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CONTENTS

OBSERVATIONS ON THE COCONUT SPATHE BUG *AXIAGASTUS CAMBELLI* DISTANT (HEMIPTERA: PENTATOMIDAE) AND ITS PARASITES AND PREDATORS IN PAPUA NEW GUINEA

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ABSTRACT

The coconut spathe bug Axiagastus cambelli *Dist.* (*Hemiptera:Pentatomidae*) *is widely distributed throughout the Bismarck Archipelago, Bougainville and the Admiralty Islands in Papua New Guinea but attains economic significance only in restricted areas of its distribution.*

Under laboratory conditions at Keravat adult A. cambelli *lived for up to 48 days. Females deposited up to 23 eggs over a period of 23 days post-copulation.*

The effects of intense feeding by adults and nymphs on coconut inflorescences are described in detail.

No important alternate host plants were discovered during the course of these investigations.

The beneficial effect of the kurukum ant Oecophylla smaragdina (*F.*) *previously reported on by many authors was confirmed. The situation with respect to the crazy ant* Anoplolepis longipes *Jerd. was in direct contrast.* A. longipes *was frequently observed on palms with high density* A. cambelli *populations.*

Parasite surveys carried out throughout the Bismarck Archipelago revealed that the most important egg parasite was the scelionid Trissolcus painei *Ferriere which attacked* 39.1 *per cent of all eggs examined. This species was present in all areas surveyed.* Anastatus *sp.* (*Eupelminae*) *was less important, attacking* 5.1 *per cent of eggs examined.*

Tachinid parasites were important bio-control agents in all areas except the Lihir Island group. Pentatomophaga bicincta *de Meij. attacked* 12.4 *per cent of adults in New Britain. In New Ireland* 10.5 *per cent of adults were attacked by an unidentified tachnid whilst on Bougainville* 4.8 *per cent of adults were attacked* by Trichopoda pennipes *F. Tachinid parasites were not recorded from the Lihir Group.*

A strepsipteron parasite was recorded from all areas and its infestation rate ranged from 1.7 *per cent on Lihir Island to* 4.8 *per cent of adults from New Britain.*

Other predators and parasites are briefly discussed.

Introductions of the tachinid P. bicincta *were made into the Lihir group from New Britain, but to date no recoveries have been reported.*

The fungus Aspergillus ochraceus *Wilhelm was isolated from adults of* A. cambelli *and also from pupae of the tachinid* Pentatomophaga bicincta.

INTRODUCTION

THE coconut spathe bug *Axiagastus cambelli* Distant (Hemiptera: Pentatomidae) is widely distributed throughout the Bismarck Archipelago, Bougainville and the Admiralty Islands in Papua New Guinea but attains economic significance only in restricted areas of its distribution. *A. cambelli* has been found associated with poor bearing conditions of coconuts by many authors but the type of damage and economic significance has not been well documented (Froggatt 1911, Simmonds 1924, Tothill 1929, Lever 1933a, 1933b, Dwyer 1937, Tercinier *et al.* 1964, Cochereau 1965, Lever 1969, Baloch 1973).

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LIFE HISTORY

The life history of *A. cambelli* has been well documented (Tothill 1928, Lever 1933). The eggs are deposited in the crown of palms usually in rafts containing 14 eggs (Baloch 1973). On hatching, the gregarious first instar nymphs do not feed but remain congregated around the egg raft. Second and subsequent instars feed on the young spathes and flowers, as do the adults.

Under laboratory conditions at Keravat, field collected *A. cambelli* adults lived for from two to four weeks. The maximum longevity recorded for a male and female was 48 and 36 days respectively. It was noted that copulation commenced in the early morning and continued for several hours if the mating pairs were not disturbed. In one cage a mating pair remained in copuluo for at least 34 hours before separating. Oviposition occurred one to eleven (mean, six) days after commencement of copulation. In the laboratory, mated females deposited one or two egg rafts. The maximum number of eggs laid was 23 in two rafts of 14 and nine eggs respectively. The two rafts were laid 11 and 23 days post commencement of copulation.

Newly moulted adults were caged in the laboratory with sections of young coconut inflorescences, but as previously reported (Baloch 1973) no mating or oviposition took place. It could be that adults require a period of flight activity before mating and oviposition take place.

The life history can be briefly summarised as follows:—

Stage	*Duration (Days)*	
Egg	7	(Lever 1933b)
	6 to 8	(Baloch 1973)
1st instar	4	(Lever 1933b)
2nd instar	7	(Lever 1933b)
3rd instar	6	(Lever 1933b)
4th instar	7	(Lever 1933b)
5th instar	10	(Lever 1933b)
Preoviposition	6	
Adult	48	

DAMAGE

First instar nymphs are gregarious. They remain around the empty egg shells and do not feed. Second and subsequent instars move onto the inflorescence and commence to feed. Adults and late instar nymphs puncture the spathes with their stylets and feed on the peripheral portions of the compacted spadix.

Damage to spathes was studied in some detail on Lihir Island at intervals during the period November 1968 to March 1969.

In general, populations of *A. cambelli* were much higher on the Lihir group than those observed on the Gazelle Peninsula, and in some areas populations were extremely high with several hundred adults and nymphs per spadix. Whilst damage to the spadix and loss of nut production from attack by high populations of *A. cambelli* occurs it is difficult to ascertain the precise loss in production as a result of such attacks.

At Lakakot Plantation spathes were caged with approximately 200 adults and late instar nymphs and then cut down and examined six days later. The spathes had not at this stage separated and the spadix was still completely encased.

The green spathes of the inflorescence were covered with diffuse brown-black areas, which had become contiguous with the constant feeding by the large number of *A. cambelli.*

These spathes were stripped away to reveal the enclosed spadix.

On the inside of the spathes which are creamy yellow in colour, reddish brown areas of discoloration with a central necrotic spot were observed. These areas were contiguous with the markings on the outside of the spathe. The discoloured areas were up to 10 mm in diameter and where puncture marks were numerous the areas had coalesced.

Areas of the spadix in contact with the spathe showed necrotic areas contiguous with the puncture marks. These areas were pinkish brown in colour and were distributed over rachis, racilli, male flower bracts, calyx and flowers of the female inflorescence. These necrotic puncture marks were only found on the outside portions of the folded spadix which, *in situ*, is in close contact with the spathes. The diffuse spots on the spadix were very numerous.

An inflorescence at a later stage of development (as yet still encased in the spathe) and also attacked by *A. cambelli* showed discoloured areas on both surfaces of the spathe and areas of the spadix in close contact with the spathe.

Most of the calyces of male flowers on the outside of the folded spadix were necrotic and black. Extensive spotting was again observed on the spadix.

Examination of an inflorescence which had opened in the field under sustained *A. cambelli* attack revealed that the racilli were dead from one half to three quarters of their length. Areas of the remaining racilli and rachis were necrotic as a result of puncture marks. Many of the young button nuts were punctured and the attendant necrotic areas were evident internally.

Examination of numerous spadices in different stages of development indicated that prolonged, intense feeding by *A. cambelli* caused premature necrosis of the terminal sections of the racilli. At a later stage the rachis was similarly affected and the young nuts were arrested at an early stage of development. Many "wizened" young nuts were observed on attacked inflorescences. Under sustained, heavy attack, most of the nuts failed to develop beyond five to eight centimetres in diameter, were retained for some considerable time and all finally dropped into the axils of fronds. The attacked inflorescence had a characteristic blackened, dried-up appearance.

Adults were observed in the act of feeding and found to be able to penetrate tissue to a depth of approximately one centimetre. When feeding they were difficult to disturb but when induced to withdraw the proboscis were found to stroke the fore-legs over the proboscis thereby returning the feeding stylets into the sheath.

The area surrounding the puncture mark internally was rather opalescent but gradually turned reddish brown and finally became necrotic.

There was no evidence of a preferred feeding site on the inflorescence. Surface browning around puncture marks occurred within 12 hours after exposure to *A. cambelli*. Similar discolourations were reproduced on sections of coconut inflorescence by puncturing them with a fine entomological pin. There was no conclusive evidence to suggest that insectotoxins were involved and it appeared that polyphenyl oxidase activity at the puncture site and dehydration (Smee 1965) were the most important factors associated with premature necrosis following intense feeding.

Feeding also occurred on older inflorescences but is usually less intense. Nuts over four months appeared to be little affected by *A. cambelli* feeding.

Following a single trunk injection 10 gm of either monocrotophos or dicrotophos, palms previously carrying very heavy populations of *A. cambelli* produced one or two flowers free of feeding punctures, but with the return of high *A. cambelli* populations by 12 weeks post-treatment these inflorescences failed to carry through any nuts (O'Sullivan 1974).

ALTERNATE HOSTS

There is one reported instance of *A. cambelli* being found on the inflorescence of a wild *Areca* sp. palm in the British Solomon Islands Protectorate (Lever 1933b). Egg masses of *A. cambelli* were also found on the leaves of *Casuarina* sp. in the British Solomons (Lever 1932) but Lever considered that the eggs were a chance occurrence on *Casuarina* sp. In the laboratory, adults have fed on fruits of the cluster palm *Ptychosperma* sp. (Baloch 1973).

Intensive search in the Bismark Archipelago of the betel nut palm *Areca catechu* and related *Areca* spp. has not revealed any *A. cambelli* on *Areca* palms even where *Areca* palms were surrounded by coconut palms carrying high numbers of *A. cambelli*. Eighty per cent of field collected adults caged with sections of *A. catechu* inflorescences were still alive after six days, but there was no evidence of deep rostrum penetration of the inflorescence by *A. cambelli*. It is thus apparent that *Areca* spp. are not important host plants of *A. cambelli*.

No other alternate host plants were located during the course of investigations.

INFLUENCE OF ANTS

The beneficial effects of the kurukum ant *Oecophylla smaragdina* (F.) have been reported by many authors. In the British Solomons, *O. smaragdina* was reported to afford almost complete protection from *A. cambelli* attack (Tothill 1929). In the Western Solomons, "good" and "bad" areas of palms were compared and it was found that "good" bearing areas had up to 93 per cent of palms colonised by *O. smaragdina* and few *A.* cambelli whereas in the "poor" bearing areas, *O. smaragdina* were few or absent and up to 100 per cent of palms were colonised by *A. cambelli* (Lever 1933a), 1933b).

On Lihir Island, adult *A. cambelli* were confined in a wire cage with a nest of *O. smaragdina* on a palm spadix. The *A. cambelli* were introduced at night and commenced feeding actively on the palm spadix. *O. smaragdina* remained inactive during the night and did not interfere with feeding by *A. cambelli.* Individuals of the *O. smaragdina* colony commenced activity shortly after sunrise and began to attack the *A. cambelli.* Small groups of *O. smaragdina* immobilized the *A. cambelli* by seizing the legs and antennae. Further arrivals helped to tear the *A. cambelli* apart and sections of the body were carried off. By evening only a few scattered sections of exoskeleton remained.

The relationship between *A. cambelli* and *O. smaragdina* was also studied in detail in the field at Lihir Island.

Regular counts of *A. cambelli* and *O. smaragdina* populations on 122 marked palms were carried out between July 1970 and January 1972. Results are shown in *Table* 1.

Table 1.—**Number of marked coconut palms occupied by *Oecophylla smaragdina* and *Axiagastus cambelli* at Lihir Island, July, 1970 to January, 1972**

Date of Recording	Palms with: Oecophylla only		Axiagastus only		Both		Neither	
	No.	%	No.	%	No.	%	No.	%
July 1970	36	29.5	45	36.9	0	—	41	33.6
Aug. 1970	61	50.0	41	33.6	2	1.6	18	14.8
Oct. 1970	66	54.1	38	31.1	6	4.9	12	9.8
Nov. 1970	53	54.4	41	33.6	6	4.9	22	18.0
Dec. 1970	58	47.5	31	25.4	5	4.1	28	23.0
Jan. 1971	48	39.3	30	24.6	2	1.6	42	34.4
Feb. 1971	53	43.4	26	21.3	1	0.8	42	34.4
March 1971	50	41.0	36	29.5	2	1.6	34	27.9
April 1971	57	46.7	27	22.1	2	1.6	36	29.5
May 1971	47	38.5	27	22.1	2	1.6	46	37.7
June 1971	57	46.7	12	9.8	3	2.5	50	41.0
July 1971	46	38.0	18	14.9	1	0.8	56	46.3
Oct. 1971	55	45.5	27	22.3	0	—	39	32.2
Jan. 1972	52	43.0	36	29.7	10	8.3	23	19.0
Total	739	43.3	435	25.5	42	2.5	489	28.7

The infrequent occurrence of both species together on palms confirmed earlier observations by Tothill (1929) and Lever (1933b). Where both species occurred together on palms investigations showed that either one or other of the species occurred in restricted numbers. There was no recorded instance of nests of *O. smaragdina* occurring together with large populations of *A. cambelli* on the same palm.

The situation with respect to the crazy ant *Anoplolepis longipes* Jerd. was a direct contrast. Palms used for systemic insecticide trials in an adjacent block (O'Sullivan 1974) were heavily colonised by *A. longipes*. *O. smaragdina* were completely absent and all palms were carrying very high populations of *A. cambelli.*

Three years observations throughout islands other than Lihir Island in the Bismarck Archipelago support these findings, in that *O. smaragdina* and *A. cambelli* infrequently occurred together on palms, whereas palms colonised by *A. longipes* invariably supported large populations of *A. cambelli.*

Observations also suggest that in areas where *A. cambelli* populations are capable of attaining high levels, coconuts with fully canopied interplanted mature cacao support lower populations of *A. cambelli* than sole planted stands in equivalent areas.

PARASITES OF AXIAGASTUS CAMBELLI

The distribution of natural enemies of *A. cambelli* on the Gazelle Peninsula of New Britain and observations on their life history have been discussed recently by Baloch (1973).

Further detailed parasite surveys were carried out throughout New Britain, New Ireland, Bougainville and Lihir Island and small collections from other areas were examined to determine the distribution and relative importance of parasites in the control of *A. cambelli*. These surveys yielded a further three records of parasites, two of them possibly new from *A. cambelli*. The parasites recorded were a strepsipteron (gen. et sp. indet.) which was collected from all areas examined, and two species of tachinids, one from New Ireland (gen. et sp. indet.), and *Trichopoda pennipes* F. from Bougainville.

T. pennipes has previously been recorded as ovipositing on *A. cambelli* in the British Solomons (O'Connor 1950) but has not previously been bred from *A. cambelli*.

Distribution details of egg parasites are shown in *Table* 2.

Table 2.—Distribution and relative abundance of *A. cambelli* egg parasites, *Trissolcus painei* and *Anastatus* sp.

Locality	Date	No. A. cambelli eggs examined	Aborted	Parasitised eggs			
				Trissolcus		Anastatus	
				No.	%	No.	%
Lihir Group	Nov./Dec. 1970	320	Not determined	43	13.4	14	4.4
Bougainville	Nov. 1971	891	22	427	47.9	48	5.4
New Ireland	Dec. 1971	41	Not determined	22	53.7	0	—

The overall rate of parasitism for *Trissolcus painei* Ferr. was 39.1 per cent. The highest individual recording was 70.2 per cent for a large collection of 191 eggs from Hohela, Buka Island. *Anastatus* sp. was bred from 5.4 per cent of eggs collected from Lihir Island and Bougainville, with the highest individual recording of 10 per cent of eggs attacked for a large collection of 400 eggs from Hagan, Buka Island. The highest combined total for the two eggs parasites was 59 per cent of eggs at Makela, Buka Island compared to the overall level of 44.2 per cent for all areas. This compares with a report of 64 per cent destruction of eggs on one island in the British Solomons (Lever 1934).

The other known egg parasite *Acroclisoides* sp. *?megacephalus* Gir. has been bred from eggs collected on the Gazelle Peninsula (Baloch 1973). It has since been bred in the laboratory from eggs collected at Massahet Island, Lihir group, some 26 days after the eggs were collected. It was not bred from any of the 891 eggs collected from eight widely scattered localities on Bougainville. It must be considered to be of very minor importance only.

The braconid nymphal parasite *Aridelus* sp., previously recorded from the Gazelle Peninsula (Baloch 1973) was not recorded from any other localities during the surveys.

Large collections of adults and nymphs of *A. cambelli* were collected from islands in the Bismarck Archipelago and examined for parasites. A strepsipteron (gen. et sp. indet.) parasite of adults was obtained from all areas so far examined. The tachinid parasite *Trichopoda pennipes* was bred from both adults and nymphs collected in Bougainville and another tachinid (gen. et sp. indet.) was bred from *A. cambelli* collected on New Ireland.

Details of collections are shown in *Table* 3.

It can be seen that tachinids are significant parasites of *A. cambelli* in regions where they are established. Of 1597 adults collected on New Britain 12.4 per cent had been attacked by *Pentatomophaga bicincta* de Meij., with a maximum rate of 15.5 per cent for 232 adults collected at Tavilo, New Britain. Of 952 adults collected on New Ireland 10.5 per cent were attacked by the unidentified tachinid with a maximum rate of 57 per cent of 88 adults

Table 3.—Relative abundance of tachinid and strepsipteron parasites of *Axiagastus cambelli* adults and nymphs

Locality	Date	No. of A. cambelli			No. and per cent with tachinids						No. and per cent with strepsipteron			
		Male ♂	Female ♀	nymph	Male ♂	%	Female ♀	%	nymph	%	Male ♂	%	Female ♀	%
1. NEW BRITAIN														
Gazelle Peninsula	Jan.-April 1971	666	884	46	61	9.2	137	15.5	0	—	21	3.2	50	5.7
Bainings	Mar. 1971	15	14	9	0	—	0	—	0	—	1	6.7	5	35.7
Lolabau Island....	Sept. 1971	5	17	0	0	—	0	—	0	—	0	—	0	—
TOTAL		682	915	55	61	8.9	137	15.0	0	—	22	3.2	55	6.0
2. BOUGAINVILLE														
Buka Island	May-Nov. 1971	476	601	122	23	4.8	38	6.3	5	4.1	4	0.8	13	2.2
North Bougainville	Nov. 1971	76	71	15	0	—	0	—	0	—	2	2.6	3	3.9
East Bougainville	Nov. 1971	156	113	147	3	1.9	3	2.7	4	2.7	5	3.2	2	1.3
S. W. Bougainville	May and Nov. 1971	199	291	145	9	4.5	19	6.5	1	0.7	5	2.5	6	2.1
TOTAL		907	1076	429	35	3.9	60	5.6	10	2.3	16	1.8	24	2.2
3. LIHIR GROUP														
Lihir Island	1970-71	904	1157	286	0	—	0	—	0	—	14	1.5	21	1.8
Massahet Island	Nov. 1970	93	68	0	0	—	0	—	0	—	1	1.1	2	2.9
TOTAL		997	1215	286	0	—	0	—	0	—	15	1.5	23	1.9
4. NEW IRELAND														
N.E. New Ireland	Dec. 1971	211	370	99	15	7.1	57	15.4	0	—	7	3.3	8	2.2
Kavieng West Coast	Dec. 1971	56	90	9	3	5.4	17	18.9	0	—	0	—	2	—
S.W. New Ireland	March and Dec. 1971	97	128	159	3	3.1	5	3.9	0	—	7	7.2	12	9.3
New Hanover Is.	March 1971	24	41	1	0	—	2	4.9	0	—	0	—	0	—
TOTAL		388	629	268	21	5.4	81	12.9	0	—	14	3.6	22	3.5
5. ANIR ISLAND	Aug. 1971	7	12	5	0	—	0	—	0	—	0	—	0	—
6. TANGAR ISLAND	Aug. 1971	20	52	2	0	—	0	—	0	—	0	—	0	—

from Fisova Village. *T. pennipes* attacked 4.8 per cent of 1983 adults examined from Bougainville, with a maximum of 14.4 per cent of 118 adults attacked in a collection from Laguai Village, Bougainville. *T. pennipes* also attacked 2.3 per cent of the nymphs collected on Bougainville.

No tachinid parasites were bred from or tachinid eggs noted on 2212 adults examined from the Lihir group or from smaller collections from Tangar and Anir Islands.

The strepsipteron parasite was isolated from 2.8 per cent of 6900 adults collected from all localities. On New Britain, 4.8 per cent of 1597 adults collected contained the strepsipteron with the highest recording of 8.8 per cent being from an individual collection of 353 adults from Napapar Village. 3.9 per cent of 952 adults collected from New Ireland were attacked by the strepsipteron, with a maximum of 13.9 per cent of 79 adults from Namatanai. 2.0 per cent of 1973 adults collected from Bougainville contained the strepsipteron with the highest individual recording being 5.7 per cent of 140 adults collected at Kessa, Buka Island. At Lihir Island, 1.7 per cent of 2212 adults collected were found to contain the strepsipteron. The highest individual collection was 10.3 per cent of a collection of 78 adults from Louise Harbour.

The strepsipteron was also isolated from a small collection from Anir Island.

The known distribution of the various parasites of *A. cambelli* is summarised in *Table* 4.

Table 4.—Known distribution of parasites of *A. cambelli* in Papua New Guinea

Stage of Axiagastus attacked	Parasite	Status of Parasites at Various Localities				
		Gazelle Peninsula	Lihir group	New Ireland	New Hanover	Bougainville
Egg	*Trissolcus painei*	+	+	+	0	+
	Anastatus sp.	+	+	+	0	+
	Acroclisoides ?megacephalus	+	+	+	0	+
Nymph	*Aridelus* sp.	+	0	0	0	0
Nymph and adult	*Pentatomophaga bicincta*	+	—	0	0	0
	Trichopoda pennipes	—	—	—	—	—
	Tachinidae, gen. et sp. indet.	—	—	—	—	+
Adult	Strepsipteron, gen. et sp. indet	+	+	+	+	—

Key: + = Present
— = Absent
0 = Status not known

INTRODUCTION OF TACHINID PARASITES, LIHIR ISLAND

Introductions of laboratory reared pupae of *P. bicincta* obtained from *A. cambelli* collected from the Gazelle Peninsula were undertaken at three localities on Lihir Island between January and December 1971. The pupae were placed in frond axils of palms which carried high *A. cambelli* populations and were free from the kurukum ant *O. smaragdina.* Releases were made at two plantations at opposite ends of the main island and in native groves at Louise Harbour.

Recovery surveys have been carried out in all areas but at the time of writing (January 1972) no recoveries of *P. bicincta* had been made from any of the release areas.

POSSIBLE FUNGAL PATHOGENS

During the course of these studies, field collected *A. cambelli* adults were held in the laboratory and examined for possible fungal pathogens. Two adults collected from Lihir Island were observed with mycelium growing from between the thoracic sternites. The fungus was subsequently identified by the Commonwealth Mycological Institute as

Aspergillus ochraceus Wilhelm. This fungus has also been isolated from pupae of the tachinid parasite *P. bicincta* on the Gazelle Peninsula.

No pathogenicity tests were carried out to determine whether this fungus was truly pathogenic. However the low frequency of occurrence suggests that the fungus is not of great importance in limiting *A. cambelli* populations.

OTHER PREDATORS

Willy wagtails (*Rhipidura leucophrys melaleuca* (Quoy and Gaimard)) and the common crow (*Corvus orru insularis* Heinroth) have been reported to feed on *A. cambelli* (Szent-Ivany in litt.). At Lihir Island, starlings (*Aplonis cantoroides* (Gray) and *A. metallicus nitidus* (Gray)) have been observed to pick up *A. cambelli* but where early instar nymphs of the coconut tree hopper *Segestidea insulana* Willemse are present in large numbers, the starlings show an apparent preference for this species. They feed voraciously on the young nymphs on the palm fronds and ignore the *A. cambelli* on the inflorescence.

Two species of unidentified lizards have also been observed to feed on *A. cambelli*, but it is doubtful whether they provide any worthwhile control.

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NEW SCOLYTIDAE AND PLATYPODIDAE FROM THE PAPUAN SUBREGION. 299. CONTRIBUTION TO THE MORPHOLOGY AND TAXONOMY OF THE SCOLYTOIDEA

by KARL E. SCHEDL*

ABSTRACT

Descriptions are given of fourteen species of Scolytidae: Margadillius papuanus, Cryphalus fugax, Taphroterus rosseli, Xyleborus abbreviatipennis, Xyleborus analis, Xyleborus annexus, Xyleborus chimbui, Xyleborus cruciatus, Xyleborus gorggae, Xyleborus granulipes, Xyleborus operosus, Xyleborus optatus, Xyleborus sus, *and* Xyleborus vestigator, *and seven Platypodidae*: Crossotarsus semicinctus, Crossotarsus ventrosus, Baiocis imitatrix, Platypus associatus, Platypus excellens, Platypus negatus *and* Platypus validus. *A description is also given for the first time of the female of* Platypus strenuus Schedl. *A new subspecies of Scolytidae,* Xyleborus emarginatus *Eichhoff* semicircularis *nov. subsp. is described.*

Margadillius papuanus nov. sp.

Dull piceous, 1.3-1.6 mm long, 1.6 times as long as wide. This new species looks like a *Cryphalus*, but the antenna shows a 3-jointed funicle, the club is circular in outline and has three strongly curved bands of sensatory pores and short setae.

Front convex, slightly aplanate below, minutely punctulate, rather densely punctured in the lower half, the punctures bearing short erect setae.

Pronotum much wider than long (23:18), widest near base, posterior lateral angles rectangular and rounded, sides subparallel on basal fourth, thence rather strongly incurved, apex broadly rounded, a subapical constriction merely indicated; summit just before base, anterior area obliquely convex, with moderately sized asperities on a wide area, basal area very short, minutely punctulate, pubescence short and erect covering the entire disc. Scutellum submerged.

Elytra somewhat wider (25:23) and 1.2 times as long as the pronotum, sides parallel on basal half, apex very broadly rounded, declivity commencing after the basal two fifths obliquely convex; disc subopaque, extremely densely covered with very small punctures bearing very small inclined and stout scales, the main rows indicated by glabrous lines, the same type of sculpture continued on the declivity.

Holotype in the Australian National Collection in Canberra, Australia, two paratypes in the Collection of the Entomology Section of the Department of Forests in Bulolo, Papua New Guinea, two paratypes in Collection Schedl.

Type-locality: Upper Manki Logging Area, Bulolo, Morobe District, 9.VI.1972, in sticky trap, F.R. Wylie.

The holotype shows a short transverse carina in the upper half of the front.

Cryphalus fugax nov. sp.

Ferrugineous, 1.46-1.66 mm long, 2.2 times as long as wide. A new species somewhat similar to *Cryphalus flumineus* Beeson, but the asperities on the anterior margin of the pronotum smaller, the sides of the pronotum more uniformly incurved from the base to the apex, and the vestiture of the elytra quite different.

Front convex, in the centre reduced to a narrow longitudinal band between the very large eyes triangularly widened below, minutely punctulate, a fringe of downwardly directed hairs along the epistomal margin.

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Pronotum wider than long (35:28), widest at the base, posterolateral angles rectangular and slightly rounded, sides gradually incurved from the base to the narrowly rounded apex, apical margin with four small asperities in the middle, a subapical constriction of the pronotum hardly noticeable; summit high, situated far behind the centre, anterior area obliquely convex, covered with widely spaced rather large and low asperities, interstices between them and the basal area minutely punctulate, with short erect pubescence, the hairs on the basal area more scale-like and inclined. Scutellum large, triangular and densely punctured.

Elytra slightly wider and 1.9 times as long as the pronotum, sides parallel on basal half, thence gradually incurved, apex moderately narrowly rounded, declivity commencing after basal half, obliquely convex; disc extremely densely and finely punctured, so that the two series, punctures of main rows and those of the interstices, are difficult to distinguish; the density of punctures on the supposed interstices irregularly threefold, on the declivity some of the interstrial punctures bearing stout semi-erect pale scales.

Holotype and one paratype in the American Museum of Natural History, New York, U.S.A., two paratypes in Collection Schedl.

Type-locality: Rambuso, Sudest Island, 0-100 m, Milne Bay District, 10.IX.1966, Fifth Archbold Expedition, collector L.J. Brass.

Taphroterus rosseli nov. sp.

Testaceous, 1.66-1.70 mm long, 2.7 times as long as wide. Smaller and somewhat more slender than the genotype *Taphroterus primitus* Schedl, also more cylindrical and the second interstice on the elytral declivity without granules or tubercles.

Front plano-convex, fairly shining, finely, rather densely punctured; antennal club subcircular with a suture close to the distal margin followed by a narrowly lunate space of short dense pubescence.

Pronotum longer than wide (35:31), postero-lateral angles rectangular, somewhat rounded, sides parallel on basal two fifths of the pronotum, gradually incurved in front, apex moderately broadly rounded, the subapical constriction merely indicated; summit in the centre, anterior area obliquely convex, densely covered by small asperities, basal area silky shining, minutely punctulate, shallowly punctured, scattered erect setae on anterior area and along sides. Scutellum triangular, shining, impunctate.

Elytra as wide and 1.4 times as long as the pronotum, sides parallel on basal half, apex very broadly rounded, declivity commencing just after the middle and rather steeply convex; disc shining; striate-punctate, the strial punctures rather large and closely placed but partly submerged, interstices narrow, each one with a series of extremely fine punctures difficult to recognize; declivity on the alternating interstices with a row of remotely placed small granules, also with a few setae between them.

Holotype in the American Museum of Natural History in New York, one paratype in collection Schedl.

Type-locality: Abaleti, Rossel Island, 0-50 m, Milne Bay District, 1-9.X.1956, Fifth Archbold Expedition, collector L.J. Brass.

Xyleborus abbreviatipennis nov. sp.

Female: Piceous, 5.0 mm long, 2.6 times as long as wide. This new species might be placed close to *Xyleborus flavopilosus* Schedl, but it is much larger, the pronotum being less cylindrical, the elytral disc with the punctures more numerous, larger and perforated in appearance.

Front broadly convex, very densely and rather coarsely punctured, with an impunctate longitudinal line in the middle, the pubescence inconspicuous except for a fringe of downwardly directed hairs on the anterior margin.

Pronotum slightly longer than wide (26:24), postero-lateral angles a little more than rectangular, sides slightly divergent on basal third, thence gradually incurved, apex very broadly rounded, apical margin armed with numerous low asperities, a subapical constriction hardly noticeable; summit rather high, just behind centre, anterior area obliquely convex and very densely covered with medium sized to very small asperities, basal area brightly shining, very densely and finely punctured, pubescence rather short but dense as far as not abraded. Scuttellum large, shining and impunctate.

Elytra about as wide and 1.4 times as long as the pronotum, sides parallel on basal half, apex very broadly rounded, declivity commencing after basal half, rather strongly convex, with a very shallow longitudinal sulcus below; disc shining, extremely densely and rather finely punctured, so that the punctures of the main striae are difficult to distinguish from those of the interstices, the density of the latter may correspond to two or threefold rows, apparently all punctures giving rise to rather long very fine semi-erect hairs except near the base where they might have been abraded; declivity with the longitudinal sulcus shallow, more narrow above. widening below, the lateral convexities low, a conical tubercle half way along the third interstices, smaller granules on all interstices above, on those towards the sides below and along the apical margin, the pubescence somewhat longer than on the disc.

Holotype in Collection Schedl.

Type-locality: Bismarck Geb., New Guinea, 1912, Burgers.

Xyleborus analis nov. sp.

Female: Ferrugineous, 3.2 mm long, 2.5 times as long as wide. A new species of the *Xylebori obtusi* allied to *Xyleborus flavopilosus* Schedl, but much smaller, the elytral disc more coarsely punctured, the declivity shallowly sulcate, and with the suture slightly elevated.

Front broadly convex, subshining, densely granulate-punctate, with sparse but long pubescence.

Pronotum slightly wider than long (32:30), postero-lateral angles only slightly more than rectangular, distinctly rounded, sides somewhat divergent on basal fourth, thence gradually incurved, apex broadly rounded, a subapical constriction difficult to recognize; summit in the centre, anterior area obliquely convex, extremely densely covered with very small asperities, basal area very densely punctured, sculpture very gradually changing from base to apex, with short rather dense pubescence. Scutellum moderate in size, shining, impunctate.

Elytra as wide and 1.6 times as long as pronotum, sides parallel on little more than basal half, apex very broadly rounded, declivity commencing just behind basal half, rather steeply convex; disc striate-punctate, the striae very fine, shallow and indistinct in parts, the strial punctures small and closely placed, interstices wide, each with a not quite regular row of fine punctures bearing semi-erect moderately long hairs; declivity with a wide but shallow depression, densely punctured, the punctures of the main rows of the same size as those of the interstices, but the latter giving rise to moderately long semi-erect setae, the two series of punctures difficult to separate.

Holotype in Collection Schedl.

Type-locality: Sydney, New South Wales, old collection.

Xyleborus annexus nov. sp.

Female: Ferrugineous, 4.9 mm long, 2.2 times as long as wide. Allied to *Xyleborus insulindicus* Egg., but somewhat smaller, the elytral disc with the interstices densely punctured, the apical margin of the declivity carinate near the suture only and the declivital face slightly convex.

Front broadly convex, subshining, minutely punctulate, with some moderately coarse punctures between the eyes, these becoming smaller and more remotely placed towards the vertex.

Pronotum slightly wider than long (26:24), postero-lateral angles a little more than ninety degrees, but slightly rounded, sides somewhat divergent on basal third, thence gradually incurved, apex narrowly rounded, beak-shaped, subapical constriction distinct; summit well behind centre, anterior area long, very obliquely convex and very densely covered with rather small asperities, basal area shining, with punctures of moderate size, smaller towards the sides, not very densely placed; pubescence moderately long on anterior area and along the sides. Scutellum large, shining, and impunctate.

Elytra somewhat wider (28:26) and 1.5 times as long as the pronotum, sides subparallel on little more than the basal half, apex very broadly rounded, declivity commencing after basal half of the elytra, rather steeply convex, apical margin carinate up to the seventh interstices; disc striate-punctate, the striae very fine and shallow, the strial punctures small and moderately densely placed, the interstices wide, with numerous punctures of similar size to those of the striae, their density corresponding approximately to twofold rows; declivital face slightly convex above, aplanate below, the punctation slightly finer but more densely placed than on the disc, the punctures of the interstices bearing very fine, moderately long hairs.

Holotype in Collection Schedl.

Type-locality: Papuan Highlands, Central District, 1959, Dr Szent-Ivany.

Xyleborus chimbui nov. sp.

Female: Body fuscous, pronotum paler, 2.04 mm long, 2.7 times as long as wide. Somewhat allied to *Xyleborus fragosus* Schedl, but the elytral declivity more abruptly declivous and the interstices of the elytral disc with some coarse granules towards the declivital face.

Front convex, shining, minutely punctulate and with some fine, scattered punctures; pubescence restricted to a short seam along the anterior margin.

Pronotum longer than wide (42:38), postero-lateral angles rectangular and somewhat rounded, sides subparallel on basal half, apex broadly rounded, a subapical constriction not distinct; summit in the centre, anterior area obliquely convex and with numerous fine and low asperities, basal area shining, minutely chagrined and also with very fine punctures, some short semi-erect setae on the anterior area and along the sides. Scutellum not visible.

Elytra as wide and 1.4 times as long as pronotum, base finely carinate towards the sutures, sides parallel on basal half, apex broadly rounded, declivity short, restricted to distal two fifths and obliquely truncate; disc with a shallow saddle-like transverse impression as is common in *Xylebori ephippiger* gradually fading out towards the base rather abruptly ceasing behind, basal fourth rather shining and with rows of fine remotely placed punctures, some still finer setose punctures on the interstices; after the basal fourth the striae distinctly impressed and the strial punctures becoming deeper and larger, the interstices with small uniseriately placed granules strongly increasing in size towards the declivity, with fine punctures between the granules giving rise to semi-erect setae; declivital face obliquely convex, the suture somewhat elevated, confusely punctured, the punctures rather dense and large but shallow, apical margin finely carinate.

Holotype in the collection of the American Museum of Natural History, New York, U.S.A., one paratype in Collection Schedl.

Type-localities: Peria Creek, Kwagira River, Milne Bay District, 50 m, 14.VIII.-6.IX.1953, Fourth Archbold Expedition, Geoffrey M Tate.

Kratke Mountains, Valley of upper Wanton River, Eastern Highlands District, 1400 m, 7-19.X.1959, Sixth Archbold Expedition, L. J. Brass.

Xyleborus cruciatus nov. sp.

Female: Piceous, brightly shining, 3.25 mm long, 2.7 times as long as wide. Allied to *Xyleborus* undatus Schedl, but distinctly larger, the second interstices of the elytra groove-like and impressed towards the declivity.

Front broadly convex, rather coarsely punctate, glabrous except for a fringe of downwardly directed hairs on the anterior margin.

Pronotum longer than wide (35:33), postero-lateral angles rectangular, the sides parallel on the basal two fifths, thence rather strongly incurved, apex very broadly rounded; summit moderately high, situated in the centre, anterior area very densely covered with rather small asperities, basal area silky shining, with numerous medium sized punctures, some erect setae on anterior area and along the sides. Scutellum very small, difficult to discern.

Elytra as wide and 1.4 times as long as the pronotum, sides parallel on basal half, thence gradually incurved, apex broadly rounded, declivity restricted to the posterior third of the elytra, rather abruptly declivous; disc shining, with rows of fine punctures in slightly impressed very fine lines on basal third, interstices finely punctured but the arrangement less regular, after the basal third the second interstices gradually widened and groove-like, impressed, ceasing rather abruptly and bearing a pointed tubercle at the commencement of the declivity, declivital face with the striae more strongly impressed, the strial punctures coarser, interstices three and five with some pointed setose tubercles, some similar tubercles on the sides, the pubescence more prominent.

Holotype in the Australian National Collection in Canberra, Australia, one paratype in Collection Schedl.

Type-locality: Vanapa River, Central District, 15.III.1972, in log *Dracontomelum* sp., F.R. Wylie. Compartment 5, Taun Logging Area, Bulolo, Morobe District, 18.V.1972, in sticky trap, B. Gray.

Xyleborus gorggae nov. sp.

Female: Ferrugineous, 2.7 mm long, 2.1 times as long as wide. Of similar size and sculpture as in *Xyleborus 12-spinatus* Schedl, but without teeth on the interstices four, five and six at the commencement of the declivity.

Front broadly convex, silky shining, minutely punctulate, glabrous except for a fringe of downwardly directed hairs along the epistomal margin.

Pronotum slightly wider than long (32:30), postero-lateral angles of more than ninety degrees, sides distinctly divergent on basal third, gradually incurved in front, apical margin armed with four asperities in the middle, the two median ones being much larger; summit just behind the centre, anterior area rather steeply convex and covered with medium sized asperities, basal area of a silky texture, minutely chagrined, also with some fine remotely placed punctures, a few short and erect hairs between the asperities on anterior area. Scutellum large, triangular, shining and impunctate.

Elytra as wide and 1.4 times as long as the pronotum, the sides subparallel on basal half, apex broadly rounded, angulate near the suture, apical margin finely carinate up to the seventh interstices, declivity commencing after the basal two fifths and very obliquely convex; disc shining, the short basal area with rather regular rows of punctures, the interstices with similar punctures but their arrangement more irregular, similar punctation also present on the sides; towards the declivity the punctures of the main rows in distinctly impressed striae, the first interstices following the declivital convexity and without any armature, the second interstices with a small pointed tubercle at the commencement of the declivity, the third interstices drawn out into large horizontal teeth projecting from the upper margin of the declivital face, the remaining interstices without any armature, declivital face rather strongly striate-punctate, the interstices densely but very finely punctured.

Holotype in the Australian National Collection in Canberra, Australia, one paratype in Collection Schedl.

Type-localities: New Ireland District, Papontamon, 30.IV.1969, in freshly fallen log "Gorgga" (Papatra Dialect Name), B. Gray. Wilelo, West New Britain District, 11.IV.1971, in *Eucalyptus deglupta* tree 42 hours after felling, B. Peters.

Xyleborus granulipes nov. sp.

Female: Ferrugineous, 2.2 mm long, 2.4 times as long as wide. A new species of the *Xylebori granulosi* easily recognized by the subquadrate pronotum, the very oblique elytral declivity and the sculpture of the latter.

Front plano-convex, rather shining, coarsely punctured, and with an indication of a longitudinal carina just above the anterior margin.

Pronotum about as wide as long, postero-lateral angles a little more than rectangular, sides slightly divergent on basal third, apex very broadly rounded, antero-lateral angles rather distinct; summit just behind the centre, anterior area densely covered with small asperities, basal area short, minutely punctulate, very finely and remotely punctured, pubescence short and erect, restricted to the anterior area and the sides. Scutellum triangular, shining, impunctate.

Elytra as wide and 1.4 times as long as the pronotum, sides parallel on basal half, apex broadly rounded, declivity commencing after basal two fifths, very obliquely convex, disc shining, with rows of moderately small punctures, those of the interstices distinctly smaller; declivity with the strial punctures somewhat larger and situated in well developed striae, the punctures of the interstices as large as those of the main striae, very closely placed and bearing very short semi-erect setae, apical margin armed with some small setose granules.

Holotype in the Australian National Collection in Canberra, one paratype in the collection of the Department of Forests in Bulolo, one paratype in Collection Schedl.

Type-locality: Mogova, Goodenough Island, Milne Bay District, 22.VI.1970, in freshly fallen log *Pterocarpus indicus*, J. Dobunaba.

Xyleborus operosus nov. sp.

Female: Dark reddish brown, 5.1 mm long, 2.3 times as long as wide.

Front largely covered by pronotum, as far as visible broadly convex and rather finely punctured.

Pronotum distinctly wider than long (15.5:13.5), postero-lateral angles rectangular and somewhat rounded, sides parallel on basal third, thence incurved, apex nearly transverse in the middle, antero-lateral angles well developed; summit distinctly behind the centre, anterior area obliquely declivous, rather densely covered with very fine asperities, not continuous to the anterior margin, along the latter a smooth transverse band on which a few setose punctures are situated, the short basal area with densely placed rather coarse punctures, pubescence long and erect, at least partly abraded. Scutellum minute, impunctate.

Elytra only slightly wider (17.0:16.5) and 1.9 times as long as pronotum, sides parallel on basal half thence gradually incurved, apex rather narrowly and somewhat angulately rounded, declivity commencing in the middle and obliquely convex; disc subshining, minutely punctulate up to the third interstices, more brightly shining on the sides, striate punctate, the strial punctures rather small, shallow and indistinct in parts, the interstices wide, each one with a row of remotely placed setose punctures, being subequal in size to those of the striae; the interstitial punctures replaced by setose granules on the first four interstices on the upper part of the declivital convexity, these granules becoming smaller and more remotely placed on the subshining lower part of the declivity, the latter faintly aplanate in the middle, apical margin finely arcuate near the suture.

Holotype in Bernice P. Bishop Museum, Honolulu, U.S.A.

Type-locality: Wau, Morobe District, 400 m, 26.IX.19?. J. & M. Sedlacek.

Xyleborus optatus nov. sp.

Female: Piceous, 2.5 mm long, 2.7 times as long as wide. A new species of the *Xylebori subsulcati* easily recognized by the sulcate elytral declivity and the five to six pointed tubercles on the lateral convexities. There is no closer relative in the Australian region.

Front plano-convex, minutely punctulate, rather coarsely punctured and with remotely placed rather long pubescence.

Pronotum longer than wide (25:23), postero-lateral angles rectangular, slightly rounded, sides parallel on basal half, apex moderately broadly rounded, apical margin with numerous low asperities, summit somewhat before the centre, anterior area convex and densely covered with rather small asperities, basal area minutely chagrined, not very closely rather finely punctured, with dense long pubescence as far as not abraded. Scutellum of medium size, shining and nearly impunctate.

Elytra as wide and 1.5 times as long as the pronotum, sides parallel on basal half, apex rather broadly rounded, declivity commencing after basal half and rather strongly convex; disc shining, with not quite regular rows of small punctures near base, these larger towards the declivity, interstices wide, finely reticulate, also with some irregularly placed punctures bearing rather long erect setae; declivity sulcate, the lateral convexities much higher than the suture and armed with five to six rather large pointed tubercles, sulcus coarsely and confusely punctured, some small granules towards the side margin of the declivity and the pubescence more conspicuous.

Holotype in Collection Schedl.

Type locality: Sydney, New South Wales, Australia, from an old collection.

Xyleborus emarginatus Eichhoff *semicircularis* nov. subsp.

Xyleborus emarginatus Eichhoff (*Ratio Tomicinorum* 1879:510) is widely distributed over the Indo-Malayan region, and its distribution extends in the north up to southern China. Two females of this species in the collection of Schedl have been compared with the type by Eggers. The apical emargination of the elytral declivity is always rather shallow, much wider than deep.

A cotype of *Xyleborus excesus* Blandford (*Trans. Ent. Soc. London*, 1894:119) to hand shows exactly the same general appearance and the same shape of the apical emargination of the elytral declivity, facts overlooked up to date. This is a new synonymy.

Xyleborus emarginatus also has been known from New Guinea. Among the specimens of this region there exist two quite different forms, the one corresponding with the beetles from the Indo-Malayan region, the other one with the apical emargination of the elytral declivity much deeper being nearly as deep as wide. It appears necessary to separate the two forms by proposing a new subspecies for the latter.

Holotype in the Australian National Collection in Canberra, Australia, three paratypes in the Collection of the Entomology Section of the Department of Forests in Bulolo, Papua New Guinea, and three paratypes in Collection Schedl.

Type-localities: Porotop Lutheran Mission Station, Western Highlands District, 6.III.1968, in *Syzygium* sp., D. H. Jeffers (S 255); Kum, 11 miles from Mt Hagen, Western Highlands District, 8.VI.1968, boring into fallen log, B. Gray and Sine (S 181).

Xyleborus sus **nov. sp.**

Female: Piceous, 4.0 mm long, 2.3 times as long as wide. *Xyleborus sus* n. sp. should be placed into the *Xylebori granulosi* near *X. cancellatus* Egg. and is easily recognized by its size, the opaque elytral declivity and the rather large tubercles on the alternate interstices.

Front broadly convex, silky shining, minutely punctulate, rather coarsely and densely punctured in the lower two thirds, pubescence inconspicuous except a fringe of downwardly directed hairs on the anterior margin.

Pronotum wider than long (42:39), posterolateral angles a little more than rectangular, only slightly rounded, sides somewhat divergent on basal two fifths, very broadly rounded at the apex, a subapical constriction difficult to recognize; summit in the centre, anterior area rather steeply convex, extremely densely covered by very small asperities, basal area fairly shining, very fine and extremely densely punctured, pubescence very short, largely abraded. Scutellum moderately large, shining, and impunctate.

Elytra slightly narrower and 1.5 times as long as the pronotum, sides parallel on basal third, thence very slightly narrowed in straight lines up to the distal third, apex rather abruptly incurved, broadly rounded, declivity commencing after basal half, rather steeply convex; disc (basal two fifths of the elytra) with extremely fine and dense punctation, the punctures of the main rows difficult to recognize and devoid of pubescence (abraded), thence and on the declivity striate-punctate, the striae at first rather deeply impressed, more shallow on the lower convexity, the strial punctures moderate in diameter and very shallow, interstices one and three each with a regular row of equidistant conical tubercles, some similar tubercles towards the sides but more irregularly placed, all interstices minutely punctulate, therefore appearing opaque, also finely punctured, the punctures bearing long semi-erect fuscous hairs, their density corresponding to two to threefold rows.

Holotype in Collection Schedl.

Type-locality: Sudost Neu Guinea, Moroka, Loria.

Xyleborus vestigator **nov. sp.**

Female: Ferrugineous, elytral declivity darker, 2.8 mm long, 3.2 times as long as wide. Allied to *Xyleborus persphenos* Schedl, but much larger, scutellum obsolete, elytral declivity finely granulate, without larger tubercles, apex strongly and rather abruptly cuneiform and apex blunt.

Front broadly convex, minutely punctulate, therefore silky shining, remotely, rather finely and shallowly punctured, the punctures bearing short erect hairs.

Pronotum longer than wide (24:22), posterolateral angles rectangular and somewhat rounded, sides parallel on basal half, apex broadly rounded, somewhat angulate when viewed from the front, apical margin with four subequal small asperities in the middle; summit well in front of the centre, anterior area obliquely convex, very densely and very finely asperate, basal area minutely chagrined, finely and sparsely punctured. Scutellum obsolete.

Elytra slightly narrower and 1.9 times as long as the pronotum, sides parallel on basal half thence rather abruptly cuneiform, apex obtusely rounded similar to certain species of the *Platypi oxyuri*; disc subshining, with very fine punctation, some of the interstrial punctures with semi-erect pale setae, these rather remotely placed even on the elytral declivity.

Holotype in the Australian National Collection in Canberra, Australia, one paratype in the Collection of the Entomology Section of the Department of Forests in Bulolo, Papua New Guinea, two paratypes in Collection Schedl.

Type-locality: Upper Manki Logging Area, Bulolo, Morobe District, 9.VI.1972, in sticky trap, F. R. Wylie (S 856).

Crossotarsus semicinctus **nov. sp.**

Male: Nearly piceous, brightly shining, 3.65-3.76 mm long, 3.5 times as long as wide. Somewhat allied to *Crossotarsus longicornis* Schedl, but slightly larger and stouter, and with a sharply pointed tubercle in continuation of the third interstices on the distal border of the elytral declivity.

Front flat, shining, minutely punctulate, rather densely covered with coarse setose punctures, a shallow transverse depression just above the epistomal margin.

Pronotum as long as wide, femoral emarginations shallow, angulate in front, gradually incurved behind, disc shining, minutely chagrined, finely and sparsely punctured, median sulcus short.

Elytra as wide and twice as long as the pronotum, sides parallel on the basal half, thence rather slightly incurved, with long and pointed postero-lateral angles, apical margin between the processes with three subequal emarginations formed by the spinose extensions in continuation of the third interstices mentioned above; declivity restricted to the distal third of the elytra, gradually convex above, with brightly shining, lunate, nearly perpendicular face below; disc with rather regular rows of very fine remotely placed punctures, the striae becoming deeper towards the apical margin of the declivity, the interstices slightly raised, nearly opaque, finely punctulate and with some fuscous semi-erect setae.

Holotype in the Australian National Collection in Canberra, Australia, six paratypes in the Collection of the Entomology Section of the Department of Forests in Bulolo, Papua New Guinea, six paratypes in the Collection Schedl.

Type-localities: Potogalai Logging Area, Hoskins, West New Britain District, boring in fallen log *Octomeles sumatrana,* 14.V.1971, F. R. Wylie and H. Ivagai, nr. 766. Kumbango Logging Area, Hoskins, West New Britain District, 16.V.1971, boring in fallen log *Eugenia* sp., F. R. Wylie and H. Ivagai.

Crossotarsus semicinctus **nov. sp.**

Male: Ferrugineous, 3.2-3.4 mm long, 3.3 times as long as wide. A new species somewhat similar to *Crossotarsus majusculus* Sampson, but much smaller, the elytral declivity distinctly higher and the postero-lateral angles more strongly developed.

Front flat, of a silky texture, minutely punctulate and indistinctly finely punctured, a fringe of setae along the anterior margin, a transverse row of more distinct and setose punctures at the commencement of the vertex.

Pronotum somewhat longer than wide, femoral emarginations of moderate depth, angulate at both ends, disc silky shining, minutely chagrined, with a few remotely placed fine punctures, a few of them being across the anterior margin with short erect setae, median sulcus very fine.

Elytra slightly wider (24:23) and twice as long as the pronotum, sides straight and parallel throughout, apex subtransverse when viewed from above, a little incurved just before the pointed postero-lateral angles, disc horizontal, truncated at the apex; disc shining, the first row of punctures indistinct but situated in a fine striae, without clearly defined punctation on the sides, in the distal fourth of the elytra increasingly striate-punctate, the interstices subcarinate, minutely punctulate, and each one with a few setose punctures at the apex; perpendicular declivity brightly shining, lunate in outline, slightly impressed, the postero-lateral angles slightly projecting and blunt at the apex.

Female of similar size and proportion as the male, front more distinctly punctate in the upper half, the punctures bearing semi-erect fuscous hairs, the elytra minutely chagrined, silky shining, without distinct punctation except for the finely striate first row, declivity restricted to the distal fourth of the elytra, rather abruptly convex, pubescence more prominent.

Holotype and allotype in the Australian National Collection in Canberra, Australia, 45 paratypes in the Collection of the Entomology Section of the Department of Forests in Bulolo, Papua New Guinea, 12 paratypes in Collection Schedl.

Type-localities: Upper Manki Logging Area, Bulolo, Morobe District, 9.VI.1972, nr. 865, in sticky trap, F. R. Wylie (Holotype and 35 paratypes); same locality and date but nr. 870 (allotype and 10 paratypes).

Baiocis imitatrix **nov. sp.**

Male: Ferrugineous, pronotum testaceous, 2.8 mm long, 4.3 times as long as wide. Of similar size and proportions to *Baiocis seminitens* Schedl, but the elytra perfectly horizontal as in *Baiocis pernanulus* Schedl, apex transverse, postero-lateral angles obtuse but slightly projecting.

Front flat, somewhat angulate towards the vertex, with shallow transverse depression below, brightly shining, minutely wrinkled in the upper half and in the middle below, sparsely and finely punctured, the punctures bearing short erect setae.

Pronotum distinctly longer than wide (21:16), femoral emargination short, deep, and angulate on both ends; disc shining, minutely chagrined along the median line in the anterior half, median sulcus fine and rather long, punctation indistinct.

Elytra as wide and 1.7 times as long as the pronotum, sides parallel on basal two thirds, slightly incurved behind apex transverse, postero-lateral angles obtuse, somewhat projecting beyond apex of the elytra; disc brightly shining, nearly impunctate, except the first row which is finely striate; the elytra thickened at apex; abdominal sternites concave.

Females of similar size and proportions, antennal scape somewhat larger, strongly flattened, the apical part of the elytra more trapezoid in outline, slightly convex above, the lower part not as perpendicular as in the male.

Holotype and allotype in the Australian National Collection in Canberra, Australia, two paratypes in the Collection of the Entomology Section of the Department of Forests in Bulolo, Papua New Guinea, 2 paratypes in Collection Schedl.

Type-locality: Upper Manki Logging Area, Bulolo, Morobe District, 9.VI.1972, in sticky trap, F. R. Wylie (S 863).

Platypus associatus nov. sp.

Male: Ferrugineous, 2.4 mm long, four times as long as wide. Another member of the *Platypi pseudoadjuncti*, the smallest species of this group and easily recognized by the declivital armature.

Front flat, slightly concave from side to side in the upper two thirds, subopaque, minutely punctulate, a few setose punctures along the anterior margin and across the beginning of the vertex.

Pronotum longer than wide (35:29), femoral emarginations deep, angulate behind, gradually incurved in front, disc shining, very densely covered with rather fine punctures, median sulcus long and fine.

Elytra somewhat wider and not quite twice as long as the pronotum, widest at the commencement of the declivity, much narrower in front; sides straight and distinctly divergent on basal four fifths, thence slightly narrowed, postero-lateral angles triangular, apex when viewed from behind with four triangular processes of equal length, the postero-lateral angles rather blunt at apex, a triangular extension from the beginning of the suture to the supposed third interstices producing a narrow notch between the postero-lateral angles; disc shining, with regular rows of very fine punctures in extremely fine striae on the basal two fifths of the elytra, thence the striae gradually becoming deeper, like narrow sulci, the interstices flat in front, indistinctly punctured, becoming carinate behind; declivity short, restricted to the distal fourth of the elytra, obliquely convex above sub-perpendicular below, first interstice gradually following the convexity of the declivity and with a series of setose punctures, interstices two to seven abruptly ceasing at the commencement of the declivity with small pointed spines, a large stout distally pointed tooth half way down the declivity on the third interstices, the tooth being only slightly longer than the apical margin, similar but blunter teeth in continuation of the interstices five and seven.

Holotype in the Australian National Collection in Canberra, Australia, and one paratype in Collection Schedl.

Type-locality: Buvusi, West New Britain District, 6.IV.1971. in felled tree *Eucalyptus deglupta*, B. Peters (nr. 719).

Platypus excellens nov. sp.

Male: Ferrugineous, 7.3 mm long, 3.3 times as long as wide. Somewhat allied to *Platypus pseudoselysi* Schedl, but the interstices 2, 4, and 6 reaching the commencement of the elytral declivity and terminating in small pointed tubercles.

Front flat, slightly concave from eye to eye, minutely punctulate, finely punctured, the punctures bearing short erect hairs, with a short longitudinal striga in the centre.

Pronotum slightly longer than wide (28:24), femoral emargination shallow, angulately ceasing behind, disc brightly shining, with some remotely placed very fine punctures, median sulcus moderately long and surrounded by a cordiform patch of very closely placed punctures.

Elytra slightly wider (28:24) and 1.9 times as long as the pronotum, sides parallel on basal four fifths, thence obliquely incurved, apex very broadly rounded, declivity very short and rather abruptly convex; disc shining, striate-punctate, the striae very fine, the strial punctures very small and partly submerged, towards the declivity the striae becoming deeper and wider, the interstices convex and terminating in small horizontal teeth, those of the paired interstices ceasing at the commencement of the declivity, the unpaired ones distincty longer projecting over declivital face, the third tooth longest, the others gradually shorter, declivital face opaque, minutely punctulate, granulate punctate, a slender cylindrical tooth in continuation of the fifth interstices, if viewed from above this tooth projecting over the apical margin of the elytra.

Holotype in Collection Schedl.

Type-locality: Sattelberg, Papua New Guinea.

Platypus negatus nov. sp.

Male: Ferrugineous, 3.2 to 3.7 mm long, 3.7 times as long as wide. General appearance very similar to *Platypus setaceus* Chapuis from the Philippines but somewhat smaller, a little more slender, the apex of the elytra more narrowly, triangularly, rounded, elytral declivity more obliquely convex, the tubercle on the seventh interstices near apical margin usually strongly reduced, the fourth abdominal sternite with a transverse row of pointed tubercles and the whole beetle with the pubescence inconspicuous.

Front flat from eye to eye, opaque, with a fine longitudinal sulcus in the centre, minutely punctulate, some scattered shallow punctures towards the vertex, the latter with a transverse row of longer setae rising from larger punctures.

Pronotum longer than wide (20:17), femoral grooves rather shallow, angulate at the anterior extremity, disc brightly shining, with numerous moderately fine punctures, somewhat more crowded around the long but very fine median sulcus, a row of setose punctures along the anterior margin.

Elytra slightly wider (25:23) and 1.7 times as long as the pronotum, sides subparallel on more than the basal half, apex a little more narrowly rounded than in *Platypus setaceus*, declivity restricted to the distal third of the elytra and obliquely convex; disc shining, striate-punctate near the base, the striae more sulcate behind, the strial punctures very small to indistinct, the interstices flat towards the base, more narrowly elevated near the declivity, on the latter each one with row of pointed granules alternating with short fuscous setae, a rather blunt tubercle on the third interstices on the lower half of the convexity, a similar tubercle, usually more reduced, on the seventh interstices. Fourth abdominal sternite with six small pointed tubercles arranged in a transverse row.

Female of similar size, but slightly stouter and with the apex of the elytra more broadly rounded than in the male. Vertex of the head more densely pubescent, pronotum with a cordiform patch of densely placed small punctures around the median longitudinal sulcus, the elytral disc of a more silky texture, the striae shallow to indistinct, the strial punctures largely submerged, the interstices minutely punctulate, the base of the third triangularly elevated and covered with transverse rugae; declivity shorter than in the male, the striae rather shallow, the interstices low, the granules extremely fine, the pubescence rather dense. Abdominal sternites without tubercles or teeth.

Holotype (male), and allotype (female) in the Australian National Collection in Canberra, two male paratypes in the Collection of the Department of Forests, Bulolo, one female and two male paratypes in Collection Schedl.

Type-localities: Gogol, Madang District, 23.I.1970, in freshly fallen log *Buchanania* sp., B. Gray (S 509). Pimaga Airstrip, Southern Highlands District, 25.XI.1969, in fallen log *Ficus* sp., B. Gray (nr. 461). Pimaga Airstrip, Southern Highlands District, 26.XI.1969, on fallen log *Spondias* sp., B. Gray (nr. 465). Kumbango Logging Area, Hoskins, West New Britain District, 16.V.1971, boring in log *Myristica* sp., F. R. Wylie and H. Ivagai (nr. 770).

Platypus strenuus Schedl fem. nov.

Female: Dark brown, elytra mostly yellow, 3.0 mm long, 3.4 times as long as wide.

Front broadly convex, with a shallow longitudinal impression in the centre, silky shining, minutely punctulate, indistinctly punctured, also with a short longitudinal stria on the bottom of the depression.

Pronotum as long as wide, widest behind the well developed femoral emarginations, disc of a silky texture, minutely chagrined, indistinctly punctured, median sulcus moderately long but not reaching the centre.

Elytra as wide and twice as long as the pronotum, sides parallel on basal two thirds, apex broadly rounded, declivity short, restricted to the distal third of the elytra; disc shining, with rows of extremely fine partly submerged punctures, base of the interstices one to three transversely granulate; declivity short, slightly convex above, perpendicular below, the entire declivity dark reddish brown, minutely punctulate, finely punctured, the punctures bearing very short setae.

*Allotype** in the Australian National Collection in Canberra, two paratypes in the Collection of the Department of Forests, in Bulolo, two more paratypes in Collection Schedl.

Type-localities: Wara sweet Logging Area, Kui, Morobe District, 10.II.1970, in freshly fallen log *Anisoptera polyandra*, J. Dobunaba; same locality, 10.II.1970, in freshly fallen log *Cinnamomum* sp., J. Dobunaba.

Platypus validus nov. sp.

Male: Ferrugineous, 2.8 mm long, 2.9 times as long as wide. Allied to *Platypus angustiformis*, but larger, with distinct posterolateral angles of the elytra and with a small semicircular emargination on the apical margin of the declivity.

Front flat, minutely punctulate, finely punctured, without distinct pubescence.

Pronotum much longer than wide (20:17), widest near base, femoral emargination very shallow, gradually incurved to the side-margins on both ends, disc brightly shining, very finely punctured, median sulcus rather long, devoid of pubescence.

Elytra distinctly wider and 1.8 times as long as the pronotum, sides subparallel on basal half, thence narrowed in arcuate lines, posterolateral angles well developed, triangular in outline, preceded by a very small pointed tooth in continuation of the ninth interstices, apical margin concave, interrupted at the suture by a small semicircular notch, declivity short, restricted to the distal third of the elytra and rather strongly convex; disc shining, polished and without remarkable pubescence, the short declivity rather densely granulate-punctate, the punctures bearing short erect setae.

Female of similar size and proportion to the male, but the pronotum with an oval patch of densely placed punctures, the elytra with the sides subparallel on the basal three fourths, apex rather abruptly incurved, apical margin subtransverse, declivity shorter than in the male but with the same sculpture.

Holotype (male) in the Australian National Collection in Canberra, Australia, allotype (female) in the same institution, four female paratypes in the Collection of the Entomology section of the Department of Forests in Bulolo, Papua New Guinea, one male, two female paratypes in Collection Schedl.

Type-locality: Taun Logging Area, Bulolo, Morobe District, 30.IV.1972, 5, 9, 10, 14, 17 and 18.V.1972, all in sticky trap, B. Gray.

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CONTROL BY ANTS OF PEST SITUATIONS IN TROPICAL TREE CROPS; A STRATEGY FOR RESEARCH AND DEVELOPMENT*

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ABSTRACT

More successes than failures have been reported in the literature of attempts at manipulation of ants for pest control in tropical tree crops. Hence, the concept of this kind of control is of more than academic interest, and it is from this standpoint that an approach is suggested to the evaluation and development of ant-induced control in such a crop.

A series of stages comprising definition of the pest problem, selection of a candidate ant species, development of techniques for manipulation of the ant, and estimation of the economic viability of a feasible control scheme are put forward.

The most difficult part of such a programme is the development of methods for establishing and maintaining large populations of the useful ant in the crop. The reasons for this vary from case to case, and some examples are discussed.

INTRODUCTION

IT is now well established that many species of ant which form large colonies have a profound effect on the species composition of the insect fauna within their foraging areas (Wheeler 1910). In Europe, Banks (1962) working on beans and Gosswald (1951), Wellenstein (1957) and others working on pine forests have recorded these effects, but most of the better documented cases relate to the effect of ants on the distribution of pests within tropical crops. *Table* 1 shows some examples from tree crops in the tropics. Attempts have been made to manipulate the ants concerned in some of these examples so as to spread the controlling effect of the ant at will over large areas. An indication of the outcome of those attempts is shown in the table, and it can be seen that there have been at least five successful cases. The concept of using ants as control agents in tree crops then, is much more than just a theoretical possibility. The present paper suggests a generalised approach to the evaluation and development of ant induced solutions to pest control problems, and considers some of the principles involved.

RESEARCH PROGRAMME

Figure 1 shows the main stages making up such a programme of evaluation and development, and the points at which the use of ants may be contra-indicated. The first step in any attempt at pest control is to define the pest problem, and in the tropics, particularly with tree crops, a complex of damaging organisms is usually involved. Obviously before starting to search for a solution to a particular problem, it is advantageous to know as much as possible about the biology of the pests involved and their interactions with the crop and with each other.

Stage 2 is to find out which possibly useful ant species are available. At first sight this appears to be an immense task because of the great diversity of tropical ant faunas. Wilson (1959), for example, collected 172 species of ant in two square kilometres of Papua New Guinea lowland rainforest. In any particular instance, however, a process of elimination quickly reduces the number of species suitable for further consideration to the order of five to ten.

First to be eliminated are all species not already present in the country in which the pest problem occurs. The risks incurred by

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Table 1.—Accounts of ants controlling insect pests of tropical tree crops

Ant	Pest	Success	Crop	Place	Author
Anoplolepis longipes	Pseudodoniella laensis	n.a.	cacao	PNG	Szent-Ivany 1961
Dolichoderus bituberculatus	Helopeltis sp.	yes	cacao	Java	Meer Mohr 1927
Oecophylla longinoda	Pseudotheraptus wayi	no	coconuts	Zanzibar	Van der Plank, 1960 Way, 1953
Oecophylla longinoda	Distantiella theobroma	n.a.	cacao	Ghana	Collingwood, 1971 Leston, 1970
Oecophylla smaragdina	Amblypelta cocophaga	yes	coconuts	Solomon Islands	Brown, 1959 Greenslade, 1971 O'Connor, 1950 Phillips, 1956 Stapley, 1971b
Oecophylla smaragdina	Amblypelta theobromae	n.a.	cacao	PNG	Szent-Ivany 1961
	Cephonodes hylas	no	tea	Assam	Corbett, 1937
Oecophylla smaragdina	Pantorhytes plutus	n.a.	cacao	PNG	Szent-Ivany 1961
Oecophylla smaragdina	Pseudodoniella laensis	n.a.	cacao	PNG	Szent-Ivany 1961
Oecophylla smaragdina	Tesseratoma papillosa	yes	citrus	Sthern China	Groff & Howard 1925
Wasmannia auropuncta	cocoa mirids	yes	cacao	Cameroun	Bruneau de Mire 1969
unidentified ant	unidentified species	yes	dates	Yemen	Botta 1841

Manipulation of ant to extend control: yes = successful
no = unsuccessful
n.a. = not attempted.

the introduction of an ant species into new geographical areas are too great for such a step to be taken with our present lack of knowledge of ant ecology. One only has to consider the problems which followed the accidental introduction of the fire ant into the southern states of the United States of America (Wilson 1958) to appreciate what can happen when the factors regulating the population of an introduced ant are not known.

Next to be eliminated are all those species not already present in the crop in the geographic region under consideration. This assumes that all those ants capable of inhabiting the crop environment are already doing so. This assumption may be false in the case of a crop recently introduced into an area or a crop which has been extensively sprayed with insecticide in the recent past. Ideally in such cases, time should be allowed for the ant fauna to stabilize itself before proceeding.

All ant species which forage exclusively in microhabitats, such as rotting logs, which are not inhabited by the crop pests can also be eliminated, as too can all species not foraging in high densities. The latter could not give the crop a sufficiently intensive protective cover.

In the case of cacao in Ghana, this process of elimination leaves some eight or nine species of ant only which are worthy of further investigation (Leston 1970, Room 1971). For cacao in Papua New Guinea the number is as low as two or three.

The short-list of possibly useful ants is next passed on to stage 3 in *Figure* 1. In stage 3 it is decided if any of the species has a potentially useful controlling effect on the pest complex. This can most easily be done

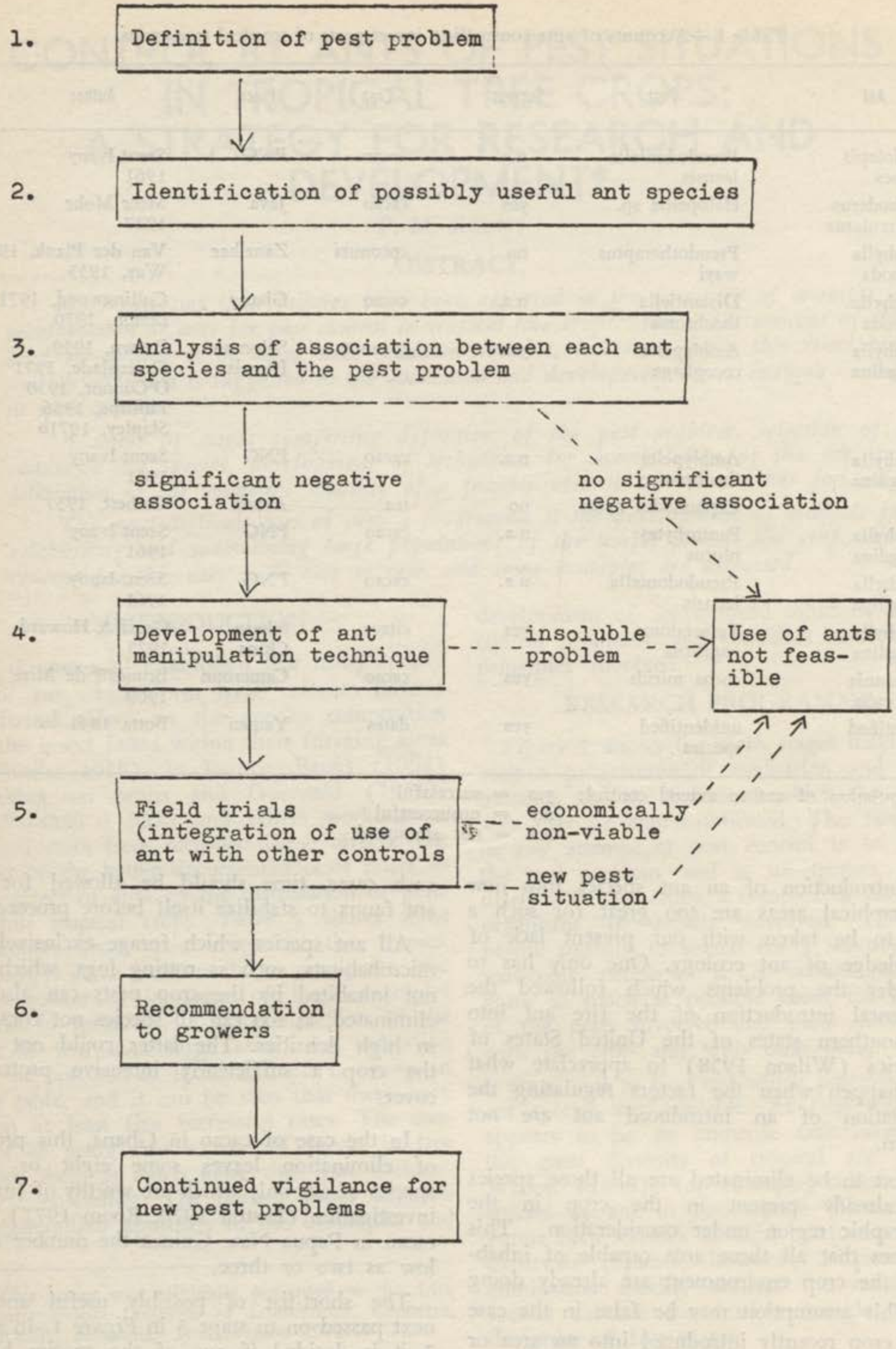

Fig. 1. Selection and development of an ant as a pest control agent

using some form of stratified random sampling technique designed to show how the pest and ant species are distributed with respect to each other in the crop. Care should be taken to separate distributional correlations reflecting true interspecific interactions, from correlations reflecting the action of other variables on the various species. In some tree crops, such factors as the species of tree used to give 'top shade' and the level of shade provided are important variables in addition to the factors which operate in all crops, such as the spacing of the crop plants, physiological condition of the crop and climatic effects.

If none of the short-listed ant species appears to affect the distribution of the pest complex in a beneficial way, then obviously some alternative to ant induced control must be sought. It may be found for example that an ant is negatively associated with part of the pest complex, and positively associated with the rest. Many predatory ants also tend plant feeding Homoptera and as a result are implicated in pest situations, sometimes even involving secondary transmission of plant virus or fungus diseases (Strickland 1951, Evans 1971). On the other hand, if one of the ants does appear promising, then a study should be made of how it can be spread and maintained throughout large areas of the crop. This is carried out in stage 4.

There is a great deal of evidence to show that in a reasonably uniform habitat, such as in a monocrop, the single most important factor affecting the distribution of an ant is the distribution of the other ants with which it competes for some limiting resource (Brian 1952, Leston 1971, Way 1958, Yasuno 1963). Thus, no rational attempt at changing the distribution of one ant in a crop can be made, without at the same time changing in a complementary way the distribution of its more important competitors.

Room (1971) examines the nature of competition in ant communities. Briefly: the most important competitors of an ant which forms large colonies are other ants which form large colonies. In such cases, it is usually observed that the ants do not compete for nesting resources, but rather for foraging area. Nesting resources are not usually limiting because most large colony ants build their nests with such super-abundant materials as soil, triturated vegetable fibres or living leaves. Food on the other hand, does appear to be a limiting resource, and most large colony ants seem to have adopted unspecialised feeding habits and the defence of large foraging territories to ensure its supply. These foraging territories are maintained almost entirely free from individuals from other large colonies, either of the same, or other species of ant.

Reference back to the correlation study carried out in stage 3 should make it abundantly clear with which other ants the potentially useful species has a mutually exclusive relationship.

DEVELOPMENT

The task in stage 4 now becomes one of introducing and maintaining large populations of the beneficial ant, while at the same time displacing and holding back the competitors of the beneficial species. This can be attempted in two steps.

First, the number of individuals of the original dominant ant inhabitants of the area must be greatly reduced. If species using single discrete nests are present, these nests and their inhabitants can be completely destroyed. If species having a large number of dispersed nests are present, then the whole area could be sprayed with a suitable nonpersistent insecticide, or poisonous baits could be used.

Next, before the original inhabitants or insurgent ants have time to build up large populations, the beneficial ant should be introduced. This should be done in such a way that the introduced species is present, and remains, in sufficiently large numbers to defeat any remaining or invading competitors.

To do this successfully, all the individuals introduced into a sub unit of the area must be from the same colony, otherwise inter-colony fighting will seriously reduce the number of introduced individuals which survive (Pontin 1969). In order to maintain the numerical superiority of the introduced species, its rate of worker production must be kept as high as possible. Obviously dealate queens must be introduced with the workers, and it must be ensured that the supply of food is adequate. If it was necessary to spray the crop to displace the original ant inhabitants, some food may have to be artificially provided for a while. In most cases, it would probably be necessary to introduce the Homoptera tended by the beneficial ant if the ant's food requirements are to be fully satisfied. This may present difficulties in that the timing of Homoptera introduction may have to be geared to the vegetative state of the crop. (e.g. flushing or fruiting) to ensure success.

Once a useful ant has been successfully introduced into an area, it might prove sufficiently resilient to maintain itself without outside help. Alternatively, the routine destruction of nests of antagonistic species and the provision of food during lean periods may be required. Provision of food in any instance would have to be carefully investigated because the foraging pattern of the ant might be disrupted to the detriment of its pest controlling effect.

If and when it is felt that an ant can be manipulated in a reliable and usable way, then the technique must be tested on a field trial basis to establish whether its use is economically viable or not. In particular, any deleterious effects arising from mutualistic relationships between the ant and Homoptera, such as disease transmission, should be assessed. At this stage it would also be advisable to consider the possibility of integrating ant induced control with other methods of control so that too much reliance is not placed on any one method.

EXTENSION

Finally, if the field trials of the complete control scheme are successful, the techniques can be recommended for general use with the crop, with the proviso that growers should remain alert for the development of new pest situations at all times.

PROBLEMS

In practice, most of the difficulties in a programme run along the lines just suggested would be expected to occur in stage 4: the development of ant manipulation techniques. The following are some brief examples of such problems.

The eradication of ants which compete with beneficial species can be difficult. *Pheidole megacephala* (Fabr.) has been particularly troublesome in attempts to spread *Oecophylla smaragdina* F. (Stapley 1971a) and *Anoplolepis longipes* (Jerd.) (Lancaster—personal communication). This is because its diverse nesting sites in the ground and in trees and its habit of constructing roofs over main foraging trails make it relatively inaccessible to insecticides. However Stapley (1971b) has recently overcome this problem using a combination of insecticides and cultural practices unfavourable to *Pheidole*.

The foraging density of an introduced ant can only be maintained if an egg-laying queen is included in each transplanted colony. *Oecophylla longinoda* (Latr.) and *O. smaragdina* would be much more useful in a number of tree crops throughout the old world tropics if only some means could be devised of ensuring the collection of the queen with each colony to be moved.

Obtaining populous colonies of some ants in an easily transportable form can be a problem. At present, the most promising approach seems to be the use of attractive artificial nests which can be sealed at a time of minimum foraging activity and then carried to the introduction site. In Cameroon, *Wassmania auropuncta* Roger has been transported in hand woven raffia trap nests (Bruneau de Mire 1969) and in Papua New Guinea *Anoplolepis longipes* was transported in bamboo nodes sealed with banana leaves (personal observation).

The maintenance of large continuous areas covered by a number of abutting foraging territories of the same species of ant may prove difficult in some cases. The reasons for this are complex, and have been dealt with in some detail by Room (1971). Briefly, it appears that one of the main reasons could be that the ants remove their particular prey spectrum so efficiently from within their foraging territories that they rely on immigration of prey from areas not foraged by them to maintain their supply of protein. The provision of proteinaceous food in such a way that the pattern and intensity of foraging are not unduly disturbed may help overcome this problem.

Finally, though an ant may be able to maintain a high rate of worker production in the environment of a crop badly damaged by pests, when the crop recovers conditions of food supply or nest site may become unsuitable. For example, a ground nesting species may have worker production reduced by a drop in nest temperature caused by an increase in the shade cast by a good crop canopy.

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A COMPARISON OF FOUR TYPES OF FLOOR FOR HOUSING GROWING PIGS IN THE HIGHLANDS

GEORGE MALYNICZ*

ABSTRACT

An experiment was conducted at Goroka (altitude 5,000 feet) with 16 pigs in a 4 x 4 Latin square to compare four different types of floor in a bush materials house. The floors used were elephant grass (Pennisetum purpureum) *deep litter, wooden slats, bare earth and concrete. No significant differences were observed for weight gain, food consumption or efficiency between any of the treatments.*

INTRODUCTION

Pig housing in the developing countries must fulfil two criteria. It must be cheap and it must be effective. For this reason as much use as possible must be made of materials available at no cost to the farmer. These include such materials as rough timber, bamboo, grass and leaves. Pig houses from such materials will spare the farmer the expense and technology involved with the more usual concrete and steel structures used in developed countries.

The two most important parts of a pig house are the roof and floor. The present study was concerned with evaluating four different types of floor with a bush materials pig house.

With respect to floors, Bond, Kelly and Heitman (1958) recommended that pigs in high temperature areas should have 15 square feet of shade per pig, that they should have access to wallows and that a concrete floor should be used, preferably cooled by surface moisture.

Meuhling (1969) reviewed the literature on space requirements and type of floor (solid v. slatted) for growing pigs. Combs and Wallace (1962) were the first to show the space allocations on concrete floors as low as 8 square feet were satisfactory. For slatted floors, similar minimal spatial requirements were shown by Jensen, Becker and Harman (1963).

Slatted floors are widely used in South East Asia by small producers (Marsh 1940); Jensen and Becker (1961) showed that pigs raised on slatted floors grew more quickly than those on concrete. The main advantage with slatted floors has been that they reduce labour requirements because they are self-cleaning.

There appears to be little published critical work on the use of deep litter for pigs. Godoy *et al.* (1970) compared wheat straw on concrete, wood boards on concrete and concrete floors for growing pigs. They found no difference in performance, but it is doubtful if a true fermenting deep litter was obtained. Unpublished work by the author (Malynicz 1970) has shown that there was no difference in weight gain or feed efficiency with pigs raised on elephant grass straw litter at spatial allocations ranging from 5 to 25 square feet.

The present experiment was conducted to compare elephant grass deep litter *Pennisetum purpureum*, rough timber slats, hand poured concrete and bare earth floors for growing pigs.

MATERIALS AND METHODS

A house was constructed from bush materials. This contained four pens with dimensions 5 x 10 feet. The whole house was roofed with *Imperata cylindrica* thatch. The roof was at an angle of 45 degrees, and it overhung the ends of the building by 3 feet. Provision was made to collect water from the roof. The walls were made from split timber posts. The four flooring treatments were allocated at random to the four pens.

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The deep litter pen contained a layer of 6 inch boulders on the ground with a layer of sun-dried elephant grass at an initial depth of 6 inches. Fresh straw was added daily sufficient to cover faeces.

The slatted floor was erected 1 foot above ground level. Rough timber slats were fashioned to provide approximate cross sectional dimensions of 3 x 1 inch. They were laid approximately 1 inch apart.

The third floor type was simply bare beaten earth. The last was a concrete floor laid by hand. There was no insulation or damp course. This is similar to concrete floors laid by village producers.

Four litters of four British pigs of various breeds were used in the experiment. All pigs were 15 weeks old at the beginning of the experiment. The feed for all pigs on the trial was a commercial 18 % crude protein ration* based on sorghum. Food and water were available at all times.

The experimental design used was meant to overcome the problems of uneven growth resulting from mixing litters and of differences between litters in growth rate. It was a 4 x 4 Latin square with litters forming columns and period forming rows. A Latin square was chosen at random from six described by Ruszczyc (1970).

Each period lasted 3 weeks and the whole experiment 12 weeks. The experiment was conducted during the months of November to February which is the wet season at Goroka (Clark pers. comm.). Pigs were weighed at the beginning and end of each period. Food consumption was recorded.

RESULTS AND DISCUSSION

Average daily weight gain, food consumption and efficiency are shown in *Table* 1. There were no significant differences between treatments, or litters, for any of the parameters. There were significant differences between periods for food consumption and efficiency.

The deep litter system is widely recommended in the Highlands where nights are cold and pigs can burrow into the warm compost. The slatted floor probably has more application for coastal conditions where temperature and humidity are higher, and maximum air circulation is needed. Slatted floors should be cleaned out regularly or poultry used to consume spilt food and fly larvae which might hatch.

Table 1.—Performance of growing pigs on different floors

	Type of floor			
	Deep Litter	Wood Slats	Bare Earth	Concrete
Ave. Daily gain (lb)	1.34	1.36	1.51	1.49
Ave. Daily Food* Consumption (lb)	5.23	5.28	5.38	5.78
Feed Efficiency[1]	4.01	3.99	3.65	3.90

* Significant differences occurred between periods.

The bare earth floor is not recommended for hygienic reasons. In this experiment no deleterious effects were observed. Over an extended period the ground would become heavily contaminated with parasites and microorganisms. The pigs dug out a wallow in the earth floor.

Significant differences occurred in food consumption and feed efficiency between different periods. Food consumption was lowest and efficiency highest during the first period and vice versa during the second period. There were no significant treatment x period interactions. There were no significant differences between litters on any of the parameters.

ACKNOWLEDGEMENTS

The author would like to thank Mr Mangiri Kipo for technical supervision of the experiment.

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REPORT ON A STUDY OF THE KURIVA SUBDIVISION, CENTRAL DISTRICT, 1970-72

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ABSTRACT

The results of two field surveys and air photo interpretation of the Kuriva Subdivision, Central District, show that clearing and planting of food crops is proceeding at a satisfactory rate.

The initial slowness in establishing settlers on the blocks could have been avoided by greater inter-departmental and inter-agency collaboration, and by more imaginative methods of team-clearing in the early stages.

THE limited aim of this paper is to make available data concerning the progress of settlement on the Kuriva River Subdivision obtained from surveys made in 1970 and 1971-72. The project originated as part of a larger study of the socio-economic effects of the Hiritano Highway. Two intensive surveys of the Kuriva Subdivision were carried out by students from the University of Papua New Guinea, the first in July 1970 by Joe Nalapan and Arnold Nindiga, and the second in December 1971-January 1972 by Joe Nalapan and Ralph Wari.

The Kuriva Subdivision occupies about 1,650 acres (670 ha.) of land between the Kuriva and Veimauri Rivers about 50 miles north-west of Port Moresby and about 10 miles east of Galley Reach in the Central District of Papua New Guinea. Inland it is adjacent to Administration owned land known as the Trans-Vanapa Timber Block, while on the south it is bordered by Boike Swamp, of which the part adjacent to the southern border of the subdivision is also Administration owned. The subdivision is crossed by the road now known as the Hiritano Highway which will link Port Moresby with Bereina and could continue eventually to Lae. The Kuriva River Bridge was completed in August 1970 and the section of road between the Kuriva and Veimauri Rivers in February 1972. This meant that the Kuriva subdivision had excellent access to Port Moresby by 1972.

The land of the subdivision is part of a purchase of some 3,200 acres made by the Administration from people of the Doura group from Douramoko, Vasagabila and Rabisi villages for £3,200 ($6,400) in 1959 (Lands Department Purchase DA2308). The area was covered by a timber lease, and was milled of its useful timber until September 1965 (Lands Department File 64/214g).

In accord with the Administration policy of making land available to smallholders with the aim of increasing the food supply to Port Moresby, approval for subdivision was granted by the Land Development Board in 1964 and survey was carried out during 1965 and 1966 (Lands Department File 64/214g). The first blocks were advertised for leasing in April 1967, others in May and October of 1968, others again in October 1970, while a few remained for advertisement in 1972.

There was keen competition for the blocks at every release, applicants outnumbering by several times the numbers of blocks available. Applicants included many indigenous people, but a number were also received from expatriate residents, some of whom were married to indigenous wives, and others who had existing business interests in the area. Most applicants intended garden production but some early enquiries included proposals for peanut growing, citrus production, poultry raising and a "butterfly factory".

Figure 1 shows the layout of the subdivision as at July 1971. There were at that date 55 blocks of which 1 was designated reserve

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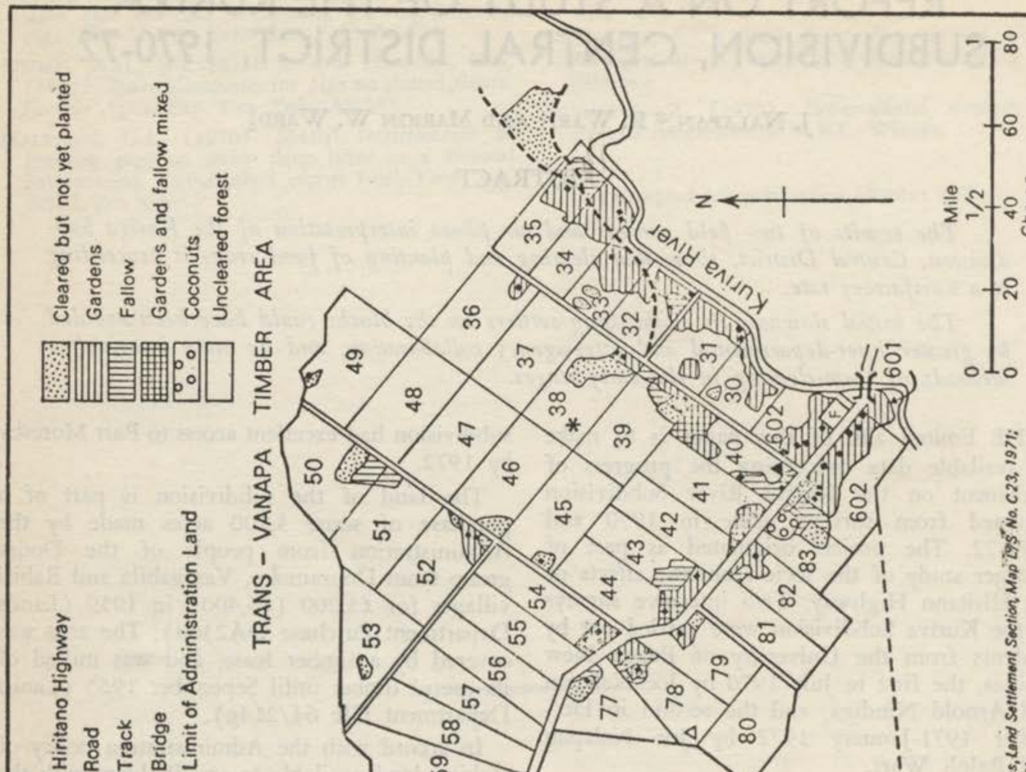

Figure **1. The subdivision as at July 1971** (intended for later development for community purposes of a school, recreation area and commercial leases) and 7 had yet to be advertised. By 1971, 47 blocks had been allocated, 9 in 1967, 6 in 1968, 23 in 1969 and 9 in 1970. However 7 of the allocated blocks had by 1971 either been suspended, forfeited, or were under recommendation of forfeiture, and would be readvertised for a second allocation, leaving 40 actually allocated. One blockholder held 4 blocks (2 agricultural and 2 associated with the sawmill), and four other blockholders had 2 (usually adjacent) blocks each, so that there were only thirty-three blockholders.

The size of 49 blocks for which this data is available ranges from 20-67 acres (8.09-27.13 ha.); the exceptional 67-acre block, which was held on a special 20-year lease, was already occupied by a sawmill and associated structures; without it the range is 20-50 acres (8.09-20.4 ha.); the mean size of block is 33.8 acres (13.68 ha.); the modal size 40 acres (16.19 ha.) and the median size 32 acres (12.96 ha.). The choice of size of the blocks was governed by the intended use of the blocks which in most cases would be extensive vegetable cultivation on a rotational basis, and within the capability of a family unit to manage. Hence a minimum of 20 acres of arable land was the basis on which sizes were determined. Only about 10 blocks fronting the Kuriva and Veimauri contain alluvial flats suitable for intensive cultivation; most are of not particularly good agricultural potential because of poor soil, stoniness or steep topography, and this probably accounts for the relatively large size finally used.

All agricultural leases are for 99 years, and the salient conditions of the Improvement Covenants for the leases of most blocks are:—

> Of the land suitable for cultivation the following proportions shall be planted in a good and husbandlike manner with a crop or crops of economic value, which shall be harvested regularly in accordance with sound commercial practice:—
>
> One-fifth in the first period of five years of the term, two-fifths in the first period of ten years of the term, three-fifths in the first period of 15 years of the term, four-fifths in the first period of 20 years of the term, and during the remainder of the term four-fifths of the land so suitable shall be kept so planted. Provided always that if at the end of the first 2 years of the term the lessee has not cleared and prepared for planting or planted a minimum area of one-tenth of the land so suited the Land Board may recommend the Administrator to forfeit the lease. . .

For blocks suitable for subsistence cultivation only the Improvement Covenant reads in part:—

> One-tenth (of the land suitable for cultivation shall be cleared and planted) in the first 2 years of the term; one-fifth in the first 5 years of the term; and during the remainder of the term one-fifth of the land so suitable shall be kept so planted . . .

These periods appear to imply anticipated rotation cycles of five to ten years, which does not seem unrealistic for the type of country and in this location.

The Physical Environment

The Kuriva Subdivision lies at the southern edge of the foothills of the Mount Cameron Ranges. The land is mainly gently to steeply undulating except for two narrow river flats along the Kuriva and Veimauri Rivers and the Boike swamp which enters the southern part of the area. Several small streams are tributary to the Kuriva River or drain to the Boike swamp. The Kuriva River is stagnant at the bridge, but is flowing less than one mile above it. The area falls within the Rubberlands land system which is described as lower forested ranges on red-weathering volcanic rocks; the long narrow ridges have bouldery slopes up to 20°, rarely to 35°, and up to 300 yards long, locally passing westward into low branching ridges less than 50 ft high (CSIRO 1965:49).

The area is generally forested with *Sterculia, Spondias, Pterogota* and *Pterocymbium* spp. on the lower ridges. In the northwest there are about 200 acres of secondary growth, while sago (*Metroxylon* spp.) occurs in the Boike swamp and *Planchonia* and *Nauclea* spp. with an understory of *Kleinhovia* around its edges (Soil Survey Report—West Kuriva Block, 31.3.1960:1).

2. Soils information in this and succeeding paragraphs is drawn from Soil Survey Report, West Kuriva Block, 31.3.1960.

Soils[2] are immature and have developed mainly from tuffaceous parent material. A large proportion of the area has a basalt boulder phase. The location of the three main types and their subdivisions is shown in *Figure* 2. Alluvial and light textured alluvial soils occupy 414 soils, made up of alluvial loams, clay loams acres along the Kuriva and Veimauri Rivers banks, and are well drained soils supporting light rain forest vegetation. They should be suitable for tree crops and gardens.

The soils of the undulating areas are shallow and immature. Boulder-strewn brown, light yellow brown and red brown sandy loams occupy 1,580 acres and support a moderately dense forest. Most of this area is unsuitable for tree crops, but could support subsistence gardening. The soils are shallow and stony and likely to experience water shortages in the dry season. There are about 402 acres of similar soils having a surface or subsurface gravel layer which are too gravelly for good crop production and which will dry out very readily. A further 188 acres have alluvial soils, predominantly brown loams. They are well drained and support light rain forest. They should be suited to subsistence cropping and tree crops, but their fertility is questionable.

The remaining soils are swamp soils or medium to poorly drained clay loams. The swamp soils proper occupy about 505 acres of Boike swamp, support swamp forest, sago (*Metroxylon* spp.) and geregere (*Pandanus odoratissimus*) and have little or no agricultural potential. Medium drained clay loams support a light vegetation on some 54 acres near the swamp. They could possibly be used for subsistence cropping but their potential is poor. The poorly drained clay loams occupy about 47 acres on the fringe of the swamp and have little or no potential.

The soils situation generally, then, is a discouraging one, with only some 400 acres out of the 3,200 acres of the original block having reasonably good agricultural potential.

Climatically the area falls into a border zone between the low rainfall of the coastal plains and the high rainfall of the main ranges of the interior. The nearest stations are Veimauri Estate some 4 miles west (which is reported to have an annual rainfall of 90 inches, with variation between 50 and 100 inches) and Brown River Forest Station some 15 miles to the southeast (which had an annual average rainfall over the last four years of 66 inches). The area falls within the zone experiencing 50-60 inches on Fitzpatrick's map (CSIRO, 1965:88) and it seems likely that it may receive 60-80 inches, owing to its closeness to the mountains.

The most significant feature of the climate of the area is a strongly marked dry season between April and November. There is likely to be a high variability of rainfall both monthly and annually, and rainless spells of 5-10 days in the wet season and of whole months during the dry season can be expected (CSIRO, 1965:90). These facts, coupled with the likely tendency of the gravelly and bouldery soils to dry out rapidly, indicate a likely water shortage especially during the dry season, hence irrigation may well be required. One block holder adjacent to the Kuriva River does intend to use water from this river for crop irrigation. Several bores were sunk on other blocks during 1971 some of which were successful and some not (see *Figure* 1), (District Agric. Office, File No. 3.2.4.2).

In common with nearby lowland areas mean temperature variation is relatively low, for Port Moresby ranging from approximately 77.5° F (25.3° C) in August to 83° F (28.3° C) in December (CSIRO, 1965:92). At all times temperatures are suitable for plant growth and there is no frost risk. Mean relative humidity is likely to be high throughout the year, and cloudiness, which is higher in the afternoons and between the months of May and September, is likely to be higher in this inland situation near the main ranges than in Port Moresby.

The Settlers

By 1971 there were 33 blockholders, one of which was the Catholic mission (and by 1973 housed a boys' town) and is excluded from further analysis, leaving 32 blockholders, some of whom held their blocks jointly with wives or other relatives. Of these 19 were identifiable as indigenous people, 2 were West Irianese, 6 were known to come from mixed race families, and 5 were expatriates (3 Australians, 2 from Europe), at least 4 of whom had indigenous wives.

Excluding the 5 expatriates information is available on the place of origin of 24 of the remaining settlers.[3] Thirteen of them came from Central District, and the majority of these

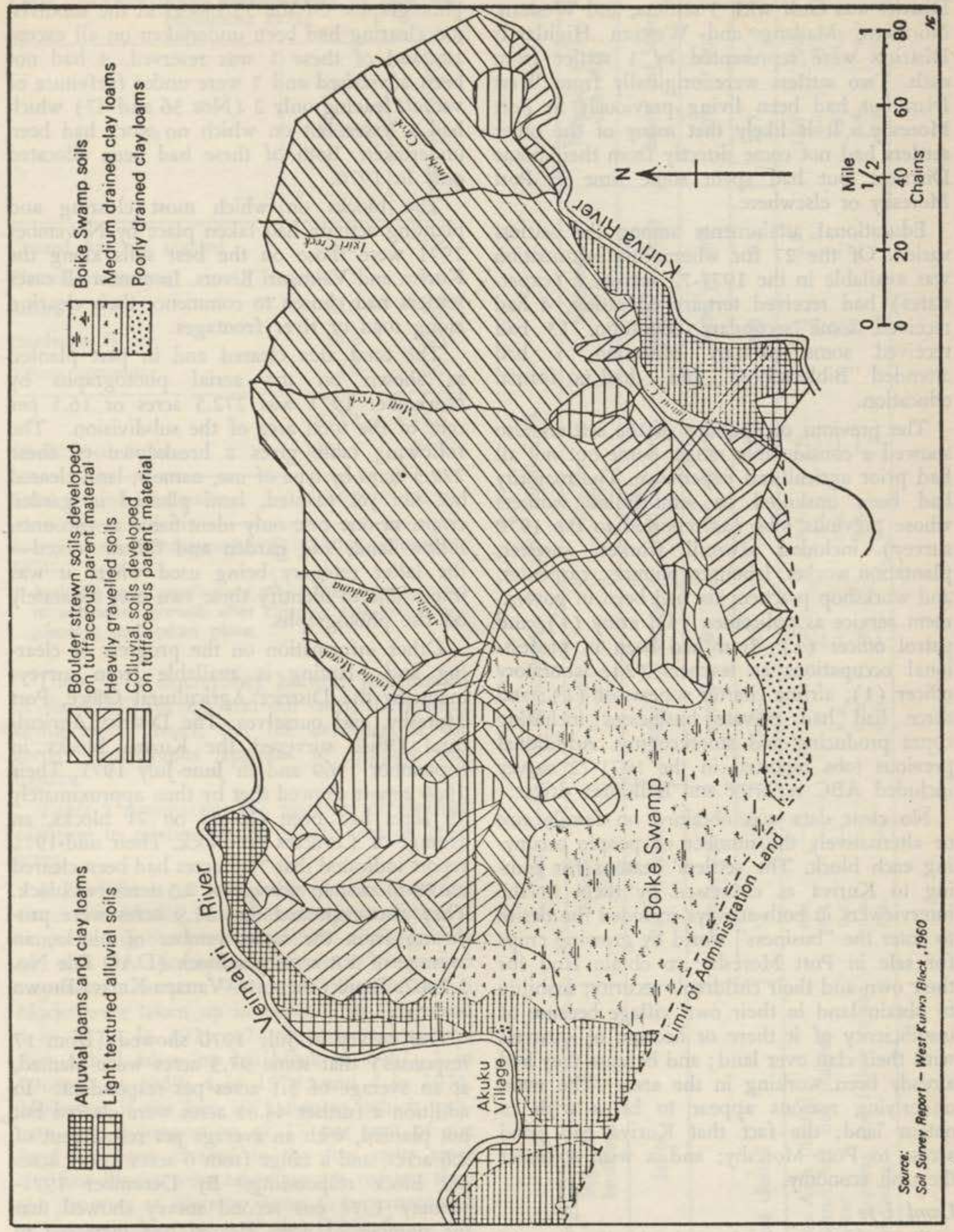

Figure 2. **The location of the main soil types**

from relatively nearby areas such as villages or plantations in eastern parts of Bereina subdistrict, 2 from Tapini subdistrict and 2 from Rigo subdistrict. The next best-represented

District was Gulf with 5 settlers, and Western, Northern, Madang and Western Highlands Districts were represented by 1 settler from each. Two settlers were originally from West Irian but had been living previously in Port Moresby. It is likely that many of the other settlers had not come directly from their home Districts, but had spent some time in Port Moresby or elsewhere.

Educational attainments among the settlers varied. Of the 27 for whom this information was available in the 1971-72 survey, 2 (expatriates) had received tertiary education, 4 had received some secondary education, 13 had received some primary education, 1 had attended "Bible school", and 7 had no formal education.

The previous occupations of the settlers also showed a considerable range. Some but not all had prior agricultural experience. The majority had been unskilled or semi-skilled workers whose previous jobs (as reported to the 1970 survey) included sawmill worker, forester, plantation worker, labourer, plumber, carpenter, and workshop practice; six had been in government service as policemen (4), army (1), and patrol officer (1); four had been in professional occupations as teachers (2), laboratory officer (1), airline charter supervisor (1); and three had had private businesses including copra producing and storekeeping. Additional previous jobs reported in the 1971-72 survey included ABC reporter and bulldozer driver.

No clear data was obtained on family size or alternatively the number of people occupying each block. The settlers' reasons for coming to Kuriva as expressed by them to the interviewers in both surveys included the desire to enter the "business" world by growing crops for sale in Port Moresby; to obtain land for their own and their children's security; inability to obtain land in their own village because of insufficiency of it there or because of quarrels with their clan over land; and because they had already been working in the area. The main underlying reasons appear to be a wish to obtain land; the fact that Kuriva had good access to Port Moresby; and a wish to enter the cash economy.

Land Use

Figure 1 shows land use in the Kuriva subdivision at November 1971 based on aerial photographs. Of the 55 blocks in the subdivision clearing had been undertaken on all except 12, and of these 1 was reserved, 4 had not been advertised and 5 were under forfeiture or vacant, leaving only 2 (Nos 36 and 47) which had a lessee but on which no work had been undertaken. Both of these had been allocated only in 1970.

The blocks on which most clearing and planting activity had taken place by November 1971 were those on the best soils along the Kuriva and Veimauri Rivers. In almost all cases settlers had chosen to commence their clearing along road or river frontages.

The total area cleared and in part planted as shown on the aerial photographs by November 1971 was 272.5 acres or 16.5 per cent of the total area of the subdivision. The following table gives a breakdown of these 272.5 acres by type of use, namely, land cleared but not yet planted, land planted in garden crops, in one case only identifiable as cocounts, fallow land, and garden and fallow mixed—the latter category being used where it was impossible to identify these two uses separately on the photographs.

Other information on the progress of clearing and planting is available from surveys made by the District Agricultural Office, Port Moresby, and ourselves. The District Agricultural Office surveyed the Kuriva blocks in September 1969 and in June-July 1971. Their 1969 report showed that by then approximately 38 acres had been cleared on 21 blocks, an average of 1.8 acres per block. Their mid-1971 report indicated that 71.3 acres had been cleared on 28 blocks, an average of 2.5 acres per block. They also estimated that 51.9 acres were producing from the same number of blocks, an average of 1.8 acres per block (DAO File No. 3.2.4.2. Project Report—Vanapa-Kuriva-Brown River).

Our survey in July 1970 showed (from 17 responses) that some 97.3 acres were planted, at an average of 5.1 acres per respondent. In addition a further 44.85 acres were cleared but not planted, with an average per respondent of 2.6 acres, and a range from 6 acres to 0.1 acres per block responding. By December 1971-January 1972 our second survey showed that the number of acres cleared had increased to 287, of which 156 acres were planted; 62 acres were cleared but not planted; and 69 acres were cleared and fallow.

3. Obtained by interview in 1971-72.

Table 1—Areas under various types of land use, November 1971

Use	Acres	Per cent of total area
Cleared but not planted	29.3	1.8
Planted in gardens	159.3	9.6
Fallow*	40.7	2.5
Garden & fallow	39.2	2.4
Young coconuts	4.0	0.3
	272.5	16.6
Undisturbed forest	1383.5	83.4
Total area of subdivision	1656.0	100.0

Source: Aerial Photography, (1:12,000), November 1971.

* Includes some small areas which may have reverted to secondary growth after clearing and before any planting had taken place.

There is a discrepancy between the results of the DAO surveys and our own, the former being much lower, but the evidence of the aerial photographs appears to support our figures.

Table 2 summarises the progress of clearing planting in relation to the whole area of 1656 acres.

It is difficult to assess this rate of progress since the blocks were taken up at different times during the period 1967-71, and our data on this is incomplete. Answers from 13 respondents in our 1970 survey showed that 3 blocks were taken up in 1967; 6 in 1969; and 4 in 1970. In 1971, 17 respondents indicated that 1 had taken up his block in 1967; 1 in 1968; 7 in 1969; 4 in 1970; and 4 in 1971. However, if the late 1971 figures, which indicate that a proportion of 17 per cent of the land has been cleared in the five years since the first blocks were taken up are correct, then the progress of clearing seems to be proceeding at a reasonable rate. If the DAO figure for mid-1971 of 4 per cent cleared to that date is taken, then progress would appear to be very slow indeed.

Table 2—Rate of development of Kuriva subdivision

Stage of Development	September 1969		July 1970		June-July 1971		November 1971		December 1971—June 1972	
Source	(DAO 1st Survey)		(Authors' 1st Survey		(DAO 2nd Survey)		Aerial Photography		Authors' 2nd Survey	
	acres	per cent	acres	per cent	acres	per cent	acres	per cent	acres	per cent
Total area cleared	38	2.3	142	8.6	71	4.3	273	16.5	287	17.3
Of which Area planted	n.a.	—	97	5.9	n.a.	—	163	9.9	156	9.4
Area cleared but not planted	n.a.	—	45	2.7	n.a.	—	29	1.8	62	3.7
Area fallow	n.a.	—	n.a.	—	n.a.	—	41	2.5	69	4.2
Area of gardens and fallow mixed	n.a.	—	n.a.	—	n.a.	—	39	2.4	n.a.	—
Area producing	n.a.	—	n.a.	—	52	3.1	n.a.	—	n.a.	—

Crops

A wide range of tropical fruit and vegetable has been planted by the settlers on the Kuriva blocks, prominent among them being the relatively quick maturing staple starches of bananas, sweet potatoes, corn, yams, taro and tapioca. *Table* 3 lists the number of plants of each species, as counted in our two surveys.

As would be expected the main crop combination on the Kuriva sudbivision (namely bananas, sweet potato, yams, corn, taro and tapioca) reflects that of the surrounding areas. The area lies at the northwest border of the area of banana-yam-sweet potato combination as shown by Lea and Ward (1970:57). These staples are supplemented by a wide range of fruits and vegetables among which papaw, pineapple, sugar cane, peanuts and cucurbits are significant. The long-term tree crops which have been planted are mainly coconuts, citrus and betel nut. A ready market exists in Port Moresby for the produce of all these crops sold fresh.

Livestock

Table 4 shows the numbers of livestock at the time of our surveys.

Fowls are the most numerous, and are a potential source of income for settlers though no sales of eggs or birds are yet reported. Several settlers expressed interest in building up their numbers of pigs and fowls for future income.

Housing

At the time of our second survey there was a total of 48 houses on the blocks, of which

Table 3—Crops planted, 1970 and 1971-72

Crop	Number 1970		Number 1971-1972	
	Mature	Immature	Mature	Immature
Banana (*Musa* spp.)	1971	1539	2898	6366
Sweet Potato (*Ipomea batatas*)	9307	2178	5559	11733
Corn (*Zea mays*)	440	463	5214	10677
Yams (*Dioscorea alata and D. esculenta*)	92	73	269	3219
Taro (*Colocasia esculenta and Xanthosoma*)	477	908	1028	3276
Tapioca (*Manihot utilissima*)	884	236	450	1114
Papaw (*Carica papaya*)	1411	27	578	858
Pineapples (*Ananas comosus*)	10	480	132	1353
Sugar cane (*Saccharum officinarum*)	388	135	547	1068
Peanuts (*Arachis hypogaea*)	60	79	—	1887
Water melon (*Colocynthis citrullus*)	—	26	756	325
Pumpkin (*Cucurbita* sp.)	71	6	51	126
Cucumber (*Cucumis sativis*)	—	2	23	123
Apica (*Hibiscus manihot*)	58	47	139	297
Beans	17	—	152	138
Cabbage (*Brassica oleracea*)	15	5	—	57
Onion (*Allium cepa*)	170	—	—	198
Tomato (*Lycopersicum lycopersicum*)	41	—	—	20
Egg plant (*Solanum melongana*)	—	—	185	40
Chili (*Capsicum* sp.)	—	—	57	50
Pit-pit (*Saccharum edule*)	15	15	—	—
Ginger (*Zingiber officinale*)	—	—	60	—
Malayan apples (*Eugenia malaccensis*)	—	3	—	9
Custard apples (*Annona squarosa*)	—	—	4	—
Copsicum (*Capsicum* sp.)	—	—	18	—
Passion fruit (*Passiflora* sp.)	—	1	2	10
Grenadilla (*Passiflora* sp.)	—	—	2	—
Rice (*oryza sativa*)	—	5	—	—
Coconut (*Cocos nucifera*)	—	555	1	1143
Citrus (*Citrus* sp.)	—	77	75	817
Betel nut (*Areca catechu*)	—	42	—	1505
Mango (*Mangifera indica*)	—	1	—	42
Bread fruit (*Artocarpus altilus*)	—	—	—	13
Castle nut (?)	—	1	—	—
Tobacco (*Nicotiana tabacum*)	10	9	25	—
Sorghum (*Sorghum vulgare*)	6	—	—	—

Source: Surveys.

Table 4—Livestock, 1970 and 1971-72

Animal	Number 1970		Number 1971-72	
	Mature	Immature	Mature	Immature
Pigs	—	5	13	13
Fowls	10	—	150	900
Ducks	—	—	30	36
Cassowaries	—	—	—	2

Source: Surveys.

21 were entirely of bush materials; 14 of sawn timber with an iron roof; 7 of bush materials with an iron roof; and 6 were incomplete. Many settlers first built a house of bush materials and were later replacing this with a more permanent structure, utilising the sawn timber available from the nearby sawmill. This accounts for the two houses on a single block shown in some cases on *Figure* 1. Some blockholders (often Europeans) have built substantial permanent houses; other structures are temporary shacks built to house workers in the initial stages of clearing. In keeping with local custom all are built on piles above the ground.

Production and Distribution

Unfortunately no quantitative data on production of various crops from the Kuriva blocks is available. However, the subdivision has already made some contribution to the food supplies of Port Moresby in that 2 blockholders have been meeting army contracts for the supply of sweet potato and papaw, and some produce has been supplied to the Port Moresby Teachers' Training College, Public Health Department, and the Catholic Mission in Port Moresby. Our 1970 survey reported that 3 blockholders had contracts to supply produce to the army or Public Health Department. Of these 1 was meeting a contract to supply weekly 1,700 lb of sweet potato and 1,200 lb of papaw.

Some settlers have begun to sell produce at Koki market. Of 30 responses to our question in the 1971-72 survey 1 indicated that the settler had visited Koki market to sell produce more than once a week; 5 once a week; 2 once in two weeks; 1 once a month; 6 more than once a month; 2 once in three months; 1 more than once in five months; 4 once a year; and 8 not at all, of which 5 were on new blocks.

There is no information on the amounts of produce sold, but among the crops taken to Koki sweet potato was the most prominent, followed by water melon and corn; cucumber, papaw, banana and pumpkin; then tapioca, sugar cane and pineapple. Small amounts of produce have also been observed for sale on roadside stands in the subdivision, and the weekend market for roadside selling to visitors from Port Moresby is probably not insignificant.

Production Inputs

The most important input has naturally been labour which has been provided by the blockholders and their relatives, and by employed labour. *Table* 5 presents the available information.

Table 5—Labour used in development of blocks

Labour source	1970	1971-72
Blockholders alone	10	11
Blockholders and relatives	10	—
Employed labour only	9	14
Blockholders and labourers	—	6
No. of respondents	29	31

Source: Interviews.

In addition in 1970 our survey reported that there were 23 labourers employed on 19 blocks (with an additional unspecified number of sawmill workers working part-time on one block); and that 21 family members (excluding blockholders) were working on blocks. The total number of workers on 19 blocks was 54, an average of 2.8 per block.

The hours worked on blocks ranged from 4 (an owner only case) to 48 per week in 1970, and from less than 20 to 45-50 in 1971-72. *Table* 6 presents our available data on this:—

Table 6—Hours worked per week on blocks

No. of hours	No. of blocks	
	1970	1971-72
4	1	—
less than 20	—	4
20-30	3	2
30-40	8	17
40-50	6	7

Source: Survey.

The average number of hours worked per week on the blocks in 1970 was 33.3 and 36 in 1971-72. If these figures are multiplied by the average of 2.8 workers per block in 1970 the total labour input would have been 93 hours per week per block in 1970, and 101 hours per week per block in 1971-72.

No information is available on other production inputs such as use of fertiliser, supply of planting material or seeds, irrigation, degree of mechanisation, etc., though it appears that there were at least 3 tractors privately owned in the area. Five of the blockholders own vehicles, 3 of which are utilities and 2 2-ton trucks. All are used personally by their owners, two of whom are expatriates.

Advisory and Financial Assistance

The two government sources from which advisory or financial help could be sought by settlers on the blocks are Department of Agriculture, Stock and Fisheries and the Development Bank. DASF help in the area had not been notably large by the end of 1971. The department intended to establish a field station on Portion 495 and this had been done by 1973. Some assistance in arranging the sinking of test bores had been given to those settlers seeking it. Our enquiries in 1970 and 1971-72 reported that in 1970 (4 out of 18 respondents) had been visited by a DASF officer, and in 1971-72, 6 respondents replied that they had had advice from DASF. It would seem that little change in this situation can be expected until DASF has a field officer resident on the blocks.

The Development Bank has granted loans to a few applicants for the development of Kuriva blocks. In 1972, 2 blockholders (out of 20 responding) reported to us that they had received loans from this source (both were expatriates), and 2 that they had made unsuccessful applications. In 1971-72, 3 (out of 29 responding) settlers reported that they had received loans from the bank. Presumably a number of the settlers (especially expatriates) were able to draw on their own financial resources for the development of their blocks, but the majority of the indigenous settlers would have little capital on which to draw.

Other Activities of Settlers

There is no systematic data available on this point, however a number of settlers do have other business activities. The most important of these is the sawmill which had been operating in this area for some years prior to the subdivision. Its owner has diversified into agriculture, already having planted a small coconut holding, and intending to diversify further into citrus production. Several blockholders were previously sawmill employees, and may still continue to work there on a part time or intermittent basis. A number of blockholders had previous employment in Port Moresby which they have continued at least until producing gardens are established on their blocks, and despite the intention of the leases that the recipients should work full time on their blocks.

One indigenous settler stated that he was working with others to save enough money to buy a community truck for the area, but this had not eventuated by 1971-72. Settlers are not, however, devoid of transport as passenger motor vehicle trucks (i.e. public passenger transport) serve the area from Port Moresby. The one-way fare to Port Moresby is $1.20, which at approximately 3c per mile is not exorbitant, but a settler would need to be confident of selling $5-$10 worth of produce before undertaking a trip to Koki to make a trip worthwhile.

There was in 1971-72 only one trade store at Kuriva, that attached to the sawmill, but there are others on the main road east of the subdivision.

Conclusions

The decision to implement the small land subdivision scheme at Kuriva was a minor part of the Administration policy aimed at increasing food supplies for Port Moresby. Other aspects of this have been the construction of the Rigo road to the south-east, which after 1966 linked the relatively fertile Kemp Welch (Wanigela) river lowlands and the large villages of the south-east coast to the town, and did increase food supplies to the town from that quarter (see Ward 1970-40-45). To the north-west and west the Hiritano Highway (earlier commonly known as the Brown River road) has been under active construction for some years and will within a short time cross the Aroa river and extend to Bereina, thereby providing good access to the capital from the potentially rich food supply areas of the western plains of the Central District. In addition the fertile lands of the Laloki flats well east of Kuriva have in part become available for settlement, though there exists no organised scheme in the area at present. These areas produced large amounts of vegetables for military use during the Second World War, and could again become major food suppliers (cf. Bowman 1946:431-33).

The Kuriva subdivision was initiated because the land was available to the Administration. Considering the eagerness of potential settlers to obtain land, and the small area involved, the allocation and actual occupation of the blocks appears in retrospect to have been a long drawn out process, continuing over at least seven years from 1964-71. There were of course problems, some of which stemmed from lack of interdepartmental collaboration. The initial subdivision was delayed by the renewal of the sawmilling licence over the area until 1965, without consultation between Forests and Lands departments. Some settlers began to clear the wrong blocks (solved by displaying the block numbers clearly on the blocks). Clearing along the Kuriva river bank caused heavy debris to float downstream threatening the Kuriva river bridge (solved by requiring the lessees not to clear forest along the river foreshore reserve). Indecision about the desirable location of the forest nursery was resolved by the Forests department agreeing to locate it on more suitable land on the Trans-Vanapa timber block further upstream on the Veimauri River. Squatters, at Akuku village on the Veimauri River, near the Kuriva River, and on the south side of the road in the middle of the subdivision presented problems, the latter case being resolved in one instance by returning the land to customary ownership or granting the lease of the appropriate block to the industrious squatter who had been developing it.

The progress of clearing and establishing production has been uneven, the most rapid progress being made by expatriates and others with greater financial resources who could afford to employ labour. The main problem is that felling heavy forest cover and preparing the ground for planting is an arduous task requiring considerable devotion to the project from the settler concerned. Experience in other resettlement schemes in Papua New Guinea has shown that indigenous settlers particularly resent what they see as a discriminatory lack of financial and advisory assistance to them in this first stage of resettlement (cf. Ploeg 1971: 115-6, and 1973:36). Possible solutions to this problem can be readily proposed: one would be to ensure that every settler (whether indigenous or not) has a Development Bank loan earmarked for this task. A second would be to arrange mobile clearing gangs with chain saws and perhaps small bulldozers to work systematically through such a land division as the Kuriva felling and preparing a suitable number of acres on each block each year. This would require adequate collaboration between, say, the Department of Lands, DASF, and perhaps Forests and Labour, and the Development Bank. It need not be very costly, and it would undoubtedly improve the morale of indigenous settlers.

Agricultural advice and extension work has been minimal in the Kuriva subdivision up to 1971-72. This may well be a function of the lack of trained staff available, but if the production of food for domestic consumption is to be an important part of future policy, then priorities in the allocation of resources will have to be adjusted to meet this need. The presence of an agricultural field officer actually living on the blocks in the early stages who could advise not only on planting and production but also on marketing and transport, and who could further diversification into small animal husbandry with its important corollary of increasing high quality protein availability, would have been and must now be a significant improvement for the majority of the settlers.

Other complaints of settlers included the condition of the access roads of the subdivision. This is a problem which could be simply overcome by interdepartmental collaboration, requiring probably only short but recurrent visits by a road maintenance group. However, Lands Department policy regards the Kuriva subdivision as a low cost scheme on which further expenditure is not justified at this stage.

The provision of community amenities was planned, but had hardly come to fruition by 1971-72. The most urgent need was for a primary school for settlers' children, and the Catholic mission had established one on Portion 601 by 1973. By 1971-72 no form of political organisation such as the establishment of a settlers' association had occurred, but it is to be hoped leaders will emerge (perhaps encouraged by an agricultural or community development officer?) to do this.

By 1971-72 the Kuriva subdivision was effectively established, but the individuals who had made most progress were by and large the expatriates with access to greater financial resources, greater technical resources, and greater organisational experience. This applies, however, only to the early stages. The efforts of some expatriate settlers had diminished by 1973 to the point where forfeiture was being considered in two cases. The scheme will probably progress and achieve its intended purpose of supplementing to a minor degree the food supplies of Port Moresby. The main lesson to be learned from its progress to date is that to be successful any development project must have co-ordinated support from many quarters. In the present and probably future situation in Papua New Guinea these quarters are likely to be government authorities whose priorities must accord with national goals.

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DRAINAGE REQUIREMENTS IN THE MARKHAM VALLEY

ABSTRACT

R. S. HOLLOWAY*

From the recent survey of the Markham Valley, information is presented that is relevant to possible drainage projects. The nature and extent of the poor drainage conditions are described, together with a discussion of the appropriate formulae for the calculation of field drainage spacings.

INTRODUCTION

POORLY drained lands occupy about 30,000 hectares in the Markham Valley. This is 27 per cent of the total area covered in a recent survey of soils and agricultural potential (D.A.S.F. Report) but represents 40 per cent of the non-gravelly soils which have better potential for arable cropping. Land drainage will be an important feature of any large scale agricultural development in this area which has as its goal the maximum productive utilisation of land in cropping activities.

The purpose of this paper is to draw together technical information made available by the recent survey that has relevance to possible drainage projects. This might be seen to have the combined utility of providing a preliminary appreciation of the type and magnitude of improvements required and of providing a framework for further investigations by identifying those aspects of importance to the designing of a drainage project.

Emphasis is given to two areas of the Markham Valley, namely the Erap-Rumu section and the neighbouring Rumu-Leron section (see *Figure* 1). By way of introduction to the discussion of drainage systems and their design, a summary is given of the nature and extent of the poor drainage conditions that are experienced in the Erap-Leron area. Background information on the selection of appropriate formulae for the calculation of field drain spacings is also provided.

1. *The nature and extent of poor drainage in the Erap—Leron area*

Surplus water on the valley floor is derived from four main sources.

(i) Direct rainfall;

(ii) Surface runoff from lands located upslope, especially the foothill catchments;

(iii) Seepage along the base of the piedmont, also derived mainly from foothill catchments; and

(iv) Radial subsurface flow and seepage from the main cross-valley streams.

It is not possible to estimate the relative contribution of each source to the condition of poor drainage. However, survey results have shown that large areas of land between the main rivers are subject to the wet conditions, commonly between December and May in most years.

The extent of poor drainage in the Erap-Leron area and the requirement for improvements for purposes of short-term cash cropping activities is indicated in *Table* 1. From this table it can be seen that of the total 39,000 hectares having some suitability for cropping in the Erap-Leron area at least 18,000 hectares (46 per cent) has a requirement for drainage if its productive potential is to be realised. A further 7,700 hectares (20 per cent) might be improved for cropping activities by stategically located drains or the improvement of natural drainage facilities.

The most common feature of poor drainage in the Markham Valley is the occurrence of ground water at shallow depth. Inundation, or very shallow flooding of the land surface, is also prevalent over extensive areas, especially following rains. Another important feature of poor drainage in the Erap-Leron area is the occurrence of highly alkaline soil conditions. Most soils in the Valley contain large amounts of free carbonates, and under poorly-drained conditions these dissolve to give calcium and

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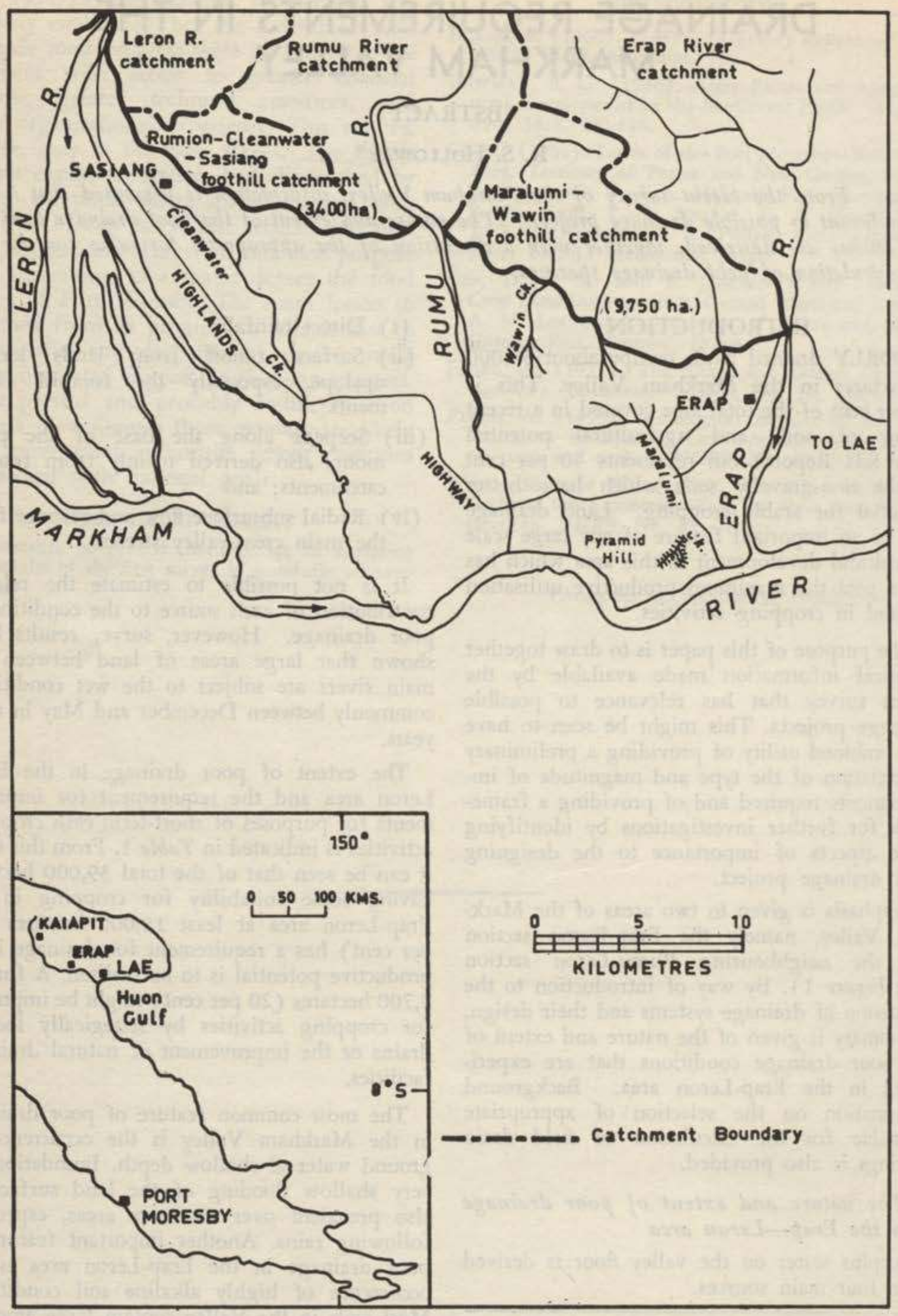

Figure 1.—Sketch map of the Erap—Leron area of the Markham Valley, showing foothill catchments and major drainage lines.

Table 1.—Classification of drainage requirements Erap-Leron

Sector	No requirement for drainage	Minor improvements may be necessary	Drainage required for row cropping	Not suitable for row cropping	Recommended not suitable for arable crops	TOTALS
Erap-Ramu (ha)	4,765	1,968	6,686	1,186	1,288	15,893
proportion (%)	30	12	42	8	8	100
Rumu-Leron (ha)	8,541	5,773	11,276	5,829	2,616	34,035
proportion (%)	25	17	33	17	8	100

magnesium bicarbonates. The calcium and magnesium ions displace sodium from the clay exchange sites, resulting in a build-up of sodium bicarbonate. In well-drained soils this sodium bicarbonate is readily leached, but under water-logged conditions it builds up and results in a serious pH rise, especially upon drying. Trace element availability is reduced in alkaline conditions and problems have been experienced with crop nutrition (e.g. rice).

The aims of drainage projects in the Markham Valley would thus be two-fold: firstly the removal of excess water, and secondly the creation and maintenance of soil conditions suitable for cropping.

2. *Selection of formulae for calculating spacings of field drains.*

Most drain spacing formulae have been developed on the basis of steady-state flow conditions i.e. continuous steady rainfall, discharged uniformly by drains and with a state of equilibrium between supply and discharge. It will be apparent that this situation does not occur in practice, especially where the poorly-drained condition derives from seasoned yet variable rainfall, surface run on and subsoil seepage. The non-steady state condition is characterised by rising and falling watertables such is common throughout most of the poorly drained lands in the Markham Valley. Despite this fact W.F.J. van Beers (1965) indicates that the use of a steady-state formula is in many cases entirely justified, especially since the hydrological constants are difficult to define with accuracy for non-steady state formulae.

In order to calculate the required drain spacing in a given hydrological situation, the required intensity of the drainage system should be known. This drainage intensity is given in quantitative terms by the drainage design criteria.

For a steady-state formula, the drainage design criteria for a given drain depth are the maximum permissible height of the ground water midway between the drains and the corresponding projected discharge. The design discharge (q) is determined by the mean rainfall distribution; the available hydraulic head (h) being determined by the depth of the drains and the minimum permissible depth of the ground water. The latter is an agronomic criterion and for arable cropping in the Markham Valley 0.5 m is considered to be a suitable value. For natural grassland and improved pastures a lower value might be acceptable, but since cropping rotations are a desirable feature of land use in the valley, the design should be based on the enterprise having the greater requirements.

For the non-steady formula the drainage intensity is determined by the required fall in the watertable over a chosen number of days, starting from a given unacceptable level.

One of the most important factors affecting the flow of ground water into a drainage system is the position of an impermeable layer (or 'barrier layer') with respect to the drains. Different drain spacing formulae are applied for different locations of the impermeable layer, and the first problem is thus to define the soil conditions so that the appropriate formula can be selected.

In general terms it can be stated that the deeper the impermeable layer, the smaller will be the horizontal resistance and the greater will be the radial resistance component of the total flow resistance which determines drain spacing. Also, the smaller the horizontal resistance factor, the greater can be the drain spacing for equivalent effectiveness in ground water removal.

There is insufficient deep soil data available from the Markham Valley to enable accurate definition of particular soil profile conditions in any given area. Drain spacing calculations have thus been undertaken for both extremes of the range of likely conditions.

METHODS AND RESULTS

1. *Estimation of surplus water derived from foothill catchments*

Water from the small foothill catchment on the northern side of the valley contributes to the condition of poor drainage on the valley floor because few of the streams have direct channel access across the valley to the Markham River. Most of the water from these streams goes underground on the piedmont and may re-appear in seepage zones at some point down slope, or may contribute directly in inundation of the surface at relatively low lying points in the landscape.

Rainfall records from Erap (20 yrs) and Sasiang (9 yrs) were used for the purpose of estimating the general magnitude of discharges from two such catchments:

(i) Maralumi-Wawin foothill catchments; and

(ii) Rumion-Cleanwater-Sasiang foothill catchment (see *Figure* 1).

Weekly totals of rainfall registrations from Erap and Sasiang were processed under 'WATBAL', (Keig and McAlpine 1969), a computer system designed by officers of CSIRO for the estimation and analysis of soil moisture regimes. Results provided an estimate of the amounts of surplus water after allowing for evaporation, transpiration and soil storage requirements (Appendix I.) These surpluses were determined on a weekly basis throughout the period of rainfall records.

Surpluses indicated for Erap and Sasiang were combined in order to judge the magnitude of discharges according to selected frequencies of occurrence (*Table* 2 volumns 1 and 2 A). An inspection of daily rainfall registrations at both stations enabled a probability estimate of surpluses on a daily basis according to amount. In these instances the surplus was taken to be 10-15 mm below the corresponding daily rainfall quantity (*Table* 2—columns 1 and 2 B). Discharge estimates given in *Table* 2 were obtained by directly relating these calculated surpluses to the area.

2. *Field drainage*

Calculation of theoretical spacing requirements for a range of conditions on agricultural land.

A. *Choice of formulae*

(a) Formula for calculating drain spacings in a homogeneous soil with impermeable layer at great depth

$$h = \frac{qL}{K} \ln \frac{L}{u}$$

(Ernst 1954, Toksoz and Kirkham, 1961; cited in van Beers, 1965).

h = height of the watertable above drain level midway between the drains (metres).

q = rate of rainfall or drain discharge per m^2 of area drained (m^3/m^2/day = m/day).

L = spacing of drains measured between centres (metres).

K = hydraulic conductivity (m/day).

ln = log..........., (2.3 $\log_{10}$ ....).

u = wetted perimeter of drain (metres).

Table 2.—Water surpluses and estimated discharges from foothill catchments

Frequency of occurrence (Years)	Surplus water	Discharge from catchment (millions of cubic metres): Maralumi—Wawin (area 9,750 ha)	Discharge from catchment (millions of cubic metres): Rumion—Cleanwater—Sasiang (3,400 ha)
		A. *Weekly*	
1 in 1	90 mm	8.8 per week	3.1 per week
1 in 5	110 mm	10.7	3.7
1 in 10	140 mm	13.7	4.8
1 in 20	190 mm	18.5	6.5
		B. *Daily*	
1 in 1	65 mm	6.3 per day	2.2 per day
1 in 5	85 mm	8.3	2.9
1 in 10	105 mm	10.2	3.6
1 in 20	125 mm	12.2	4.3

This is a steady-state formula and can be considered as representing the soil condition presenting the least problems for effective drainage. It has been used in calculating the spacings required on Soil type A as shown in *Tables* 3 through 6.

(b) Formula for calculating drain spacings in a homogeneous soil with an impermeable layer at shallow depth (less than $\frac{1}{4}$ of the distance between the drains)

$$h = \frac{qL}{8K_1D_1} + \frac{qL}{K_1} \ln \frac{Do}{u}$$ (Ernst 1954; cited in van Beers 1965).

K_1 = hydraulic conductivity in layer of thickness D_1 (m/day).

Do = thickness of layer for which the radial resistance is calculated. Water level to layer of different permeability (metres).

D_1 = average cross-section for the horizontal component. (D_1 = Do + 0.5 h) (metres).

Other parameters as described above.

This also is a steady-state formula and has been applied in this current work to represent the most difficult conditions expected in the Markham Valley. It has been used to calculate spacings on Soil type B in *Tables* 3 through 6.

(c) Formula for calculating drain spacings for transient flow conditions in a soil with an impermeable layer at shallow depth (less than $\frac{1}{4}$ of the distance between the drains).

$$j = \frac{VL^2}{\pi^2 KD}$$ (Glover/Dumm, 1954; cited in van Beers, 1965).

where $D = Do + \frac{ho + ht}{4}$.

j = reservoir coefficient (in days). Incorporates main hydrological properties of a given situation.

V – volume fraction of pores drained at a falling watertable. This can be estimated by $V = \sqrt{K}$, where K is in cm/day and V is expressed in ratios by volume.

ho = midpoint watertable height at beginning of drainout period (metres).

h_t = midpoint watertable height at end of drain-out period (metres).

Other parameters as described above.

Table 3.—Spacing required for the drainage of soils having moderate permeability (3 cm/hour) using ditches 1.5 metres deep (metres)

Amount of water to be removed per unit area (q)	Soil type	Depth to watertable midway between drains			
		0 m	0.5 m	0.75 m	1.0 m
0.004 metres/day (5n in. per month)	A	150	114	90	66
	B	78	60	51	40
0.008 metres/day (10 in. per month)	A	90	66	52	38
	B	54	42	35	28
0.016 metres/day (20 in. per month)	A	52	38	30	22
	B	37	29	24	19
0.024 metres/day (30 in. per month)	A	38	26	22	18
	B	30	23	19	15

Table 4.—Spacing required for the drainage of soils having moderately rapid permeability (8 cm/hour) using ditches 1.5 metres deep (metres)

Amount of water to be removed per unit area (q)	Soil type	Depth to watertable midway between drains			
		0 m	0.5 m	0.75 m	1.0 m
0.004 metre/day (5 in. per month)	A	340	255	200	143
	B	130	100	84	67
0.008 m/day (10 in. per month)	A	200	143	115	83
	B	91	70	59	47
0.016 m/day (20 in. per month)	A	115	83	67	47
	B	63	49	41	33
0.024 m/day (30 in. per month)	A	83	60	47	35
	B	51	39	33	26

This is a non-steady state formula and has been used to enable comparison of results from the steady-state formula for different

Table 5.—Spacing required for the drainage of soils having rapid permeability (15 cm/hour) using ditches 1.5 metres deep (metres)

Amount of water to be removed per unit area (q)	Soil type	Depth to watertable midway between drains			
		0 m	0.5 m	0.75 m	1.0 m
0.004 metres/day (5 in. per months)	A	600	440	345	245
	B	150	134	116	93
0.008 m/day (10 in. per (month)	A	345	245	190	140
	B	122	98	82	65
0.016 m/day (20 in. per month)	A	190	140	108	77
	B	85	66	57	45
0.024 m/day (30 in. per month)	A	140	98	77	57
	B	70	55	46	37

Table 6.—Spacing required for field ditches 1 metre deep to draw watertable 0.5 metres below land surface (metres)

Permeability	Soil Type	Amount of water to be removed (m/day)			
		0.004	0.008	0.016	0.024
Moderate 0.72m/day (3 cm/hour)	A	60	34	20	16
	B	38	26	17	13
Moderately rapid 1.92 m/day (8 cm/hr)	A	132	76	42	32
	B	65	45	31	24
Rapid 3.60 m/day (15 cm/hr)	A	230	128	71	52
	B	91	63	43	35

drainage conditions. It has been used in the calculation of drain spacings required on Soil type A and Soil type B is shown in *Table* 7.

B. *Parameter values*

(a) Height of watertable above drain level midway between the drains, h (meters). Drain spacings were calculated for drain depths of 1.5 m and 1.0 m using the steady-state formula.

Four values of h were applied, as follows:—

Drain depth	h values	Watertable depth
1.5 m	1.5 m	0.0 m (surface)
1.5 m	1.0 m	0.5 m
1.5 m	0.75 m	0.75 m
1.5 m	0.5 m	1.0 m
1.0 m	0.5 m	0.5 m

For the transient flow formula two drain depths were also used. Values for ho and ht were taken as follows:—

Drain depth	Value ho	Value ht	Watertable depth
1.5 m	1.5 m	1.0 m	0.5 m
1.0 m	1.0 m	0.5 m	0.5 m

Table 7.—Required spacing of field ditches to lower the watertable from the surface to 0.5 metres in stated period of time (metres)

Permeability	Soil type*	Time required to lower watertable by 0.5 metres at end of wet conditions			
		Drain depth = 1.5 metres		Drain depth = 1.0 metres	
		5 days	10 days	5 days	10 days
Moderate 0.72 m/day (3 cm/hr)	A	70	120	45	80
	B	45	64	35	52
Moderately rapid 1.92 m/day (8 cm/hr)	A	105	170	65	115
	B	58	83	46	67
Rapid 3.60 m/day (15 cm/hr)	A	130	210	85	150
	B	68	97	55	80

*In this case Soil Type A does not have an impermeable layer 'at great depth', but at 20 metres below the base of the drains. This enables a spacing correction to be applied to the transient flow formula (van Beers, 1965). Results however, can be realistically compared with those determined for Soil Type A according to the steady-state formulae.

In both cases the watertable depth refers to the vertical distance from soil surface to ground water at a point midway between the drains, and under transient flow conditions this depth will prevail at the end of the drainout period.

(b) Drainage coefficient, q (metres per day, or more completely m^3/m^2/day. Rainfall data from eight stations in the valley reveal average monthly totals ranging from less than 30 mm to greater than 350 mm depending on time of the year and station location. Wet season conditions commonly range between 120 mm and 250 mm per month. In the Markham Valley the poorly drained condition also arises because of surface run-on from land located upslope, and from sub-surface seepage from minor catchments and the main rivers. The relative contribution of the various sources cannot be estimated, but it is reasonable to assume that the seepage and run-on components are highest in those areas classed as poorly and very poorly drained on the maps accompanying the report of the recent survey of soils and agricultural potential (D.A.S.F. Report).

Drain spacing calculations were made for four values of q, as follows:—

q value	mm. per month	Approx. inches per month
0.004 m/day	120	5
0.008 ,,	240	10
0.016 ,,	480	20
0.024 "	720	30

(c) *Hydraulic conductivity, K (metres per day)*

The auger-hole method of determining average permeabilities (van Beers 1970) was applied to a limited number of soils in the Markham Valley. Results suggested that the classes moderate and moderately rapid (0.48 to 3.0 m/day) are most common and that the slow categories (less than 0.12 m/day) are rare. In the absence of detailed permeability data for specific soil types, three values of K were chosen and computations for drain spacings made for each condition.

K value	permeability rate	permeability class
0.72 m/day	3 cm/hour	moderate
1.92 m/day	8 cm/hour	moderately rapid
3.60 m/day	15 cm/hour	rapid

(d) *Drain dimensions*

Depth of drains, and the wetted perimeter (u) are also important determinants of drain spacing. Drain dimensions are dependent on soil engineering factors and economic considerations. Deeper drains allow wider spacing but are more costly to establish and maintain. Drain spacings in this paper have been calculated for two different drain sizes: 1.5 m (u=1.0 m) and 1.0 m (u=0.6 m).

(e) *Depth to impermeable layer for determination of D, Do & D_1*

Results of ground water drilling on river fans in the Markham Valley reveal that water occurs in porous beds lying immediately above relatively impermeable layers. A number of such layers is commonly encountered at any one drilling site. Limited deep augering information obtained during the recent land resources survey suggests a very complex inter-relationship between coarse, medium and fine textured materials in different geomorphic locations in the valley. Detailed survey work will be necessary in order to identify profile hydrological characteristics for site-specific drain spacing determinations.

Drain spacing calculations have been made using two assumptions with respect to the depth of an impermeable layer: viz. 3.7 metres (approx. 12 ft); and 'at great depth'. Allowances are made for drain depth in the calculation of D values where these are required by the drain spacing formula.

C. *Results of calculations to determine spacings of field drains*

The spacings indicated in *Tables* 3 through 7 represent both extremes of the range of likely soil conditions. Soil type A is assumed to be homogeneous and has no impermeable layer within the top 20 metres. Soil type B on the other hand is assumed to have an impermeable layer at shallow depth, 3.7 metres.

3. *Field drain design capacity and rainfall surpluses at various locations*

Drain spacing requirements as determined by steady-state formulae are based on assumptions as to the amount of water to be removed by the drains (q). This drainage coefficient is expressed in metres per day which is the same as cubic metres per square metre of area drained per day.

Calculations have been made to test the adequacy of different design capacities of the field drain system in coping with water surpluses expected at various locations in the valley.

Rainfall records from seven stations were processed by 'WATBAL' and week by week estimates of water surpluses were determined after having allowed for evaporation, transpiration and soil storage (see Appendix I). Surpluses thus derived were compared with the amounts of water removed under three possible design discharges of the field drain network. The three values used were 0.004, 0.008 and 0.016 metres per day. These are the same as were applied in calculating drain spacings in part 2 above.

For purposes of the calculations, a week was considered to be a "high watertable week" if the surplus for that week exceeded the design discharge. Similarly, high watertables were said to occur for at least two weeks if the total amount of surplus in two consecutive weeks exceeded twice the design discharge. Results are shown in *Table* 8.

DISCUSSION

The estimates of quantities discharged from the foothill catchments as shown in *Table* 2 are only approximate. Although run-off collection and recession times are expected to be fairly short in these catchments, the use of daily surpluses for calculating daily discharges could well over-state the peak flow. Weekly values should be more in line with actual conditions. On the other hand rainfall in the foothill catchments is known to be higher than that over the valley centre. The use of Erap rainfall data as the major component of the surplus estimates thus to some extent under-states the magnitude of the surpluses at all frequency levels.

Figures in *Table* 2 demonstrate that large amounts of water are discharged onto the valley floor from the foothill catchments. This suggests that a drainage project for agricultural development in these areas should include in its basic design, facilities for the efficient collection and disposal of water from these sources.

Table 8.—**Occurrence and duration of high watertables between drainage ditches**

	Station	Estimated occurrences per 10 years according to duration in weeks			
		>1 week	>2 weeks	>3 weeks	>4 weeks
Drainage system designed to remove 0.004m/day (110 points per week)	Erap	23	4	1	1
	Sasiang	65	23	12	6
	Leron	56	18	8	4
	Kaiapit	151	59	30	18
	Mutsing	86	34	18	10
	Gusap	103	38	19	11
	Dumpu	116	46	26	15
Drainage system designed to remove 0.008m/day (220 points per week)	Erap	12	2	1	0
	Sasiang	35	12	5	2
	Leron	24	5	2	1
	Kaiapit	101	35	19	12
	Mutsing	52	16	10	6
	Gusap	51	14	8	3
	Dumpu	66	25	12	10
Drainage system designed to remove 0.016m/day (440 points per week)	Erap	1	0	0	0
	Sasiang	9	1	0	0
	Leron	5	1	0	0
	Kaiapit	28	7	2	1
	Mutsing	12	2	0	0
	Gusap	10	0	0	0
	Dumpu	8	0	0	0

1. *Surplus Disposal System*

Planning for the location and design of channels in the Markham Valley environment will be a complex exercise. Water levels in the disposal channels for instance should be maintained below the desired ground water level on the neighbouring arable land. In determining this level in the disposal channel a possible criterion might be the ninth decile of daily discharges during the months January to March. If this level was made equal to the desired ground water level on the nearby cropping land there would be little risk of lateral dispersion of water and salts.

Another important factor in channel design is land gradient. Information obtained during the recent survey of land resources has enabled a contour map to be prepared covering all the poorly drained land located between the Erap and Leron Rivers. Estimates of gradients can be obtained from these maps and used by engineers in the preliminary stages of drainage investigations. Field traverse data are available for poorly drained zones west of the Leron River, but contour maps have not been prepared. In general terms the land gradient is about 1.0 per cent near the base of the piedmont and reduces gradually to about 0.3 per cent close to the Markham River.

Channel design will need to take into account a critical velocity of flow. This is the speed at which the material of the bed and banks is not quite set in motion. It depends on the soil type (mainly texture) and the degree of protection (by vegetation). Under conditions of high discharge, considerable quantities of silt and sand will be suspended in the water. Design specifications will be of major importance in determining how much of this material will be transported through the system, and how much will be deposited within the drains and thus necessitate expensive maintenance work.

A further aspect in channel design is the inclination of side slopes. For example, collection drains near the base of fans will receive considerable water by seepage. Side slopes must be designed flatter to allow for this, and mechanical properties of the soil will need to be investigated. Also, if cattle have access to the drain or if there is a roadway along the edge of the channel, flatter side slopes will be required. On the other hand the large variations in flow from week to week and season to season will enable dense grass cover to establish on the channel banks and this will enable a slightly steeper design of side slopes. Soil texture variations especially near the base of the piedmont will mean the choice of flatter slopes on channel banks than would be required for channels located in the finer textured basin sediments.

In general terms the steeper the hydraulic gradient and channel side slopes, the less earth moving will be required and the cheaper will be the construction of the surplus disposal system. Given the constraint of critical velocities however, as can be expected in the Markham Valley environments, the permissible hydraulic gradient decreases with increasing discharge.

By application of the Manning formula (Appendix II) and taking into account the factors mentioned above, two suggestions concerning disposal design can be made.

(a) Channel design might be expected to alter along its length from a shallow, board vegetated waterway with a flood levee on the downslope side near the base of the piedmont, to a progressively deeper channel with steeper side slopes closer to the Markham River.

(b) A surplus disposal system for the Rumion-Cleanwater-Sasiang catchment could comprise two collection drains and one main channel. Collection drains could originate in the vicinity of map units 156 and 130 (D.A.S.F. Report), and some modification of Cleanwater Creek would be necessary to facilitate the removal of water.

Surplus disposal from the Maralumi-Wawin catchment on the other hand should comprise at least two main cross-valley channels rather than one. This would reduce the requirements for extensive modification of the existing Maralumi Creek channel. One system worth investigation would be the channelling of Wawin Creek from the base of its fan in a south-westerly direction into the Rumu River, or alternatively in a south-easterly direction for outfall into the Markham River near the western end of Pyramid Hill. Maralumi Creek could then be modified to become a disposal channel for collection drains located near the base of the piedmont and extending from map unit 17 in the north-east and the vicinity of map unit 41 in the north-west (D.A.S.F. Report).

From *Table* 2 it can be seen that large differences can be expected between normal wet season flow and peak flow requirements. This suggests that a composite channel cross-section might be cheapest, and the use of flood levees might also be considered. Further, the requirement of the surplus disposal system to cope with occasional high discharges poses problems for this system's integration with a field drainage network. Field drainage outfall into a main disposal channel would need to be located sufficiently downslope to prevent the banking back of water at periods of high discharge. Alternatively, or in addition, separate outfall points to the Markham or other rivers should be considered.

2. *Field Drainage*

The field drainage network would be required to remove excessive rainwater and sub-surface seepage. A primary objective would also be to maintain the net movement of water in a downward direction through the soil so that chemical limitations for agriculture will be minimised. This downward movement will result in the leaching of sodium and bicarbonate ions, the main causes of nutritional problems in crops grown in these areas. Whilst bicarbonates will continue to come into solution it is thought that their concentration in equilibrium with calcium and magnesium ions will not cause nutritional problems to the same degree as when sodium is present.

Crops vary in the extent to which they can tolerate wet conditions, or soil and ground water alkalinity. Peanuts and sugar cane for instance will not grow whilst watertables are near the surface (cf. rice). On the other hand rice will not tolerate the strongly alkaline soil conditions such as is known to occur in the area between the Erap and Leron Rivers (cf. grain sorghum). It is clear that in order for engineers to be able to make a decision on drainage system design, it will be necessary to specify the purpose for which the land will be required.

For known agronomic requirements with respect to watertable depth, the most important factors determining the appropriate spacing of field drains are the amount of water to be removed, soil permeability, presence and location of a 'barrier' layer and the drain dimensions. Assuming that a drainage project in the Markham Valley would be designed with an adequate surplus disposal capacity, it is then possible to use the results of *Table* 8 as a rationale for selecting a design capacity in the light of agronomic requirements. This can be seen to vary for different locations in the valley. For example, at Erap an appropriate design capacity might be q = 0.004 metres per day, whereas in the Cleanwater area (Sasiang) a similar order of control might require a design capacity closer to q = 0.008 metres per day. Similar control in the vicinity of Mutsing, Gusap and Dumpu might be achieved with a design capacity of q = 0.011 metres per day, and at Kaiapit, 0.016 metres per day.

The drain spacings indicated in *Tables* 3 through 7 demonstrate clearly the importance of hydraulic conductivity. Detailed tests will be needed to enable the selection of suitable values for different soil units. It will also be necessary to investigate the drainage condition and water movement in the soil at depth. For all soil types the presence of an impermeable layer within the top 15 metres or so can have an important effect on drain spacing. In the case of an impermeable layer at very shallow depth, say 4 metres, twice as many drains might be required for efficient water removal in the Erap-Leron area than if the soil has no relatively impermeable layers.

Drain dimension is another important aspect. Deeper drains permit wider spacing as can be seen from *Table* 7. The choice of drain depth depends mainly on economic factors but also on the position of suitable soil layers, the level of available outlets and the salt content of the ground water.

Results from *Tables* 3 to 8 enable a generalised statement to be made concerning the spacing of field drains. In the Erap-Rumu area for instance, assuming a design discharge of 0.004 metres per day, and a drain depth of 1.5 metres, it should be possible to place drains at a distance up to 100 metres apart on the finer textured soils having moderate permeability. On medium textured soils about 160 metres would be satisfactory and on the rapidly permeable or moderately well-drained soils distances up to 300 metres could be used. For the area between the Rumu and Leron Rivers rainfall records indicate a higher design discharge for field drains although the requirement for surplus disposal is not as high as in the Erap-Rumu area. Using q = 0.008 and drains 1.5 metres deep it would appear that drains should be placed about 70 metres apart on clay-loam and clayey soils, about 120 metres apart on the loamy soils and 200 metres apart on the sandier sites.

CONCLUSIONS

A. *Surplus Disposal*

1. Large quantities of water are discharged onto the valley floor from foothill catchments along the northern margin of the valley. In this paper an example has been made of two such catchments: the Maralumi-Wawin (located between the Erap and Rumu Rivers) and the Rumion-Cleanwater-Sasiang foothill catchment (between the Rumu and Leron Rivers). A system for the collection and disposal of this water would be an essential component of any drainage project which aims to release for cropping purposes a large proportion of the seasonally poorly drained land.

2. The design of surplus disposal systems for the Markham Valley environment will require detailed investigations. Basic information is already available on land gradients in the Erap-Leron area and the results of climatological analyses also in hand will assist in the selection of normal and peak flow design requirements. Fieldwork will be needed to determine the distribution of discharges along the mountain front and to relate actual flows to measured rainfall (both on site and at stations with longer records).

Other important factors to be investigated include the water levels of disposal channels in relation to groundwater in neighbouring crop land, velocities of flow and channel cross section features such as side slope inclination, composite sections and the use of levees.

3. Preliminary estimates of discharge and capacities of surplus disposal channels suggest that two cross-valley channels may be required in the Erap-Rumu area, and that one would be sufficient in the Rumu-Leron area. Calculations also suggest that channel design might be expected to change from shallow vegetated waterway near the base of the piedmont to a propressively deeper channel with steeper side slopes nearer the Markham River. Since large differences are expected between normal and peak flow requirements of the disposal channels, the use of composite channel sections and flood levees needs investigation. There may also be problems for the integration of field drainage systems because of the risks of flooding arable land at times of high discharge in the disposal channels.

B. *Field Drainage*

4. Surplus water from direct rainfall and soil chemical conditions necessitate a field drainage system being implemented in conjunction with a surplus disposal system if large areas of poorly drained land are to be cropped during December to May inclusive.

5. Climatological and soil survey investigations have enabled some general statements to be made on the order of drainage required on different soils and at different locations in the valley. Climatological work for instance has shown that the design capacity will change from place to place along the valley. Soil survey has indicated a range of hydraulic conductivities for different soils and the distribution of poorly drained lands. It has also shown the extent of areas most severely affected by excessive bicarbonates and sodium. Interpretation of this work in terms of the reclamation (drainage) requirement however, is limited by the lack of specific data on hydraulic conductivity, and lack of information on water movement (soil characteristics) at depths between 1.5 metres and about 15 metres.

6. Detailed investigations into agronomic requirements and economic factors in addition to the abovementioned engineering factors will be needed before a field drainage system or total drainage project can be designed for any particular area of the Markham Valley.

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APPENDIX I

DETERMINATION OF WATER SURPLUSES*

1. ***Parameter values***

(*a*) Rainfall (NRAIN)—weekly totals of station registration.

(*b*) Evaporation (EVAP)—estimated from mean maximum temperature daylength and vapour pressure data by method of Fitzpatrick, 1963.

(*c*) Maximum soil moisture storage (MAXST)—100 mm.

(*d*) Transpiration (PETCF)—constant potential rate of 80 per cent of weekly evaporation.

(*e*) Actual evapotranspiration (AETCF)—100 per cent of potential rate until soil storage falls below 50 per cent of maximum. Then 50 per cent of potential rate.

2. *Method*

a) Water demand for week N, ($NDMD_N$):

$$NDMD_N = AETCF_N \times PETCF_N \times EVAP_N$$

b) Soil moisture storage for week N, ($NSTR_N$):

$$NSTR_N = (NSTR_{N-1} + NRAIN_N) - NDMD_N$$

Note: If $NDMD > NSTR_{N-1} + NRAIN_N$ then $NSTR_N = O$

c) Surplus water for week N, ($SPLS_N$):

$SPLS_N = NSTR_N - MAXST$, when $NSTR > MAXST$

Recorded $NSTR_N$ value for the subsequent week of estimate = MAXST.

* Source: Keig, G., & McAlpine, J.P. (1969).

APPENDIX II

FORMULA FOR CALCULATION OF DISPOSAL CHANNEL CROSS SECTION*

For vegetated and rough-bed channels the empirical formula of Manning is appropriate:

$$V = K_M R^{2/3} S^{1/2} \; ; Q = V A$$

V = average velocity of flow (m/sec.)

K_M = a coefficient related to bed roughness ($m^{1/3}$ sec.)

R = hydraulic radius of cross-section (m)

S = gradient of channel (dimensionless)

Q = discharge (m^3/sec.)

A = cross sectional area of flow (m^2)

* Source: Int. Inst. Land Recl. Impr., (1964).

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