ecological answer lies in inserting such features of natural ecosystems into the artificial ecosystems as will allow efficient but more stable levels of pest control to be attained.

In practice, this simply stated solution is often complex and difficult to attain, largely because of the insufficiency of our knowledge. We urgently require much more fundamental research, for example, on the structure and functioning of natural ecosystems. We need to know precisely and in detail why they are frequently so stable. To what extent and under what conditions do factors such as variety of habitat, complexity of food chain, or climate contribute to stability? We have to understand more clearly why some elements of natural ecosystems, such as certain secondary forest herbivores, rather than others are more likely to invade and disrupt artificial ecosystems. Above all, we need to learn how the characteristics of stability can be infused into artificial ecosystems without depressing their yields. Does the complexity and organization of the natural ecosystem have to be reproduced in detail or can stability be achieved by the addition of only a few very carefully selected features, and if so which ones? Action on these questions becomes even more urgent when we realize that much of the world's remaining areas of natural ecosystems is fast disappearing. If we lose these altogether, the solutions will become even more difficult and in many cases impossible.

Research of this kind must inevitably be long term, and in the meantime we have to take the utmost advantage of information already available. Much work has already been done by ecologists on the problem of stability in natural ecosystems. Studies in some depth have been carried out on the influence on pest situations of natural or semi-natural vegetation, such as hedgerows in temperate countries. Further, a great many pests have been the subjects of research for a long time. The information, though, is scattered and often disconnected. More attention needs to be devoted to gathering this together in an attempt to uncover common principles. For example, a great deal is known about locusts, insects which are commonly regarded as rather special or unique. Yet in so many of their characteristics they seem to be the very epitome of a pest. Perhaps as Sir Boris Uvarov suggests (30), we should look closely at other pests to see if the knowledge gained of locusts applies more widely than has been realized.

The available information needs also to be used more formally to build theoretical constructs which can contribute to a sounder basis for pest control decisions. The complexity of such a task may seem daunting, but in recent years electronic computing and developments in applied mathematics under the general heading of systems analysis, have provided powerful tools for analyzing natural phenomena. Ecosystems can be mimicked by models built in mathematical or computer language and depending on the information available and the skill and discipline of the model builder, these models can yield great insights (31). As yet this approach has been hardly used in pest control, but the potential benefits are very great. For example, well-developed models of pest populations and their interactions would be invaluable in training applied entomologists.

Finally, there are the immediate day-to-day practical pest problems throughout the world which have to be acted upon. All too frequently, there is little detailed information for the field entomologist to go on, and decisions have to be based on a wide variety of considerations, economic and social, as well as ecological. For these each entomologist will have to continue to develop his own strategy based on how he sees the workings of pest situations in the particular country, climate, and general environment with which he is concerned.

From what has been said in this paper, it is evident that I feel that in countries with conditions similar to those of Malaysia, the overall pest strategy must place prime importance on the utilization of natural enemies as regulatory mechanisms and must recognize the hazards to such control which can arise from the use of contact-acting insecticides. As a general rule, it would seem desirable to attain, at the outset, as high degree as possible of natural control through cultural and other measures. This means taking into account the environment of the crop and that of nearby natural vegetation, considering the latter not only as a possible source of many of the pests present in the crop but also as a potential reservoir of regulating natural enemies. I have suggested previously that this may call for a policy of preserving such natural vegetation, leaving intact blocks of forest or keeping elements of the natural vegetation within the crop itself. Probably, though, the amount of such vegetation left and its ratio to that of the crop area is a critical one; with our present lack of knowledge only trial and error in each case will tell what needs to be done in practice. This strategy undoubtedly provides most chance of success against problems of perennial tree crops which in many respects come most closely to recreating natural forest conditions. At the other end of the scale quick-maturing, high-value vegetable crops which are grown under largely artificial conditions which would seem to provide much less opportunity for a stable form of natural control to be established. Perhaps, though, by careful rotation and a mosaic form of cropping, some success can be achieved.

In some cases the recreation of natural control may provide all that is necessary, but for the most part pest problems, particularly arising from low density pests, will remain, and these will require further artificial control measures. The strategy then must be to concentrate above all on choosing measures which are selective. They may be biological, cultural, mechanical, or insecticidal in form. Many pesticides are available, e.g., lead arsenate, trichlorphon, Thuricide, which have been shown to be highly selective. If there is no alternative and residual contact-acting insecticides have to be used, then they must be so applied as to ensure a minimum of interference with natural control (c.f. the control program devised by Rao). This means in practice a conscious and energetic effort on the part of applied entomologists to avoid the use of these insecticides and on the part of the manufacturers and distributors of pest control material to concentrate on producing and providing the kind of selective materials that are required.

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