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Department of Agriculture, Stock and Fisheries,
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TERRITORY OF PAPUA AND NEW GUINEA

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Although "date of publication" is given as March 1970, actual publication date was August 1970.

ERRATA

P. 98, Table 7, column 3, 1.89* should read 1.80*

P. 105, line 1, 20 in. should read 200 in.

You can argue with judges and experts but not with RESULTS ! !

BRAHMANS

In 1970 at CARCASS and FAT STOCK SHOWS have gained TOP RESULTS

- SYDNEY

  (May)—Royal Show fat stock and Carcass Show—Brahmans were Champion Pen three Carcasses.

- ROCKHAMPTON

  (June)—at Rockhampton Show, Brahman breeders were the most successful exhibition of fat cattle and carcasses.

- BRISBANE

  (August)—Brahmans won all THREE CARCASS CONTESTS and champion carcass.

- GUNNEDAH, N.S.W.

  (August)—against 140 entries, a Brahman was grand champion carcass at the Gunnedah annual prime stock Show.

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ABSTRACTS

EFFECTS OF TIME OF AMMONIUM SULPHATE APPLICATION ON THE GROWTH OF NEWLY TRANSPLANTED COCONUT SEEDLINGS

J. H. SUMBAK. *Papua and New Guinea agric. J.*, 21 (3, 4) : 93-101 (1970)

In a soil known to be deficient in nitrogen and sulphur, the uptake of these elements was studied through applications of ammonium sulphate at different intervals after transplanting. Fertiliser applied at transplanting resulted in increases in sulphur levels within a month of application with uptake reaching its maximum level from fertiliser applied as early as one month after transplanting. Consistent responses, in terms of increases in leaf nitrogen, became evident when fertiliser was applied two months or later after field planting.

If transplanting methods are similar to those utilised in the trials, fertiliser should be applied first at 4 to 6 weeks after transplanting, although a delay of up to 12 weeks would probably not cause much growth setback.

Indications were that more frequent or perhaps heavier applications of nitrogen might be necessary for maximum growth while intervals between applications of sulphur could well be prolonged.

The relatively poor growth over the first 12 months of seedlings transplanted with 4 to 7 leaves showed a need for better establishment techniques. Alternative methods are suggested.

FURTHER SPREAD OF BLISTER SMUT OF MAIZE IN PAPUA AND NEW GUINEA

DOROTHY E. SHAW. *Papua and New Guinea agric. J.*, 21 (3, 4) : 102-105 (1970)

The further spread of *Ustilago maydis* in Papua and New Guinea, as indicated by confirmed infected cobs in new areas, is recorded. The incidence of the disease in previously infected areas remained low and the possible reasons for this are discussed.

EFFECTS OF LIGHTNING STRIKE ON COCONUTS, CACAO AND *LEUCAENA LEUCOCEPHALA* IN A MIXED PLANTING IN THE GAZELLE PENINSULA

R. J. VAN VELSEN and I. L. EDWARD. *Papua and New Guinea agric. J.*, 21 (3, 4) : 106-111 (1970)

The effects of a lightning strike on coconuts, cacao and *Leucaena leucocephala* in a mixed planting in the Gazelle Peninsula, New Britain, are described.

The effects of a lightning strike on coconuts, cacao and leucaena were observed at intervals of 1 day, 7 days, 21 days, 7 weeks, 19 weeks and 32 weeks after the strike. Three coconut palms showed symptoms within 24 hours and others developed symptoms for the first time between 3 and 7 weeks after the strike. Survivors were showing recovery by the nineteenth week. Affected cacao trees were recovering by the time of the 7-week reading. Foliage damage on the cacao trees was similar to that produced by fire. Leucaena trees appeared to be more tolerant of the effects of the strike than cacao or coconuts.

[*continued overleaf*]

SOME NET-RADIATION AND SOIL THERMAL DIFFUSIVITY MEASUREMENTS FOR THE PORT MORESBY AREA

R. DRINKROW. *Papua and New Guinea agric. J.*, 21 (3, 4) : 112-117 (1970)

Measurements of net-radiation and soil heat flux levels for February 1968 are presented and discussed. It is believed these are the first direct measurements of these parameters to be obtained for Papua and New Guinea. By means of two measurements of soil heat flux at differing depths a value is obtained for the thermal diffusivity of the soil. This value is at the low end of the range of values quoted by other workers and needs checking by more direct methods.

ACTIVITY STUDIES IN NEW GUINEA VILLAGES

D. A. M. LEA. *Papua and New Guinea agric. J.*, 21 (3, 4) : 118-126 (1970)

University students, working in their own villages, collected data on how villagers spent their time during the day. There were numerous problems in the exercise but it is believed that such studies not only give some idea of present-day demands of traditional and non-traditional activities, but they also provide a valid interregional comparison on how existing demands can act as a constraint on economic development.

In 7 different villages, 34 different activities were recorded for 320 individuals during a 24-hour day. Most of the day-time activities were recorded to the nearest 10 minutes. Only adults (over 16 years of age) were included in the study and it appears that even the most 'westernised' villages are still tradition-orientated and that, in the light of present needs and village realities, neither sex has excessive leisure time.

NOTES ON THE CROWN-OF-THORNS STARFISH: ITS DISTRIBUTION IN PAPUA AND NEW GUINEA (ECHINODERMATA : ASTEROIDEA : ACANTHASTERIDAE)

REX R. PYNE. *Papua and New Guinea agric. J.*, 21 (3, 4) : 128-138 (1970)

The crown-of-thorns starfish, *Acanthaster planci*, until recently regarded as a rare nocturnal marine animal, is now menacing the reef-building corals in many Indo-West Pacific areas. Notes on the taxonomy, distribution, habitat, feeding, movement, breeding, growth rate and age at maturity, natural enemies and regeneration are discussed and current methods of control are outlined.

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CONTENTS

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J. H. SUMBAK*

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In a soil known to be deficient in nitrogen and sulphur, the uptake of these elements was studied through applications of ammonium sulphate at different intervals after transplanting. Fertiliser applied at transplanting resulted in increases in sulphur levels within a month of application with uptake reaching its maximum level from fertiliser applied as early as one month after transplanting. Consistent responses, in terms of increases in leaf nitrogen, became evident when fertiliser was applied two months or later after field plantings.

If transplanting methods are similar to those utilised in the trials, fertiliser should be applied first at four to six weeks after transplanting, although a delay of up to 12 *weeks would probably not cause much growth setback.*

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INTRODUCTION

RESPONSES by coconuts to added nutrients in terms of better early growth and earlier bearing have been a common occurrence on a multitude of soil types in the tropics.

The question arises as to whether, using normal plantation establishment techniques, nutrients applied at, or soon after, field planting can be effectively utilised. In the Territory of Papua and New Guinea, as well as in many areas of the Pacific, coconut seedlings are usually transplanted from nurseries at between the 4 and 9 leaf stage of development.

Work by Foale (1968a) in the British Solomon Islands Protectorate indicated that at the stage when transplanting is normally carried out the seedling is deriving most of its growth from its external environment and hence, provided that its absorptive mechanisms are sufficiently effective, responses to fertiliser could be expected. Foale showed that up to four or five months after the commencement of germination (as indicated by the emergence of the shoot through the 'germ pore') the seed supplies most of the seedling's requirements. Thereafter photosynthesis makes substantial contributions to development and by the 11th month 90 per cent of assimilation can be attributed to this source. The author's observations at a number of nurseries in the Gazelle Peninsula, New Britain, showed that symptoms of sulphur deficiency do not generally become evident until the four or five leaf stage (that is, about four to five months after the commencement of germination) where coconut seedlings derived from seednuts with normal sulphur contents are grown in a sulphur deficient soil. This tends to support Foale's findings.

It is common knowledge that traditional methods of transplanting retard subsequent development to varying degrees as the considerable contribution to assimilation from the leaves is drastically reduced by root damage. Root recovery appears to be very gradual and a setback to growth estimated to be as much as six months can result. It would appear likely, therefore, that fertiliser applied at about the time of transplanting could only be taken up in limited amounts initially and could be largely wasted. Indeed, it is conceivable that a premature application may be detrimental in that vigorous weed growth and hence added competition for coconut seedlings could result. On the other hand, it is possible that limited uptake could occur (per-

* Agronomist, L.A.E.S., Keravat

haps even through tissue at the base of the seedling or through the foliage) and this might suffice if the nutrients concerned were required in relatively small amounts.

In an attempt to clarify the situation, a set of experiments which varied the time of fertiliser application in relation to transplanting time was conducted on soils where responses to fertiliser had been clearly demonstrated.

On the soils chosen, joint applications of sulphur and nitrogen have been shown to be virtually essential if coconut seedlings are to be brought through to bearing. This requirement is widespread in grassland tracts of the Gazelle Peninsula, New Britain, and responses in nurseries to ammonium sulphate have been observed in seedlings with as few as three or four leaves. As nitrogen and sulphur from ammonium sulphate are usually readily available soon after application, and as seedling tissues appear to be quite sentitive to changes in either nutrient, it was anticipated that any uptake would be readily detected.

EXPERIMENTAL METHODS

Two areas, both of which had previously responded to nitrogen and sulphur, were selected.

Site 1.—The plot selected had a ground cover of kunai (*Imperata cylindrica*) and supported a very sparse stand of old coconuts. The soil was a deep volcanic ash, well supplied with phosphorus and bases, and typical of much of the Gazelle Peninsula. Frequent burning of grass had helped to induce a low nitrogen and sulphur status.

Vigorous seedlings with 5 to 6 leaves were selected from a slightly shaded nursery and planted in plots of 20 on a 10 ft square spacing. Four replicates of five treatments in a randomised block design were used. The close spacing was used as the experiments were of only 12 months' duration and hence inter-seedling competition would be expected to be negligible.

Site 2.—Another area of volcanic ash origin supporting a rather chlorotic sward of a *Sorghum* species was utilised. The area tended to be excessively wet on occasion.

Seedlings with 4 to 7 leaves were used from a trial comparing germination and development of partially dehusked nuts with unhusked nuts. Equal numbers of each type were allocated to plots of 16 seedlings and the design was similar to that used on Site 1.

Treatments

Treatments were as follows:

- T1 = 4 oz ammonium sulphate at transplanting;
- T2 = 4 oz ammonium sulphate 1 month after transplanting;
- T3 = 4 oz ammonium sulphate 2 months after transplanting;
- T4 = 4 oz ammonium sulphate 3 months after transplanting; and
- T5 = Control (unfertilised).

Initial applications were followed by subsequent additions at 3-monthly intervals.

The amount of 4 oz of fertiliser was chosen as this dosage had resulted in good responses in previous experimets and was thought to be adequate at this stage.

Fertiliser was spread evenly over a circle about 3 ft in diameter around the base of the seedling. The fertilised area was clean-weeded every month and the remainder of the plots slashed simultaneously. Seedlings in the unfertilised plots were also clean-weeded and the grass slashed.

Recordings

The following records were taken:

(i) Height at monthly intervals;

(ii) Frond production at 3-monthly intervals; and

(iii) Fresh weights of the above-ground portion of seedlings at the termination of the experiment about 12 months after commencement.

Foliar Samples

Leaf samples from the newest fully opened fronds were collected from each plot at monthly intervals over the first 10 recordings while samples from the first, second, third and fourth youngest fronds were taken over the last two samplings. Replicates for each treatment were bulked in the latter case.

Analyses for sulphur and nitrogen were conducted by the Chemistry Section of the Department of Agriculture, Stock and Fisheries at Port Moresby.

RESULTS

General Observations

In general, unfertilised seedlings showed chlorotic symptoms within three months of transplanting while fertilised seedlings were a normal green colour even though height determinations failed to reveal any differences at that stage. Colour differences had become very obvious after four months when significant height differences between fertilised and unfertilised seedlings were recorded. In some instances a slight chlorosis was noted in the month prior to refertilising suggesting that fertiliser effect was short-lived. Seedlings at Site 1, probably as a consequence of initial growth in a shaded nursery, showed signs of sun scorch soon after transplanting.

Site 1

(i) Height.—Height measurements (as shown in *Table* 1) failed to reveal statistically significant differences between treatments until four months after transplanting, although fertiliser responses, in terms of better colour, were evident prior to this. Six months after transplanting, differences between fertilised and unfertilised seedlings were quite noticeable and seedlings fertilised one month after transplanting were significantly taller than those receiving their initial application either two or three months after field establishment. At 12 months all fertiliser seedlings were vastly superior to the unfertilised ones while differences, although not very marked, were noted between seedlings fertilised one month after transplanting and those fertilised at other times. It was noted that unfertilised seedlings at the completion of the experiment had not shown any growth (in height) over the whole period. This is attributed to severe nitrogen and sulphur deficiency and supports the contention that very few seedlings could be brought through to the bearing stage without adequate fertilising.

(ii) Frond production.—Cumulative frond production recordings shown in *Table* 2 did not show a consistent trend. There appeared to be a positive response to fertiliser 6 and 9 months after transplanting but none after 12 months. Overall frond production for the duration of the trial was lower than at Site 2 with an

Table 1.—Seedling growth at Site 1. Average heights (inches) at intervals after transplanting.

Treatment		3 Months	4 Months	6 Months	9 Months	12 Months
T1		45.4	49.4	51.6	57.5	60.7
T2		44.2	47.0	53.1	60.8	65.1
T3		44.9	46.5	50.0	59.5	60.8
T4		44.0	46.1	49.6	54.4	59.9
T5		44.1	40.6	38.8	41.0	43.8
Least significant difference	5%	Not significant	3.27	3.11	4.44	4.52
	1%		4.58	4.37	6.22	6.34

Table 2.—Seedling growth at Site 1. Average cumulative frond production at intervals after transplanting.

Treatment		3 Months	6 Months	9 Months	12 Months
T1		1.38	3.74	6.45	8.27
T2		1.43	3.80	6.57	8.46
T3		1.43	3.78	6.97	8.68
T4		1.41	3.95	7.86	9.91
T5		1.34	3.08	6.45	9.10
Least significant difference	5%	Not significant	0.36	0.83	Not significant
	1%		0.51	1.16	

average of 8.88 fronds per seedling produced over the 12-month period. This is possibly a reflection of periods of moisture stress.

(iii) Fresh weights.—The good response obtained from fertiliser application is shown in *Table* 3. Treated seedlings were about twice as heavy as untreated ones. Again an initial fertiliser application one month after transplanting appeared to produce the best response although differences between the four fertiliser treatments were barely significant.

Table 3.—Seedling growth at Site 1. Average fresh weight 12 months after transplanting.

Treatment		Weight (lb)
T1		5.06
T2		6.12
T3		5.69
T4		5.36
T5		3.10
Least significant difference	5%	1.00
	1%	1.40

Site 2

(i) Height.—Height measurements shown in *Table* 4 showed less definite differences than those at the other site. Significant differences between fertiliser treatments and controls were evident six and nine months after transplanting but not at 12 months. The lack of statistical significance was possibly a consequence of large experimenetal error arising mainly from variations in soil moisture although Site 2 was probably also less deficient than Site 1 as the control increased in height as much as fertilised treatments at Site 1.

(ii) Frond production.—Frond production comparisons (*Table* 5) failed to reveal any treatment effects. Overall frond production was slightly higher than at Site 1 with an average of 9.59 fronds being produced in 12 months.

Table 4.—Seedling growth at Site 2. Average heights (inches) at intervals after transplanting.

Treatment		3 Months	6 Months	9 Months	12 Months
T1		33.6	39.5	47.7	65.9
T2		34.8	40.1	43.3	66.3
T3		35.8	40.8	48.5	66.6
T4		34.0	40.4	47.2	69.9
T5		34.0	33.4	36.5	50.1
Least significant difference	5%	Not significant	4.19	7.82	Not significant
	1%		5.88	10.97	

Table 5.—Seedling growth at Site 2. Average cumulative frond production at intervals after transplanting.

Treatment	3 Months	6 Months	9 Months	12 Months
T1	1.57	3.66	7.43	10.17
T2	1.59	3.89	6.73	9.39
T3	1.56	3.84	6.84	9.39
T4	1.39	3.80	6.82	9.54
T5	1.61	3.55	6.80	9.47
Least significant difference	Not significant	Not significant	Not significant	Not significant

(iii) Fresh weights.—Fresh weight determinations (*Table* 6) showed a good response to fertiliser but failed to reveal any effects of time of initial applications.

Table 6.—**Seedling growth at Site 2. Average fresh weights 12 months after transplanting.**

Treatment		Weight (lb)
T1	....	6.34
T2	....	6.45
T3	....	5.95
T4	....	6.32
T5	....	3.31
Least significant	5%	2.15
difference	1%	3.02

Chemical Analyses

Nitrogen levels for Sites 1 and 2 are shown in *Tables* 7 and 8 respectively.

Levels varied greatly with time, from 2.04 to 1.48 per cent in unfertilised seedlings at Site 1, while 2.05 and 1.40 per cent were the corresponding values for Site 2.

In terms of leaf nitrogen, Site 2 showed slight uptake of nitrogen applied at transplanting but no uptake of nitrogen applied a month later. Site 1 failed to reveal uptake at the first two samplings. Uptake of nitrogen applied as ammonium sulphate within a month of transplanting appears to be very limited. At both sites weather conditions following application appeared to be suitable for uptake.

In most cases nitrogen applied two months or more after transplanting appears to have been absorbed in considerable amounts. Although absolute increases in nitrogen level did not always follow application, levels were maintained, suggesting that additional growth had balanced uptake, since levels in unfertilised seedlings decreased in the same interval.

At Site 2, fertiliser applied 4, 7 and 11 months after transplanting failed to affect nitrogen levels by comparison with levels in unfertilised seedlings. It was noted that rainfalls between the times of these applications and the next sampling were some of the lowest recorded. In absolute terms, however, the rainfalls received at Site 2 on these occasions were higher than those recorded on Site 1 on five occasions. On those five occasions nitrogen levels remained quite high. It is probable that sometimes a study of leaf content alone fails to elucidate the situation unless combined with a knowledge of assimilate production. Nitrogen may well have been absorbed but leaf levels only maintained or lowered through extra growth.

Responses to nitrogen fertiliser appear to be of relatively short duration. Three months after application, nitrogen levels in many cases had dropped considerably, occasionally to below that of unfertilised seedlings. The appearance of mild chlorotic symptoms at these stages points to inadequate nitrogen availability.

The position of the leaf sampled can affect levels, as illustrated in *Table* 9. One of the aims of analysing the four different positions was to determine if recently applied fertiliser was taken up into older leaves as well and whether levels in older leaves might remain higher for longer after fertilising than in young leaves. The two samplings, however, showed little sign of uptake of recent fertiliser, so little was achieved.

Generally, contents appeared to increase from the newest leaf to the third and to decrease in the fourth. There were exceptions, however, as with the eleventh determination at Site 1 where there was no consistent trend.

Tables 10 and 11 show sulphur levels for Sites 1 and 2 respectively.

As with nitrogen, levels of sulphur fluctuated considerably with time. The maximum and minimum levels for controls at Site 1 were 251 and 50 p.p.m. respectively while the corresponding figures for Site 2 were 245 and 45.

A definite, although suboptimal, uptake of sulphur applied at transplanting was evident at both sites. Applications of fertiliser a month after transplanting and thereafter resulted in high sulphur levels being attained. Only one application (10 months after transplanting at Site 1) showed a relative low sulphur level a month later.

In most instances, levels of sulphur were still high 3 months after application and longer intervals between applications may be warranted.

There appears to be little consistent relationship between sulphur levels and the positions of young fronds, as shown in *Table* 12.

Table 7.—Average nitrogen levels (percentage dry matter) of first fronds at Site 1.

Treatment	Trans-planting	Time from transplanting (months) 1	2	3	4	5	6	7	8	9	10	11	12
T1	*	1.99	1.84	1.86*	1.92	1.90	1.93*	2.00	1.64	1.97*	2.09	1.94	1.70
T2		1.97*	1.89	1.92	1.54*	1.95	2.37	2.13*	1.82	2.13	1.76*	1.96	1.89
T3		1.96	1.75*	2.05	1.69	1.62*	2.30	2.29	1.82*	2.04	2.05	1.76*	1.69
T4		2.02	1.81	1.89*	2.01†	2.05	1.90*	1.84	1.58	1.87*	2.08	1.84	1.72
T5		2.04	1.82	1.80	1.61	1.59	1.86	1.75	1.64	1.91	1.88	1.78	1.48

* Denotes fertiliser application

† Average of three replicates

Table 8.—Average nitrogen levels (percentage dry matter) of first fronds at Site 2.

Treatment	Trans-planting	Time from transplanting (months) 1	2	3	4	5	6	7	8	9	10	11	12
T1	*	1.90	2.11	1.90*	1.91	1.83	1.78*	2.17	1.86	2.00*	2.09	1.85	1.59
T2		1.79*	2.17	1.83	1.64*†	1.62	1.84	1.56*	1.26	1.66	1.76*	1.94	1.65
T3		1.80	2.06*	2.12	1.80	1.70*	2.35	2.00	1.61*	2.08	2.05	2.01*	1.49
T4		1.77	1.99†	1.80*	1.98	1.97	1.87*	2.15	1.90	1.99*	2.08	1.86	1.69
T5		1.80	2.05	1.76	1.76	1.89	1.82	1.59	1.40	1.87	1.88	1.57	1.47

Table 9.—Nitrogen levels (percentage dry matter) of four youngest fronds.

	Time from transplanting: 11 months				12 months			
Treatment	Frond 1	2	3	4	Frond 1	2	3	4
Site 1								
T1	1.94	1.96	1.93	2.07	1.70	1.87	1.94	1.86
T2	1.96	1.91	2.42	1.88	1.89	1.93	2.00	1.89
T3	1.76	1.96	2.02	2.04	1.69	1.78	2.05	1.89
T4	1.84	1.38	1.87	2.01	1.72	1.94	1.96	1.86
T5	1.78	1.74	....	1.60	1.48	1.61	1.85	1.77
Mean	1.86	1.79	2.06	1.92	1.69	1.83	1.96	1.85
Site 2								
T1	1.85	1.99	1.96	1.87	1.59	1.63	1.73	1.47
T2	1.94	2.01	2.12	2.06	1.65	1.79	2.00	1.76
T3	2.01	2.04	2.11	1.74	1.49	1.58	1.58	1.38
T4	1.86	2.02	2.11	1.93	1.69	1.83	1.72	1.39
T5	1.57	1.76	1.75	1.60	1.47	1.54	1.55	1.37
Mean	1.85	1.96	2.01	1.84	1.58	1.67	1.72	1.47

Table 10.—Average sulphur levels (p.p.m.) of first fronds at Site 1.

Treatment	Trans-planting	Time from transplanting in months 1	2	3	4	5	6	7	8	9	10	11	12
T1	*	185	361	334*	420	413	571*	673	693	713*	750	320	600
T2		96*	396	459	304*	510	624	651*	740	770	481*	228	560
T3		93	153*	470	353	313*	550	344	538*	634	800	570*	310
T4		98	158	171*	272†	300	541*	474	589	576*	765	735	250
T5		101	170	181	50	108	251	145	210	123	235	220	180

* Denotes fertiliser application

† Average of three replicates

Table 11.—Average sulphur levels (p.p.m.) of first fronds at Site 2.

Treatment	Trans-planting	Time from transplanting in months 1	2	3	4	5	6	7	8	9	10	11	12
T1	*	149	324	305*	433	395	628*	473	575	674*	750	860	644
T2		71*	669	633	360*†	785	526	508*	501	440	481*	455	415
T3		81	168*	791	455	433*	560	526	684*	685	800	955*	725
T4		79	133	164*	378	550	718*	605	489	749*	765	745	675
T5		68	158	189	45	75	219	185	202	219	235	180	245

* Denotes fertiliser application

† Average of three replicates

Table 12.—Sulphur levels (p.p.m.) of four youngest fronds.

	Time from transplanting							
	11 months				12 months			
	Frond				Frond			
Treatment	1	2	3	4	1	2	3	4
Site 1								
T1	320	970	710	835	600	655	405	590
T2	288	810	945	430	560	655	500	735
T3	570	520	645	470	310	600	365	540
T4	735	655	195	580	250	470	230	510
T5	220	225	....	190	180	95	180	110
Mean	427	638	624	501	380	495	336	497
Site 2								
T1	860	1005	1085	640	644	710	760	587
T2	455	530	445	770	415	550	530	540
T3	955	830	770	675	725	600	620	570
T4	745	1040	820	945	675	620	590	613
T5	180	....	230	205	245	210	180	245
Mean	639	851	662	647	541	538	536	511

DISCUSSION AND CONCLUSIONS

Chemical analyses of the youngest frond demonstrated that coconut seedlings transplanted with 4 to 7 leaves can absorb sulphur and nitrogen quite soon after field planting. Ammonuim sulphate applied at transplanting resulted in significant increases in sulphur levels within a month of application, while responses, in terms of increases in leaf nitrogen, became consistently evident when fertiliser was applied two months or later after field planting. Uptake of sulphur reached its maximum level from sulphate of ammonia applied as early as one month after transplanting.

It would appear that, despite damage to the seedlings' absorptive system at transplanting, added nutrients can be utilised in substantial quantities when applied as early as two months after transplanting and can be absorbed in limited quantities even sooner. The greater early response to sulphur is probably a consequence of its being required in much smaller quantities than nitrogen and the readily available form in which it was applied.

The occasional apparent lack of response in terms of leaf nitrogen content subsequent to fertiliser application could have a number of explanations. It is difficult to ascertain uptake in such cases, unless growth responses are known, preferably in terms of dry matter produced, as uptake may be utilised in extra assimilate production. In such cases leaf levels may remain constant or even decrease. Apart from this consideration, fluctuations in apparent response will also depend on nutrient availability following application, losses through leaching, and the capacity of the seedling to absorb and utilise nutrients. Large fluctuations in nutrient levels of unfertilised seedlings from month to month were obviously tied up with variations in environmental conditions, soil moisture probably being dominant although consistent simple relationships between rainfall and leaf nutrient levels were not evident. A survey of literature by Richards and Wadleigh (1952) appeared to indicate that plants grown at low moisture contents are relatively high in nitrogen, low in potassium, and sometimes low and at other times high in phosphorus, calcium and magnesium. Apparently insufficient moisture supply limits utilisation of nitrogen more than is does uptake. This phenomenon may offer a partial explanation for the substantial variation in nutrient levels in unfertilised seedlings as well as occasional anomalies in the response to fertiliser application.

The dangers of relying on single or limited samplings of young fronds as indicators of nitrogen status, especially without appropriate field descriptions, are demonstrated by analyses of unfertilised seedlings. Unfertilised seedlings, however, served as a useful basis for assessing uptake of fertiliser. For instance, the uptake of a nitrogen application two months after transplanting is indicated by comparing unfertilised levels which, although high at the time of fertilisation, had dropped sharply by the following month, with fertilised levels, which remained about constant.

The relatively short effect of ammonium sulphate as a source of nitrogen was noted. Levels often dropped within three months of application, suggesting the need for more frequent or heavier applications or preferably a fertiliser capable of releasing nitrogen gradually. This contention was supported by the frequent appearance of chlorotic symptoms within three months of fertiliser application. Sulphur levels appeared to be maintained at adequate levels for a considerable time suggesting that less frequent applications of sulphur would suffice. This would be particularly true if sulphur were supplied as granular elemental sulphur.

There was substantial agreement between indications from chemical analyses and growth measurements. The superiority of seedlings fertilised initially one month after transplanting at Site 1, as indicated by height and fresh weight determinations, resulted probably from sulphur uptake preventing the occurrence of a deficiency. The appearance of deficiency symptoms within three months of transplanting in the absence of fertiliser points to a need for added nutrients at a relatively early stage on deficient soils. An initial fertiliser application is recommended four to six weeks after transplanting under conditions similar to those described. However, the absence of outstanding differences in growth between seedlings receiving first fertiliser applications at varying intervals up to three months from transplanting suggests that as long as applications are made within three months growth is not greatly retarded.

Despite the ability of seedlings in these experiments to utilise supplementary nutrients relatively soon after transplanting, growth in the first 12 months was relatively poor. The destruction of much of the seedlings' root systems at transplanting was followed by a slow regeneration and an obvious retardation of growth. Alternative methods of transplanting are needed.

One approach would be to transplant at a stage where most growth needs are still derived from internal sources so that root damage at field planting would have only a minor effect on growth. A quick regeneration of roots could be expected and hence hindrance to nutrient and moisture uptake should be minimised. Fertiliser could then be applied effectively when needed. This method has its drawbacks in that it lessens the efficiency of nursery selection based on seedling vigour as well as necessitating a longer maintenance period in the field, with a resulting increase in costs.

A suggested technique is the growing of seedlings in earth-filled bags, as is done successfully with oil palms and has been shown to be promising by Foale (1968b) with coconut seedlings. Seedlings are germinated, then transferred and set upright in 'polybags' (tough polythene bags) where they are grown for a prolonged period before transfer to the field. Details of optimum bag sizes, fertiliser requirements and ideal stage for transplanting need to be worked out.

ACKNOWLEDGEMENTS

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REFERENCES

FOALE, M. A. (1968a). The growth of the young coconut palm (*Cocos nucifera* L.). 1. *Aust. J. agric. Res.*, 19 : 781-789.

FOALE, M. A. (1968b). *The Solomon Islands farmer*, Vol. 4 (2).

RICHARDS, L. A. AND WADLEIGH, C. H. (1952). Soil physical conditions and plant growth. In *Agronomy*, Vol. 11, p. 203 (Academic Press: New York).

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FURTHER SPREAD OF BLISTER SMUT OF MAIZE IN PAPUA AND NEW GUINEA

Dorothy E. Shaw*

ABSTRACT

The further spread of Ustilago maydis *in Papua and New Guinea, as indicated by confirmed infected cobs in new areas, is recorded. The incidence of the disease in previously infected areas remained low and the possible reasons for this are discussed.*

INTRODUCTION

IN a previous report (Shaw 1968) the distribution in Papua and New Guinea of blister smut of maize, caused by *Ustilago maydis*, was given up till October 1967. At that time records had been reported for most of the northern side of the mainland of Australian New Guinea as well as one record for New Britain, at Dagi near Hoskins. No infections had been recorded in the large islands of New Ireland and Bougainville or in Papua.

RECORDS IN NEW AREAS SINCE OCTOBER 1967

Records in new areas in both Papua and New Guinea since October 1967 are given below. The first record in a new area may not, of course, have been the first infection in that area.

NEW GUINEA

New Britain

The second record of *U. maydis* in New Britain occurred in November 1967 at an animal industry station near Rabaul in the north of the island. Some of the seed was said to have come from the Eastern Highlands on the mainland where infections had been recorded for several years. Eleven cobs were infected in a small area; all the diseased maize was burnt after drenching with dieseline.

In the following year another record was made at a corrective institution 30 miles from Rabaul, and by July infections were reported throughout an area with a 30 mile radius around Rabaul. A more isolated infection was later recorded in the Upper Wide Bay area, apparently derived from seed supplied from an infected garden near Rabaul.

No further records, however, have been reported for the Dagi area near Hoskins, the site of the first outbreak in New Britain, where diseased crops were also destroyed.

Bougainville, Solomon Islands

In January 1968 the first outbreak on Bougainville was reported. Two cobs were found infected at Kunua on the north-west coast. In November 1968 infected cobs (number unspecified) were reported at two villages in the Siwai area in the south of the island and in September 1969 one infected cob was reported from a village garden near Kieta.

New Ireland

In September 1968 the disease was recorded for the first time on this large island in a garden at a corrective institution at Namatanai, but to date no other infections have been reported.

Menyamya area, mainland New Guinea

In February, 1968 six plants were found infected in two gardens in the Menyamya area. It is probable that this area was infected previously, as diseased cobs had been reported in October 1967 near Kaintiba in Papua only 20 miles distant from Menyamya and on a direct walking track with that centre.

Western Highlands

As previously reported (Shaw 1968) records of the disease were made in the Western Highlands of the mainland before October 1967. In November 1968 the first records were made in the far west of the Highlands at Laiagam, about 60 miles by direct line north-west from Mount Hagen.

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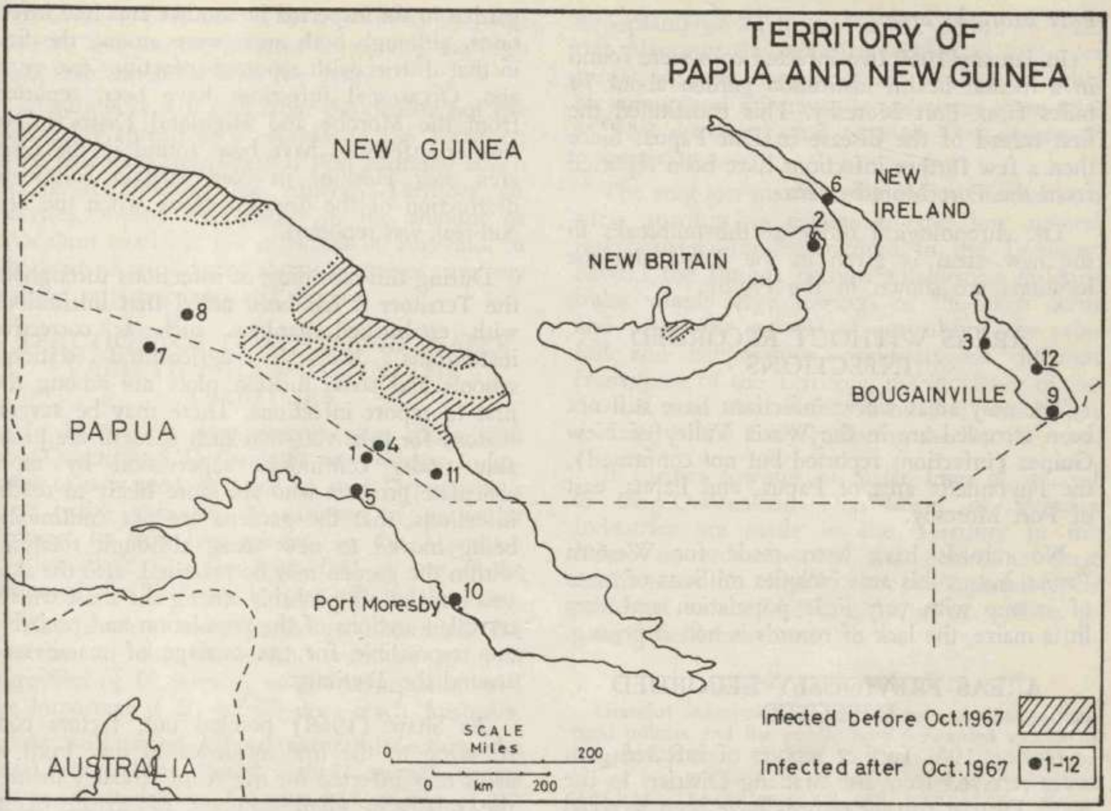

Figure.—Areas infected with *Ustilago maydis* prior to and after October 1967.

Wau area

The first record of infection in the Wau area was in April 1969. Wau is in a valley in the mountains south of Lae, but it has direct road contact with Lae, one of the earliest infected areas, and it had been expected that infected cobs would have been found at Wau earlier than April 1969.

PAPUA

Central Papua

In October 1967 an agricultural officer found some infected cobs at a mission station near Kaintiba, a village in Papua 12 miles from the New Guinea border and 20 miles from the larger population centre of Menyamya, 8 miles on the New Guinea side of the border. No other infections were found on this patrol which covered the surrounding areas.

On 1 March 1968 five infected cobs were found at Kaintiba and on 14 March 14 cobs were found infected at Murua near the end of the walking track from Menyamya through Kaintiba. Murua is only 5 miles in direct line from the large centre of Kerema on the South Papua coast. The relative positions are shown in the *Figure*. All infected cobs were burnt. No information could be obtained as to the source of the seed.

Southern Highlands

The first record of the disease in the Southern Highlands was made at Tari in October 1968. Tari is a small centre 80 miles due west of Mount Hagen in New Guinea, and 40 miles south-west from Laiagam, also in New Guinea, where smut was first recorded in November 1968.

Port Moresby area

In January 1969 two infected cobs were found in a mental health institution garden about 14 miles from Port Moresby. This constituted the first record of the disease in East Papua. Since then a few further infections have been reported from the Port Moresby area.

The chronological order of the outbreaks in the new areas is given in the *Table* and the locations are shown in the *Figure*.

AREAS WITHOUT RECORDED INFECTIONS

The only areas where infections have still not been recorded are in the Waria Valley of New Guinea (infections reported but not confirmed), the Popondetta area of Papua, and Papua, east of Port Moresby.

No records have been made for Western Papua, but as this area includes millions of acres of swamp with very little population and very little maize, the lack of records is not surprising.

AREAS PREVIOUSLY RECORDED INFECTED

During 1968 further reports of infected cobs were received from the Madang District. In the Sepik District further records have been received but the incidence has been low. During two surveys caried out by agricultural officers only one garden in 12 inspected in one area and one garden in six inspected in another area had infections, although both areas were among the first in that district with reported infections five years ago. Occasional infections have been reported from the Morobe and Highland Districts. No further infections have been found in the Dagi area near Hoskins in New Britain following destruction of the diseased maize when the first outbreak was reported.

During the recording of infections throughout the Territory it has been noted that institutions with established gardens, such as corrective institutions, hospitals, agricultural stations, schools and some mission plots are among the first to report infections. There may be several reasons for this, viz., that such gardens are probably under continuous supervision by more articulate growers who are more likely to report infections, that the gardens are not continually being moved to new areas, although rotations within the garden may be practised, also the staff and inmates are probably among the most widely travelled sections of the population and probably are responsible for the carriage of maize seed around the Territory.

As Shaw (1968) pointed out, factors contributing to the low incidence to date even in areas now infected for five years probably include the relatively small numbers of maize plants grown in the village gardens, the system of shifting agriculture used in most areas excepting the established gardens of institutions, the rain-

Table.—Chronological order of outbreaks of smut in new areas.

Date		Map Reference No.	Locality	Region
1967	October	1	Central Papua (Kaintiba)	Papua
	November	2	North New Britain	New Guinea
1968	January	3	North-west Bougainville	New Guinea
	February	4	Menyamya	New Guinea
	March	5	Central Papua (Murua)	Papua
	September	6	New Ireland (Namatanai)	New Guinea
	October	7	Southern Highlands (Tari)	Papua
	November	8	Far Western Highlands (Laiagam)	New Guinea
	November	9	South Bougainville	New Guinea
1969	January	10	Port Moresby area	Papua
	April	11	Wau	New Guinea
	September	12	East coast, Bougainville (Kieta)	New Guinea

fall which is over 200 in. in some areas and over 100 in. per annum in most areas, and the high temperatures throughout the year.

Australia is still free from the disease but the increasing spread of *U. maydis* in the Territory, especially its occurrence near Port Moresby which is the terminal of the Australia-Territory air services, means an increase in the amount of inoculum available for infection in Australia in the form of wind-borne spores or spores passively carried on passengers and freight.

REACTION OF QUEENSLAND MAIZE VARIETIES TO SMUT IN THE TERRITORY

In 1968-1969 arrangements were made with the Queensland Department of Primary Industries to sow seed of some of that Department's best maize varieties, or varieties of particular interest to that Department, in the Markham Valley about 12 miles from Lae, in one of the areas of the Territory longest affected by smut.

The sowings were made to determine the reaction of the Queensland varieties to field infection of *U. maydis*, as this information will be important if *U. maydis* does reach Australia.

As well as relying on natural infection, the seed was heavily dusted with *U. maydis* spores from infected cobs. Of the 837 plants of 32 lines which reached maturity, only two bore cobs that were infected. Another sowing with new seeds was made several months later and, as well as natural infection, the seed was again heavily dusted with spores, and infected cobs from other areas were attached to stakes around the plot from the time the first leaves appeared above ground level. In this planting there were 10 infected cobs on individual plants out of 656 plants of 24 lines. For the period of these two plantings the rainfall averaged 11.35 in per month and the ranges of the average monthly maximum and minimum temperatures were 83.9 to 92.8 degrees F and 69.5 to 73.4 degrees F respectively.

The very low number of infections found with these sowings is similar to the low natural infections so far experienced in the Territory. Should the fungus become established in Australia where large sowings of the crop occur and where the systems of agriculture, the rainfall and temperature conditions are different from those of the Territory, the incidence of the disease may also differ from that which has occurred in the Teritory during the last six years.

If further sowings of maize lines of interest to the Queensland Department of Primary Industries are made in the Territory in the future in order to try and determine their reactions to *U. maydis*, they will probably be subjected to artificial inoculation as well as to natural field infection.

ACKNOWLEDGEMENTS

Grateful acknowledgement is made to the agricultural officers and the public who forwarded specimens for identification, to Mrs C. Croft for drawing the Figure and to Mr A. W. Charles for critically reading the text. The agronomists and staff of the Bubia Agricultural Centre at Lae are thanked for their co-operation in the sowings of the maize varieties provided by the Queensland Department of Primary Industries.

REFERENCE

SHAW, DOROTHY E. (1968). Outbreak of blister smut of maize in New Guinea and its attempted eradication. *Res. Bull. Dep. Agric. Stock Fish., P. Moresby*, Pl. Path. Ser., 2 : 3-19.

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EFFECTS OF A LIGHTNING STRIKE ON COCONUTS, CACAO AND LEUCAENA LEUCOCEPHALA IN A MIXED PLANTING IN THE GAZELLE PENINSULA

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ABSTRACT

The effects of a lightning strike on coconuts, cacao and Leucaena leucocephala *in a mixed planting in the Gazelle Peninsula, New Britain, are described.*

The effects of a lightning strike on coconuts, cacao and leucaena were observed at intervals of 1 day, 7 days, 21 days, 7 weeks, 19 weeks and 32 weeks after the strike. Three coconut palms showed symptoms within 24 hours and others developed symptoms for the first time between 3 and 7 weeks after the strike. Survivors were showing recovery by the nineteenth week. Affected cacao trees were recovering by the time of the 7-week reading. Foliage damage on the cacao trees was similar to that produced by fire. Leucaena trees appeared to be more tolerant of the effects of the strike than cacao or coconuts.

INTRODUCTION

SEVERAL plantations in the Gazelle Peninsula, New Britain (New Guinea), had reported restricted areas of cacao (*Theobroma cacao* L.) and the shade tree *Leucaena leucocephala* suddenly dying from unknown causes. One such area has been investigated and recorded (Shaw and Van Velsen 1968).

On the afternoon of 28 April 1966, lightning was observed by Edward to strike several coconut palms on a plantation near Kokopo on the Gazelle Peninsula. The palms struck by lightning were located the same afternoon. Cacao trees with some *L. leucocephala* shade trees were planted between the coconuts. In order to determine the spread of mortality and the extent of recovery, observations and recordings were made in the affected area at the following intervals after the strike: 24 hours, 7 days, 21 days, 7 weeks, 19 weeks and 32 weeks.

RECORDS

At each visit records were made of the extent of damage to individual trees and any signs of recovery. In the *Figure,* coconut, cacao and *L. leucocephala* trees in the observation area are shown.

Coconuts

The coconuts in the area affected by the lightning strike were all pre-1939 planting and were approximately 20 m or about 60 ft tall. On the first visit (at 24 hours after the strike) palms A, B and C (see *Figure*) were the only ones showing symptoms. Edward had observed these palms to be affected one hour after the strike. On the second visit, one week after the strike, palms D and J were showing some frond damage and on the third visit, 21 days after the strike, palms F, H, I, K, M, N, P, Q and R were also showing frond damage. For ease in comparing progress of symptoms, the damage observed at each visit is tabulated in the *Table.*

From these observations it is evident that in a number of palms the effect of the strike was not noticeable for some time after its occurrence. This delayed effect was recorded by Charles (1960) and Shaw (1968). At the end of 32 weeks, only three of the affected palms had died and other palms which had shown frond damage appeared to have recovered. The centre of the strike appears to have been at palms A, B and

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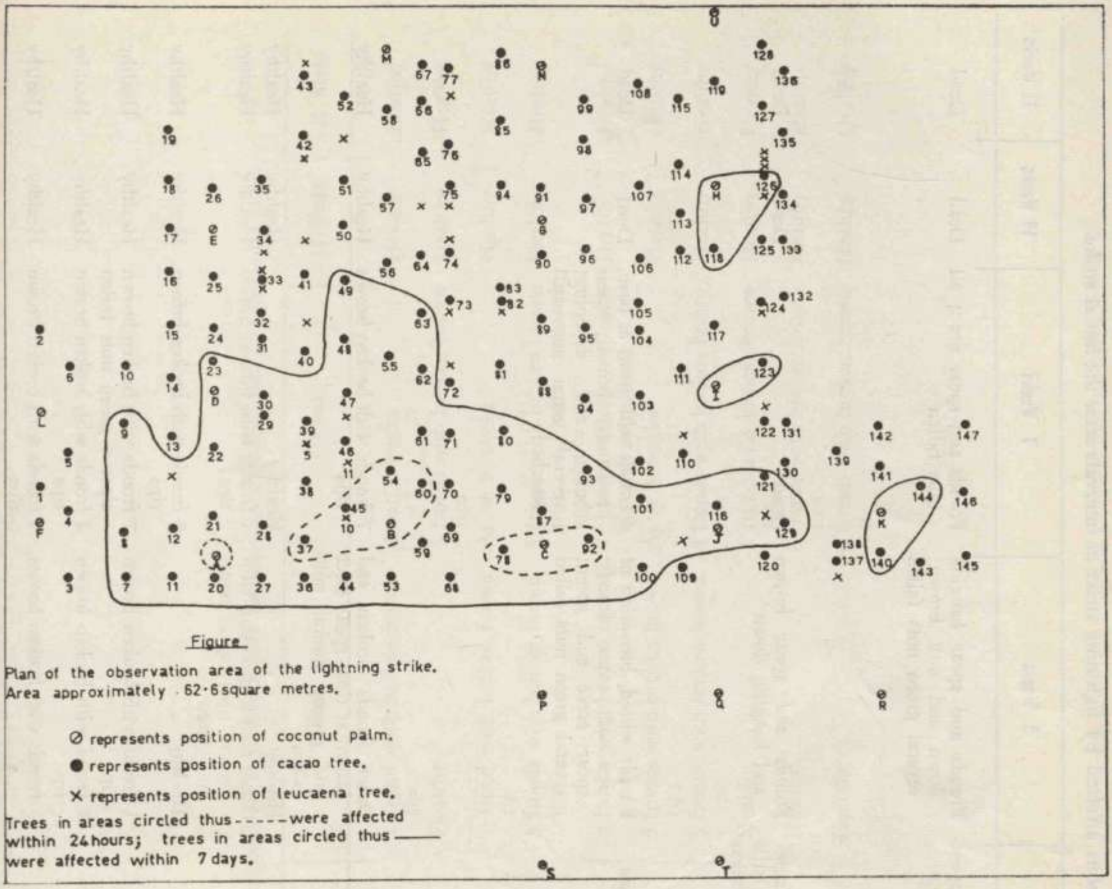

SCALE
0.5 cm = 3.8 m
(¼ in = 32.4 ft)

C. On other affected palms, the initial damage was a breakage of the midrib 46 to 90 cm (18 to 36 in) from the frond tip and subsequent browning of the leaflets beyond the break.

Symptoms first appeared on the older fronds (that is, the fronds at the base of the head) progressing to the younger fronds. Each frond appeared to die from the tip with death progressing to the base. Immature green nuts fell prior to the death of the spear, which was the last part of the cabbage to die.

Theobroma cacao

The cacao trees, approximately 8 to 12 years old, were interplanted between the coconuts, together with scattered *L. leucocephala* shade trees. They were approximately 3 to 4.5 m (10 ft to 15 ft) tall and were vigorous bearing trees. On the first visit, the trees numbered 37, 45, 54, 60, 78 and 92 showed a dark green to black discolouration of the mature leaves on the branches closest to the coconut palms B and C. Young pink leaves had a dark brown discolouration of the mid and secondary veins. This damage resembled heat damage from a ground fire. No fire was observed in the area during the storm. No other cacao tree was found to be affected at this time. However one week later many trees were observed to be affected with mild to severe darkening of the foliage. The trees were divided into seven groups according to severity of symptoms as follows:

Table.—The symptoms on coconut palms affected by lightning strike at intervals after the initial strike.

Palm	24 Hours	1 Week	3 Weeks	7 Weeks	19 Weeks	32 Weeks
A	Several fronds with brown tips; crown appeared wilted; piece of stem 61 cm by 12.7 cm by 3.8 cm blown out approx. 12.2 m (40 ft) above ground level	All fronds wilted; spear still green	Fronds and spear hanging down and dull brown; several green nuts fallen	Fronds and spear dead; all nuts fallen	Dead	Dead
B	Fronds appeared healthy; 2 patches of fibre extruded from stem at 4.58 m and 5.49 m above ground level; each area 61 cm by 5 cm	Fronds brown and hanging down; spear still green; all nuts fallen	Fronds and spear brown and hanging down	Dead	Dead	Dead
C	3 young fronds on ground with brown scorch patches; small areas, approx. 10 cm by 5 cm, of exposed fibre from ground level to 3.05 m on the trunk; groove 7.6 cm wide and 10 cm deep carved through fibrous roots at the base of the palm	No further symptoms	Fronds wilted, browning of tips of outer fronds; spear erect and green; several green nuts fallen	6 fronds still green at base, remainder brown; spear brown and drooping; several green nuts still attached	Dead	Dead
D	Healthy	2 fronds tattered	Outer fronds broken and brown at tips; spear erect and green; several nuts fallen	7 fronds with broken brown tips	Healthy	Healthy
E	Healthy	Healthy	Healthy	Healthy	Healthy	Healthy
F	Healthy	Healthy	Outer fronds drooping with brown tips; spear erect and green	4 fronds with broken brown tips	Healthy	Healthy
G	Healthy	Healthy	Healthy	8 fronds with broken brown tips	Healthy	Healthy
H	Healthy	Healthy	1 frond with broken brown tip	7 fronds with broken brown tips; 4 green nuts fallen	Healthy	Healthy
I	Healthy	Healthy	1 frond with broken brown tip	4 fronds with broken brown tips	Healthy	Healthy
J	Healthy	2 fronds tattered	3 fronds with broken brown tips	7 fronds with broken brown tips	Healthy	Healthy

Table.—The symptoms on coconut palms affected by lightning strike at intervals after the initial strike—*continued.*

Palm	24 Hours	1 Week	3 Weeks	7 Weeks	19 Weeks	32 Weeks
K	Healthy	Healthy	1 frond with broken brown tip	At at 3 weeks	Healthy	Healthy
L	Healthy	Healthy	Healthy	3 fronds with broken brown tips	Healthy	Healthy
M	Healthy	Healthy	1 frond with broken brown tip	As at 3 weeks	Healthy	Healthy
N	Healthy	Healthy	3 fronds with broken brown tips	3 fronds with broken brown tips; 3 with tattered appearance	Healthy	Healthy
P	Healthy	Healthy	4 fronds with broken brown tips	4 brown fronds, 2 with tattered appearance	Healthy	Healthy
Q	Healthy	Healthy	6 fronds with broken brown tips	As at 3 weeks	Healthy	Healthy
R	Healthy	Healthy	3 fronds with broken brown tips	4 fronds with broken brown tips	Healthy	Healthy
S	Healthy	Healthy	Healthy	1 frond with broken brown tip	Healthy	Healthy
T	Healthy	Healthy	Healthy	6 fronds with broken brown tips	Healthy	Healthy
U	Healthy	Healthy	Healthy	3 fronds with broken brown tips	Healthy	Healthy

(i) Trees showing no foliage symptoms: trees 1 to 6 inclusive, 10, 13 to 19, 24 to 26, 31 to 35, 40 to 43, 50 to 52, 56 to 58, 64 to 67, 72 to 77, 81 to 86, 88 to 91, 94 to 99, 102 to 115, 117, 119, 120, 122, 124, 125, 127, 128, 130 to 139, 141 to 143, 145. These trees showed no symptoms on the first and subsequent visits.

(ii) One branch with 3 to 6 dark green mottled leaves at the tip; trees 7, 8, 9, 62, 118, 121, 126, 129, 140.

(iii) Two branches with 3 to 6 dark green mottled leaves at the tips: trees 30, 49, 55, 69, 71, 116, 123, 144.

(iv) Three branches with 3 to 6 dark green mottled leaves at the tips: trees 29, 48, 68, 70, 101.

(v) Four branches with 3 to 6 dark green mottled leaves at the tips: tree 100.

(vi) Trees with some branches and all leaves showing dark green mottling: trees 23, 53, 1 branch affected out of 5 (1/5); 28, 80 (2/5); 27, 59, 61 (3/5); 20, 46, 93 (4/5); 36 (2/6); 47, 79, 92 (3/6); 44 (4/6); 87 (3/4).

(vii) Trees with complete defoliation: trees 11, 12, 21, 22, 37, 38, 39, 45, 54, 60, 78.

On the third visit, three weeks after the strike, the dark green mottled leaves present on the second visit had died and some leaves had fallen. The tip wood tissue was also dead and the affected tips were hanging down. The recordings were as follows:

(i) One branch with brown dead leaves at the tip: trees 8, 9, 62, 63, 118, 121, 126, 129, 140.

(ii) Two branches with brown dead leaves at the tips: trees 7, 30, 49, 55, 69, 71, 116, 123, 144.

(iii) Three branches with brown dead leaves at the tips: trees 29, 48, 68, 70, 101.

(iv) Four branches with brown dead leaves at the tips: tree 100.

(v) Trees with complete branches of brown, dead leaves: trees 23, 53 (1/5); 28, 80 (2/5); 27, 61 (3/5); 20, 46, 93 (4/5); 36 (2/6); 47, 79, 92 (3/6); 44 (4/6).

(vi) Trees with dead branches devoid of leaves: trees 87 (3/4); 59 (4/5).

(vii) Completely dead trees with no leaves: trees 11, 12, 21, 22, 37, 38, 39, 45, 54, 60, 78.

On the fourth visit seven weeks after the strike a number of affected trees were showing signs of recovery with the production of vigorous young leaf flush. Tree 44 was completely defoliated and dead. Recovering trees were recorded in three groups as follows:

(i) Vigorous young flush and shoots at the jorquette: trees 8, 20.

(ii) Vigorous young leaf flush on branches: trees 27, 61, 68, 69, 118, 121.

(iii) Vigorous young leaf flush and shoots on the trunk: trees 36, 79, 87.

On the fifth visit, 19 weeks after the strike, the previously surviving cacao trees had all recovered and had started to produce flowers and young cherelles. There was no evidence of delayed effects leading to later deterioration of trees not severely affected during the first 3 weeks. At 32 weeks after the strikes, the cacao trees alive on the third visit had all produced new growth.

Leucaena leucocephala

Although the *L. leucocephala* shade trees in the affected area were taller than the cacao trees, only three were found to have been affected by the strike. On the first visit none of the leucaena trees showed symptoms, but 1 week later tree number 10 was completely defoliated and the green seed pods were shrivelled. Tree 11 was defoliated on the branches nearest to coconut B and the remaining branches had normal healthy leaves. Tree 5 had lost the leaves on the branches closest to coconut A. None of the other leucaena trees was affected.

On the third visit, tree 10 was dead and tree 11 had inadvertently been stumped. Tree 5 was showing the same amount of defoliation as recorded on the second visit. After seven weeks there was no change in field symptoms or recovery by affected trees. On the final visit tree 5 had new vigorous growth, but the branch which had been defoliated was dead.

As with the cacao, there was no evidence after the initial period of three weeks of delayed effects amongst the leucaena trees.

CONCLUSIONS

Although observations were made for only 8 months after the initial strike, there was no evidence at the final recording of delayed symptoms on coconut palms as described by Charles (1960). The strike observed may have been less severe than that observed by Charles or the effect may have been dissipated through the cacao and leucaena trees, or both. The foliage symptoms on cacao resembled those induced by heat from fires under trees. There was no evidence at the final recording of delayed symptoms on the cacao and leucaena trees.

REFERENCES

CHARLES, A. E. (1960). Coconut lightning strike. *Papua New Guin. agric. J.*, 12 : 192-195.

SHAW, DOROTHY E. (1968). A lightning strike of coconuts in New Guinea. *Papua New Guin. agric. J.*, 19 : 147-150.

SHAW, DOROTHY E. AND VAN VELSEN, R. J. (1968). Lightning strike of cacao and leucaena in New Britain. *Papua New Guin. agric. J.*, 20 : 75-82.

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SOME NET-RADIATION AND SOIL THERMAL DIFFUSIVITY MEASUREMENTS FOR THE PORT MORESBY AREA

R. DRINKROW *

ABSTRACT

Measurements of net-radiation and soil heat flux levels for February 1968 are presented and discussed. It is believed these are the first direct measurements of these parameters to be obtained for Papua and New Guinea. By means of two measurements of soil heat flux at differing depths a value is obtained for the thermal diffusivity of the soil. This value is at the low end of the range of values quoted by other workers and needs checking by more direct methods.

INTRODUCTION

FOR Papua and New Guinea, a country dependent on primary production, there are few direct measurements of the physical parameters affecting crop growth. There are records of rainfall, temperature and humidity at some locations but records of evaporation for Port Moresby only. These measurements do not give a complete picture of the agricultural environment. For instance the growth of the plant is highly dependent on the rate of photosynthesis which in turn is influenced by the level and spectral composition of the incoming radiation. Similarly the evapotranspiration rate is strongly dependent on the radiation level. Measurements of radiation, in particular net-radiation, appear to have been neglected although Fitzpatrick (1965) has attempted to estimate the radiation level using standard meteorological data and empirically derived formulae.

During the day radiation reaching the earth's surface is predominantly direct solar radiation with a smaller contribution due to diffuse and scattered radiation from the atmosphere and long-wave radiation from clouds. Of this incident radiation some is refleected and some absorbed into the surface which in turn will be heated and thus re-radiate long-wave radiation back into space. The net-radiation N at any level is defined as the difference between incoming and outgoing radiation levels or as it is usually expressed:

$$N = R_s (1 - \rho) - R_L \qquad (1)$$

where R_s is the incoming solar radiation, scattered, diffuse and direct, ρ is the fraction of short-wave radiation reflected from the surface, or more commonly, the albedo and R_L is the outgoing long-wave radiation.

At the surface this net-radiation which is positive or incoming during daylight, is partitioned into several energy dissipating terms. They are:

(*a*) the heat flux into the soil, G;

(*b*) the direct flux of heat into the turbulent air over the surface, H; and

(*c*) heat in the form of evaporated water, or latent heat for which we shall use the symbol L.

Symbolically we can write:

$$N = G + H + L \qquad (2)$$

Figure 1 shows diagramatically these terms of the energy balance during daylight.

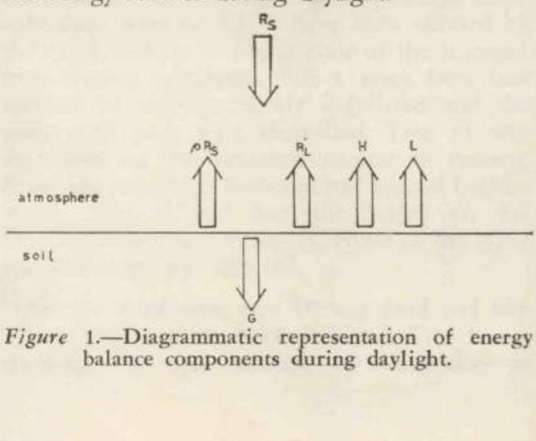

Figure 1.—Diagrammatic representation of energy balance components during daylight.

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The present research programme is aimed at accurate measurements of each of these terms over various surfaces and crops for Papua and New Guinea. Extensive work has been done over temperate grasslands but extrapolation of these results to tropical agriculture is open to question.

EXPERIMENTAL METHODS

Over the period January to March 1968, sensors were installed on a site in the University campus to measure the terms N and G in equation (2) above. The soil was dark cracking clay typical of most of the Waigani Valley floor. Over this was a thin growth of *Axonopus compressus* (Sw.) established not long previously; it was showing a good rate of growth but kept mown so that the overall height was about 1 cm.

The sensors used were a net-radiometer from a design by Funk (1959) and soil heat flux plates from a design by Deacon (1950). These instruments are available commercially and are supplied with a calibration certificate from the CSIRO Division of Meteorological Physics, Melbourne. The net-radiometer was mounted approximately 1.5 m above the surface with a clear view of at least 80 degrees from the vertical all around. The soil heat flux plates were buried in the soil nearby at two depths. This arrangement enables additional information to be obtained on parameters of the soil. *Figure* 2 illustrates a cross-section of the arrangement.

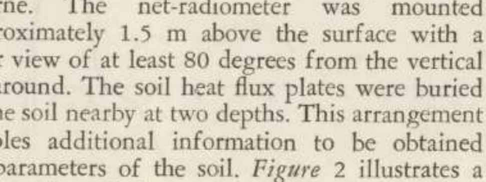

Figure 2.—Cross-section of experimental arrangement of sensors.

A 3-channel potentiometric chart recorder enabled continuous records to be obtained for the quantities N, G_1, G_2 where the subscripts 1 and 2 denote the heat flux at depths Z_1 and Z_2, respectively 1 cm and 6.5 cm in this experiment.

RESULTS AND DISCUSSION

Approximately seven weeks of records were obtained but some events, such as power failures and excessive rainfall, rendered some sections unsuitable for analysis. Satisfactory analysis could be carried out for the month of February and data for this period only are presented.

Figures 3 and 4 give the daily average for the 3 parameters and *Figures* 5 and 6 the hourly average for 24 hour periods over the whole month. Also shown in *Figure* 5 is the quantity $(N - G_1)$ which from equation (2) is equal to the term $(H + L)$, the total heat flux removed by the atmosphere due to turbulent transfer. This graph shows two points of interest. Firstly a large flux of heat away from the surface which predominantly follows the net-radiation except for a phase-lag of approximately half-hour. At the peak some 86 per cent of the net-radiation level is being removed by this means, the remainder being temporarily stored in the soil for release later in the day. It is a reasonable assumption that the heat stored in the 1 cm of soil above the G_1 flux plate does not introduce an error of more than several per cent in this value though the observed phase-lag is possibly due to this. That the atmospheric heat flux should follow the net-radiation curve so closely is to be expected from the large increase in atmospheric turbulence following instability generated by surface heating.

Secondly we find that in the evening the $(N - G_1)$ term becomes negative from around 1800 to 2300 hours, and then becomes positive again from 2400 hours on through the morning. The negative value indicates that heat is being radiated by long-wave radiation away from the surface at a greater rate than that supplied from the lower soil layers where it was stored during the daylight period. The rate of heat flow to the surface through the soil is determined by the thermal conductivity of the soil whereas long-wave radiation from the surface is a function of surface temperature and cloud cover. In general to satisfy equation (2) both H and L will be negative which in turn implies that the atmosphere is being cooled by contact with the surface and water vapour is condensing on the surface as dew. In view of the high moisture levels in the air and the large value for the latent heat of condensation it is expected that the latter is the more significant.

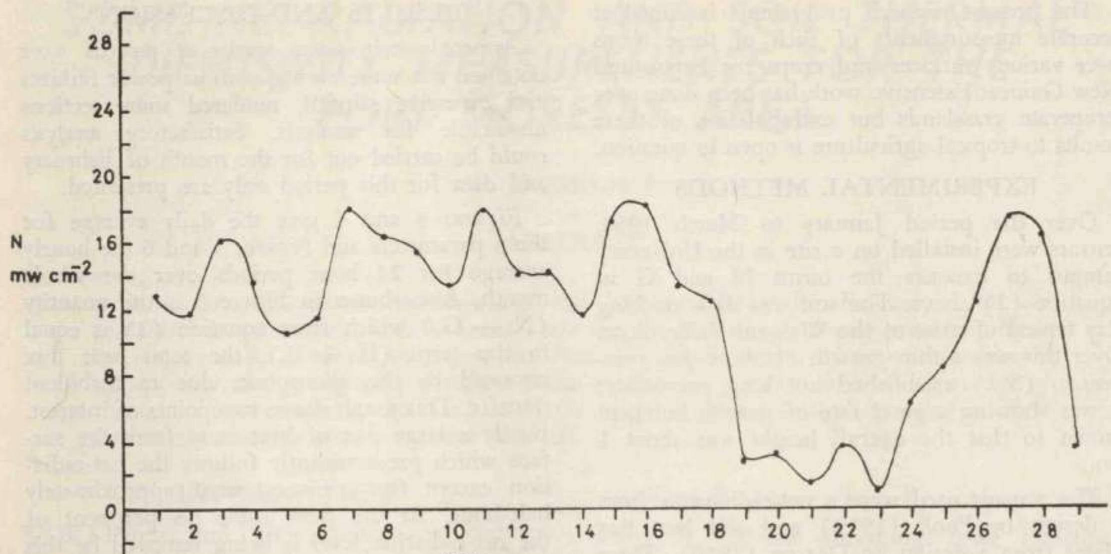

Figure 3.—Daily average values of net-radiation for February 1968.

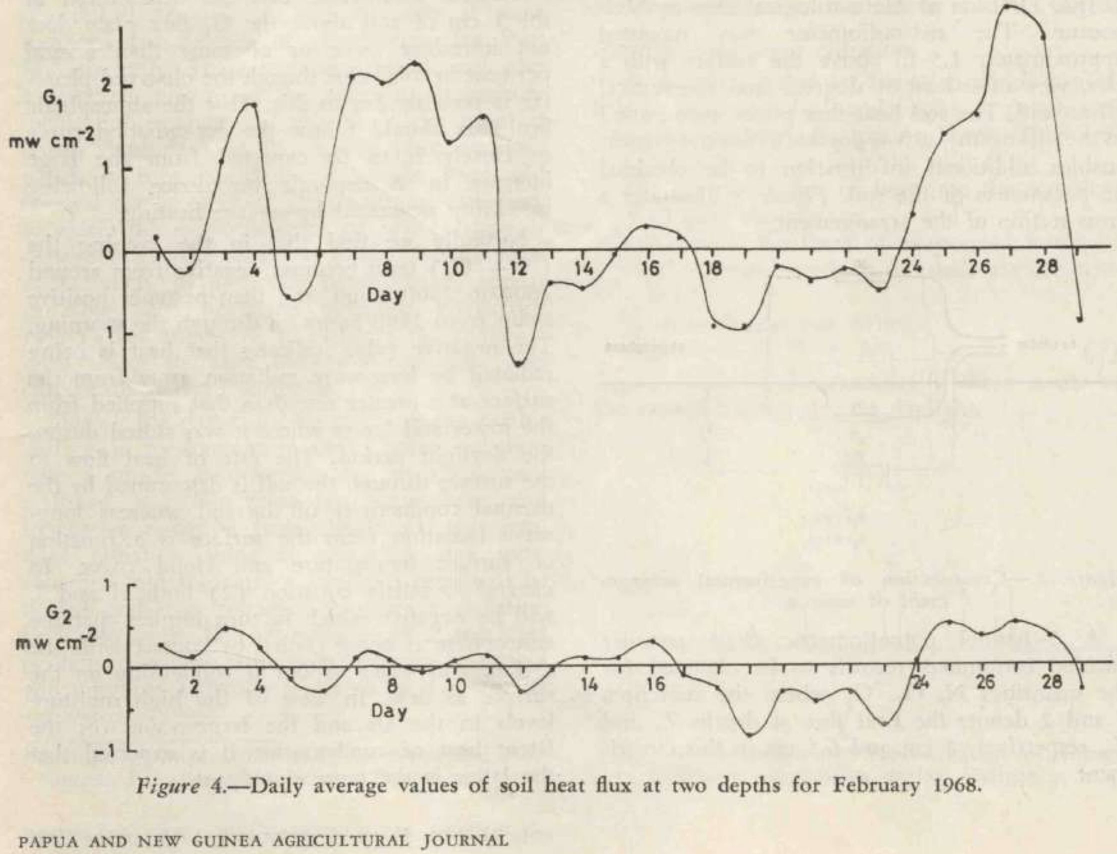

Figure 4.—Daily average values of soil heat flux at two depths for February 1968.

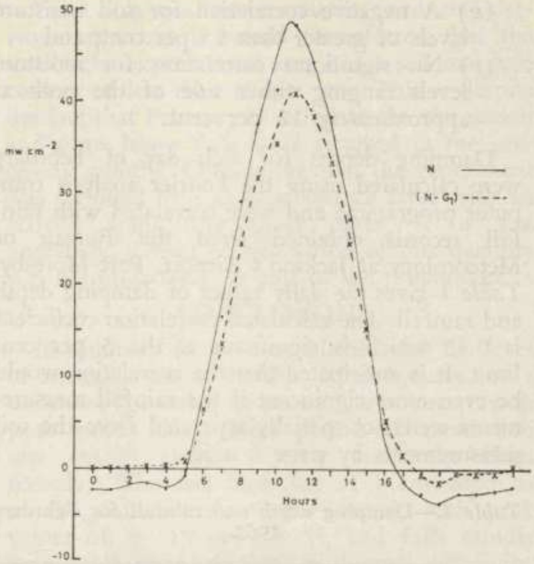

Figure 5.—Diurnal variation of net-radiation and the quantity (N-G_1).

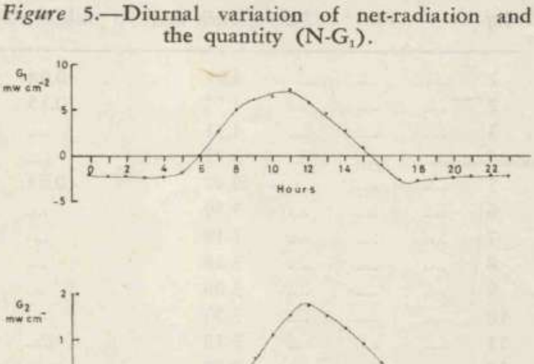

Figure 6.—Diurnal variation of soil heat flux at two depths.

The positive nature of the ($N - G_1$) curve in the morning hours would appear to result from a decrease in radiation from the surface, due to the lower surface temperature and possibly from thin fog layers, relatively common during this period. The flux of heat through the soil is relatively constant over the night-time period and hence a reduction in N would imply that the heat was being given to the atmosphere either directly by warming or in evaporation.

As yet no direct measurements are available to indicate how the heat may be distributed between the direct and latent terms. Sellers (1965) gives examples for three different sites and finds large differences in the relative importance of the two terms during the night.

The graphs of G_1 and G_2 in *Figure* 5 illustrate the typical damping of heat flux and the shift in phase of the peak value with depth, both being due to the low value of thermal conductivity for soil. The theoretical treatment of the damping of a temperature or heat flux wave as it penetrates a layer of soil is well established, e.g., Van Wijk (1966) for the case of a sinusoidal wave. The waveforms G_1 and G_2 are obviously not well defined sinusoids but by using the technique of Fourier analysis we can treat this complex wave as a combination of sinusoids each of which can be treated by the method above.

From the theoretical work we have that the amplitude of any sinusoidal wave shows a decrease with depth usually expressed as:

$$\frac{A_1}{A_2} = \exp\left\{\frac{Z_2 - Z_1}{D}\right\} \quad (3)$$

where A_1, A_2 are the amplitudes at depths Z_1, Z_2 and D is the 'damping depth' for the soil layer. D is defined as the depth in the soil for which amplitude of a sinusoidal temperature wave will be reduced by a factor of 0.368 (approximately one-third).

A computer analysis of the waveforms G_1 and G_2 plotted in *Figure* 4 gave the sinusoid of period 24 hours, or the fundamental as containing the greatest contribution and a solution for (3) was obtained for this Fourier component only. Lettau (1954) has outlined some of the errors possible in using the amplitude of higher order harmonics in solving for damping depth. The value for D was found to be 4.5 cm. It is readily shown that the damping depth for the annual variation in temperature is approximately 19 times this value, i.e., 85.5 cm.

Extending the theory of propagation of a temperature or heat-flux wave through a soil layer leads to the result that the damping depth parameter is itself expressible in terms of other parameters related to the soil, in particular we have

$$D = \frac{2a}{\Omega}$$

where a is the thermal diffusivity for the soil and Ω is the angular frequency of the temperature sinusoid.

Substituting appropriate values for the diurnal temperature wave we obtain a value for a of 0.8×10^{-3} cm² sec^{-1}. Quoted values for other soils are 1×10^{-3} for peat and 2 to 5×10^{-3} for clay (Van Wijk 1966), and 1 to 5×10^{-3} (Rose 1966). The figure obtained would appear to be in reasonable agreement.

Up to this point we have considered calculation of soil parameters only for data averaged for the diurnal cycle over the whole month. We can, just as readily, calculate the damping depth and thermal diffusivity for the soil for each day of the month using the waveforms of G_1 and G_2 obtained for each 24-hour interval. The results will of course not have the reliability of the averaged values but will show day to day fluctuations as a result of the modulation of the thermal diffusivity term by soil water content. A relation between thermal diffusivity and soil moisture for clay soil is shown in *Figure* 7 after Sellers (1965).

The particular point of interest is not in the absolute values given but in the phenomena of the change of slope of the curve as the water content increases beyond 12 per cent. Hence if we obtain daily values of thermal diffusivity, or damping depth (which differs from it only by a constant factor) and correlate these with rainfall data we would expect one of the following results:

(*a*) A positive correlation for soil moisture levels of less than 10 per cent;

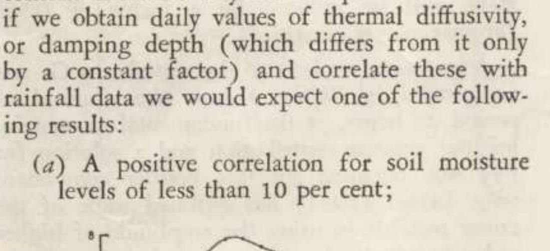

Figure 7.—Thermal diffusivity of clay soil as a function of volumetric fater content, after Sellers (1965).

(*b*) A negative correlation for soil moisture levels of greater than 15 per cent; and

(*c*) No significant correlation for moisture levels ranging either side of the peak at approximately 12 per cent.

Damping depths for each day of February were calculated using the Fourier analysis computer programme and were correlated with rainfall records obtained from the Bureau of Meteorology at Jackson's Airport, Port Moresby. *Table* 1 gives the daily values of damping depth and rainfall. The calculated correlation coefficient is 0.45 which is significant at the 5 per cent limit. It is anticipated that the correlation would be even more significant if the rainfall measurements were not spatially separated from the soil measurements by some 6 miles.

Table 1.—**Damping depth and rainfall for February 1968.**

Day	Damping Depth (cm)	Rainfall (in)
1	4.91	0.04
2	4.53	0.35
3	4.31	....
4	3.22	....
5	4.47	0.44
6	3.59	....
7	3.18	....
8	3.18	....
9	3.06	....
10	3.53	....
11	3.15	....
12	5.07	....
13	5.88	0.60
14	5.40	0.12
15	5.22	0.06
16	4.77	0.07
17	3.91	0.04
18	5.44	0.42
19	6.75	0.26
20	10.21	1.12
21	4.24	0.28
22	5.69	0.52
23	2.71	0.14
24	7.05	0.85
25	5.75	....
26	4.17	....
27	3.84	....
28	3.61	....
29	4.56	....

From this positive correlation and the previous argument it would be inferred that the soil in the experimental area had a soil moisture content of less than 10 per cent. This is despite the fact that February is well into the wet season and some heavy falls were received in the preceding months. Considering that the experiment was confined to a shallow surface layer with an actively transpiring grass cover, it is not unrealistic. Direct determination of this quantity was not undertaken as part of the programme.

CONCLUSIONS

In summary we have established that the level of net-radiation in the Port Moresby area has a daily average value of up to 5 mw cm^{-2} with peak values during this period of about 106 mw cm^{-2} (taken directly from the chart records). The soil heat flux at 1 cm depth is of the order of $\pm$ 8 mw cm^{-2}, with peak values of $\pm$ 15 mw cm^{-2}, and falls rapidly with depth owing to the low thermal diffusivity. A value of 0.8×10^{-3} cm^2 sec^{-1} obtained for the thermal diffusivity is in approximate agreement with that quoted by other workers for clay soils.

REFERENCES

DEACON, E. L. (1950). The measurement and recording of the heat flux into the soil. *Q. Jl R. met. Soc.*, 76 : 479.

FITZPATRICK, E. A. (1965). Lands of the Port Moresby-Kairuku area, Territory of Papua and New Guinea. *Land Res. Ser. CSIRO Aust.*, 14.

FUNK, J. P. (1959). An improved polythene shielded net radiometer. *J. scient. Instrum.*, 36 : 267.

LETTAU, H. (1954). Improved models of thermal diffusion in the soil. *Trans. Am. geophys. Un.*, 35 (1) : 121.

ROSE, C. W. (1966). *Agricultural Physics* (Pergamon Press: London).

SELLERS, W. D. (1965). *Physical Climatology* (University of Chicago Press: Chicago).

VAN WIJK, W. R. (1966). *Physics of the Plant Environment* (North-Holland Publishing Co.: Amsterdam).

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ACTIVITIES STUDIES IN NEW GUINEA VILLAGES

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ABSTRACT

University students, working in their own villages, collected data on how villagers spent their time during the day. There were numerous problems in the exercise but it is believed that such studies not only give some idea of present-day demands of traditional and non-traditional activities, but they also provide a valid interregional comparison on how existing demands can act as a constraint on economic development.

In 7 different villages, 34 different activities were recorded for 320 individuals during a 24-hour day. Most of the day-time activities were recorded to the nearest 10 minutes. Only adults (over 16 years of age) were included in the study and it appears that even the most 'westernised' villages are still tradition-orientated and that, in the light of present needs and village realities, neither sex has excessive leisure time.

INTRODUCTION

DURING the 1968-1969 Christmas vacation, seven university students were employed by the Department of Agriculture, Stock and Fisheries to collect data in their own villages. The study was primarily to collect statistical data on how people spend their time in various activities in their villages, and was a pilot project in the colection of quantitative data for a long-term study of indigenous agriculture being carried out by the Geography Department of the University of Papua and New Guinea. It was also an attempt to tap the cognitive world of the village by using literate villagers to do the field work and to write up the problems of economic and social development from a village point of view.

The students worked in their home villages. They all spoke at least three languages—the local dialect, English and the regional lingua franca (e.g., Pidgin). Villages were distributed over the Territory with examples in the Highlands and in coastal and island areas (*Figure* 1). They were Malu (near Ambunti), Bilbil (near Madang), Pavaere (near Kieta), Kerapi (near Hoskins), Oba (on Sideia Island), Mintima (near Kundiawa) and Kaiap (near Wabag). Totals in this article refer to all these villages although data for only Bilbil, Pavaere, Oba, Mintima and Kaiap are presented in any detail.

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METHOD

The four main tasks of the students were:

1. To carry out a sociological census. This involved collecting basic demographic data by individuals and households with data on intervillage movements, number of trees used for cash cropping, languages spoken, material possessions, education and employment histories and annual incomes and expenditure.

2. To fill in daily time sheets on how men and women in the village over the age of 16 spent their time. Each day a different person's activities were noted for every day of the week. Categories were made for sleeping, resting, group discussion, eating (regular and feasting), travelling (method and purpose), subsistence and cash cropping (16 divisions), and many other socio-economic activities.

3. To fill daily record sheets of who worked in selected gardens and what activities they carried out. This was an attempt to measure the labour input per unit area. Most students selected two or three gardens at different stages of maturity so that for the period they were in the village, records were kept of labour expended on areas averaging just over one acre.

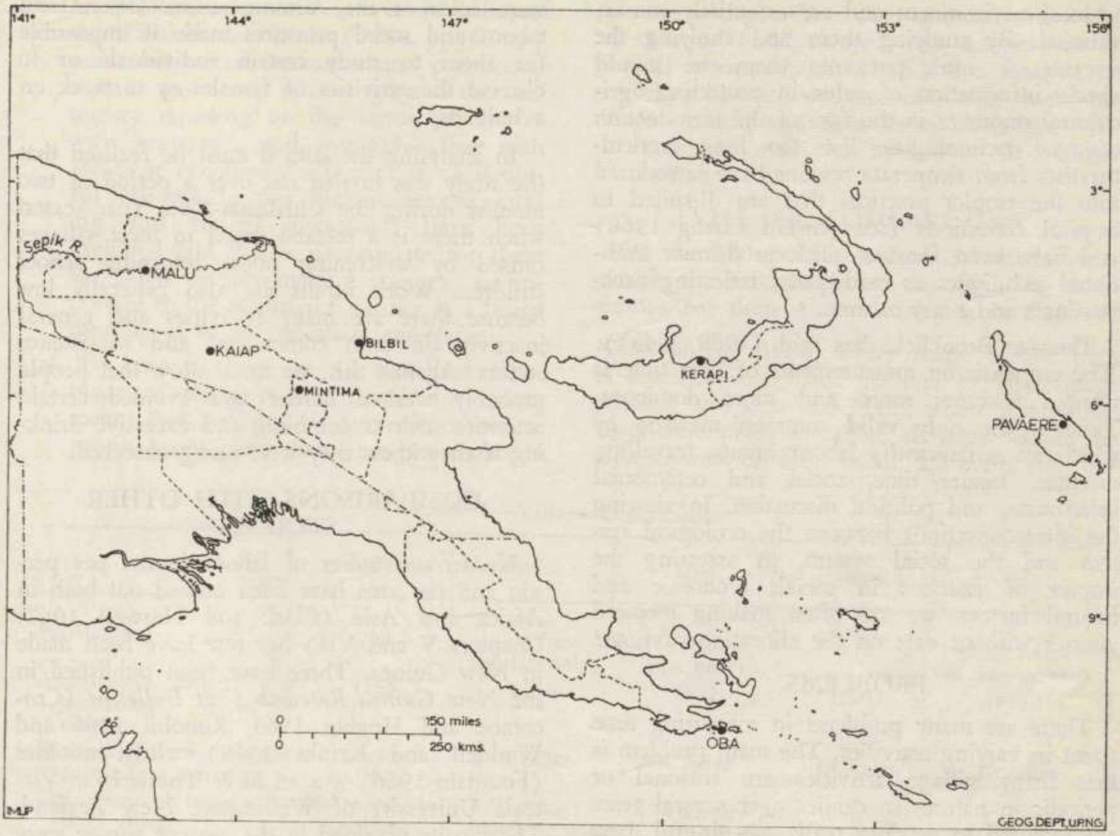

Figure 1.—**Location of study villages.**

4. To write a long essay on the village, its environment, its people, gardening techniques and practices, livestock, diet, cash cropping, individual incomes and expenditures, transportation and schooling. The bias in these essays was to highlight indigenous categorisation of the village environment and socio-economic problems, rather than to be merely descriptive. One such essay has already been published (Alaluku 1970).

Students were also expected to keep a field diary and to keep in touch with the supervisor by post at least once a fortnight. These tasks were carried out under the supervision of the writer, who visited each student in the field at least once.

PURPOSE OF THE PROJECT

This article deals only with the activity studies. The basic aim here was to seek answers to questions such as whether 'the requirements of the subsistence sector of the economy imposes limitations on the expansions of activities in the monetary sector and, conversely, whether participation in the monetary sector involves restrictions on subsistence activities' (Waddell and Krinks 1968:xix).

More generally, activity studies may provide a valid method for making interregional comparisons. This is important because socio-economic practices at the village level affect the degree of acceptance of cash cropping and traditional agricultural practices are relevant to the successful introduction of cash cropping. Some traditional systems of agriculture show close adjustments to local environment and are essentially conservational. By studying them and studying the amount of work put into them we should obtain information of value in protecting agricultural resources in the face of the introduction of new technologies. For too long, agriculturalists from temperate regions have introduced into the tropics practices that are ill-suited to tropical conditions (see Jen-Hu Chang 1968) and have been far too quick to dismiss traditional techniques as inadequate, reflecting backwardness and a lazy nature.

Thus as Brookfield has said (1968, p.434), 'The emphasis on measurements of how time is spent . . . becomes more and more dominant. Time is the only valid common measure by which we can quantify labour inputs, travelling distance, leisure time, social and ceremonial intercourse, and political discussion. In viewing the interconnections between the ecological system and the social system, in assessing the impact of changes in social, economic and natural factors, we are often making inspired guesses without data on the allocation of time.'

PROBLEMS

There are many problems in measuring time spent in varying activities. The main problem is that many village activities are seasonal or periodic in nature, so studies over several years are required to produce really meaningful data. Also in this particular study proper sampling procedures were impossible because villages were chosen solely on the basis of having University students who were willing to do the work: in this sense each village is probably atypical. Related to this was the fact that it was often impossible to separate certain activities. For example, while cooking an evening meal, a woman may be minding children, making a string bag and talking, while a man may combine a hunting trip with a visit to a sago patch or a potential garden site. The best that could be done was either to divide total time spent among the different activities or to count only the predominant activity.

There were many problems for the students even though they were working in their own society. Naturally they were unable to observe all activities all the time and they had to be careful not to cause offence in their own societies: initially it was felt that some of them were spies of the Administration. Often local taboos and social pressures made it impossible for them to study certain individuals or to observe the activities of females or to work on a holy day.

In analysing the data it must be realised that the study was carried out over a period of two months during the Christmas-New Year season when there is a relaxed mood in most villages caused by welcoming home returning school children. Work inputs are also generally low because there are many festivities and general inactivity in both commercial and subsistence sectors. Against this, we must allow that people probably worked harder and avoided certain activities such as gambling and excessive drinking if they knew they were being observed.

COMPARISONS WITH OTHER STUDIES

Numerous studies of labour inputs per person and per area have been carried out both in Africa and Asia (Clark and Haswell 1967: Chapters V and VII) but few have been made in New Guinea. Three have been published in the *New Guinea Research Unit Bulletins* (Crocombe and Hogbin 1963, Rimoldi 1966 and Waddell and Krinks 1968) whilst another (Fountain 1966) was an M.A. Thesis from Victoria University of Wellington, New Zealand. The results obtained in the present survey were very similar to these earlier surveys although the methods of obtaining the data were somewhat different. The main aims in this survey were as follows:

1. To obtain data in contrasting villages in the Territory for comparative purposes. Some differences between the villages are shown in *Table* 1.
2. To actually observe most activities and to measure all activities to the nearest 10 minutes. This means that short rests during particular activities are not included with the activity.
3. To keep track of all activities including eating, resting, sleeping and talking during a 24-hour day. Because of widely differing degrees of success among the students, these categories are excluded from the present discussion but it is obviously unsatisfactory to restrict such a study to what

are productive spheres in western cultures. As Waddell and Krinks (1968, pp. 67-69) point out, social, economic and ceremonial threads are closely interwoven and the customary equating of the terms *productive* with *economic*, and *non-productive* with *social* or *ceremonial* activities is of doubtful validity. In this present exercise talking and formal discussions have been excluded and this is unfortunate for these are often decision-making sessions, as important to the subsistence farmer as a board meeting is to an industrial enterprise.

4. To keep a check on all travelling time, mode of transport and reason for movement. For reasons of convenience where people spent more than nine hours outside the village they were deleted from the sample. In all, this was only 2.8 per cent of all persons studied and the reason for their absence was normally that they went to market and then stayed the night with someone near the market or in another village.

VILLAGE COMPARISONS

Of the 320 people studied, 92 made visits outside the village during the day. The main reasons for these visits are shown in *Table* 2.

Except for Bilbil, where many of the trips to market were made in one of the village vehicles, and Oba and Malu, where intervillage visits were made in canoe, all trips outside the villages were on foot. In all, 2.7 hours each day

Table 1.—Village Comparisons

....	Bilbil	Mintima	Kaiap	Pavaere	Oba
Population	298	222 (one subclan only)	146 (Lokai clan only)	135	43 (a hamlet of Sauasauaga)
Approximate date of first permanent European contact	1885	1930	1932	1890?	1890?
Distance from nearest government centre	7 miles	6 miles	6 miles	14 miles	10 miles
Main form of travel away from village	Motor vehicle; walking	Walking; motor vehicle	Walking	Walking	Canoe; launch
Main staple in rank order	Taro Yam	Sweet potato	Sweet potato	Taro Yam	Taro Yam
Main cash crop in rank order	Coconut	Coffee	Coffee Pyrethrum	Cocoa Coconut	Coconut
Altitude (in feet)	On beach	5,000	7,000	800	On beach
Approximate average annual rain (inches)	140	90	116	120	108
Wettest season	Nov-May	Jan-April	Sept-April	Jan-April	March-June

Table 2.—Reasons for travel outside villages

	Percentage of all visits outside village				
....	Oba	Bilbil	Pavaere	Mintima	Kaiap
Selling produce	25	12	96	31	38
Church or meeting	....	6	....	35	....
Buying	13	41	4	4	25
Visiting	62	6	....	19	13
Visiting sick or getting treatment	....	18	....	....	13
Paid work	....	18	....	4	6
Trading trip	....	....	....	8	....
Government business	....	....	....	....	6

were spent in all forms of travel with much of the intravillage travel made up of visits to the gardens. Obviously much of the casual walking around the village was missed for the travel time counted only includes those occasions when walking or travel was an integral part of one of the activities measured (cf. Waddell and Krinks 1968: iii and 1969 were in the two villages studied 18 per cent and 25 per cent of all activity time was spent in travel).

A synopsis of the results is shown in *Figure* 2 (for the average results of all villages) and *Figures* 3 to 5 (for some individual villages). Full circles would represent an average 24-hour day: the half circles shown in the diagram represent a 12-hour day. Diagrams show males and females separately.

Activities obviously have to be grouped and the following categories were made:

1. Travel—
   (*a*) Travelling to and from garden
   (*b*) Other movement within the village
   (*c*) Travel outside the village when the person concerned spent the greater portion of the day in his own village
2. Subsistence gardening—
   (*a*) Clearing
   (*b*) Digging and planting
   (*c*) Weeding
   (*d*) Fencing
   (*e*) Care of crops
   (*f*) Harvesting
   (*g*) Processing
3. Other food sources and non-food gathering—
   (*a*) Sago
   (*b*) Fishing
   (*c*) Hunting
   (*d*) Food gathering
   (*e*) Collecting non-food items
4. Cash cropping—
   (*a*) Clearing
   (*b*) Planting
   (*c*) Weeding
   (*d*) Care of crops
   (*e*) Fencing
   (*f*) Harvesting
   (*g*) Processing

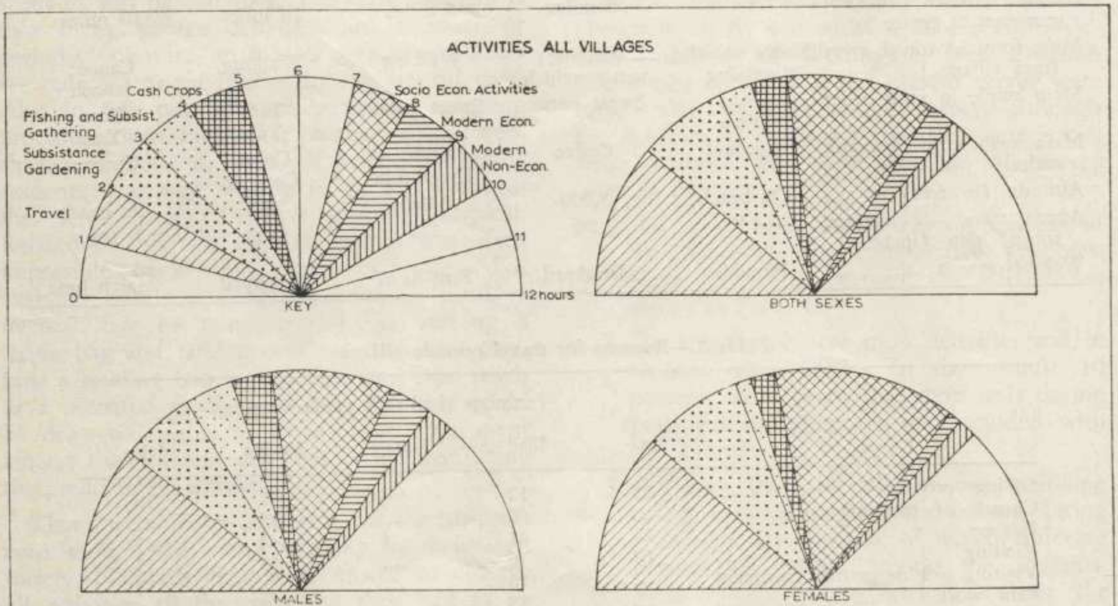

Figure 2.—Average activities in all villages.

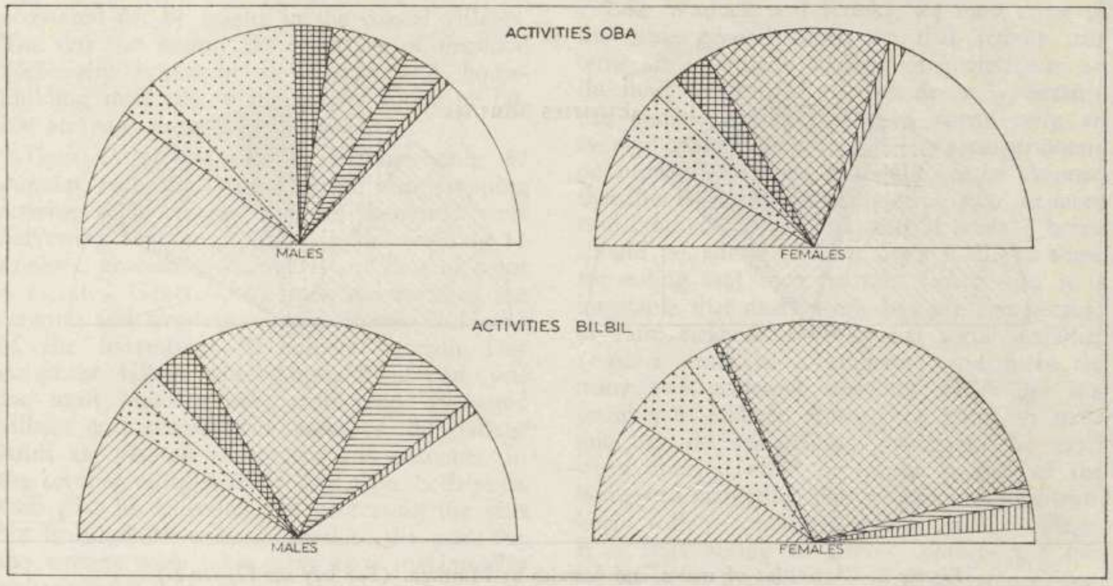

Figure 3.—Activities of males and females at Oba and Bilbil. (For key see *Figure* 2.)

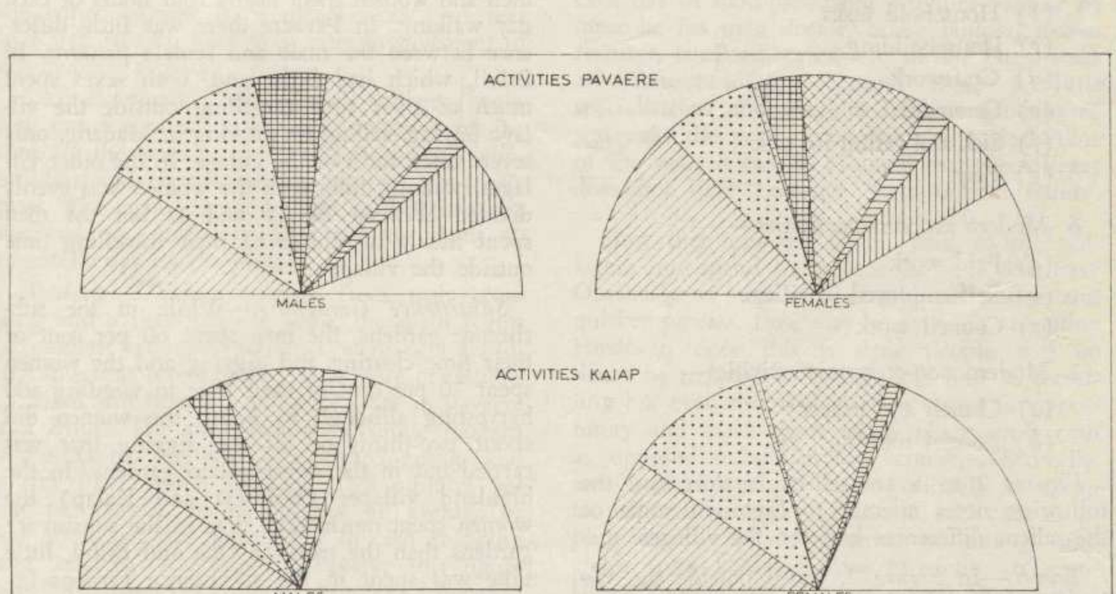

Figure 4.—Activities of males and females at Pavaere and Kaiap. (For key see *Figure* 2.)

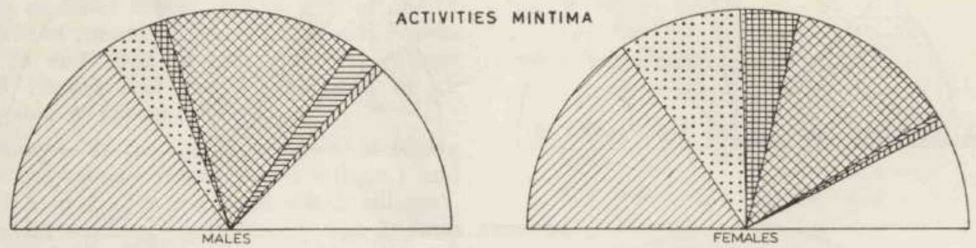

Figure 5.—Activities of males and females at Mintima. (For key see *Figure* 2.)

5. Other socio-economic activities—
   (*a*) Cooking
   (*b*) Household tasks
   (*c*) Housebuilding
   (*d*) Craftwork
   (*e*) Ceremonial
   (*f*) Sick and caring for sick
   (*g*) Play
6. Modern economic activities—
   (*a*) Paid work
   (*b*) Self-employed in village
   (*c*) Council work
7. Modern non-economic activities—
   (*a*) Church and prayer
   (*b*) Formal meetings, etc.

Figures 2 to 5 are self-explanatory and the following notes attempt to highlight some of the salient differences between the villages.

Travel.—In *Figure* 2, travel outside the village took up half the travelling time (2.7 hours) and the rest of the travel time was divided evenly between travel to gardens (1*a*) and other movement within the village (1*b*). The total travelling time was approximately the same for all villages except Mintima where both men and women spent nearly four hours of each day walking. In Pavaere there was little difference between the male and female patterns. In Bilbil, which had little land, both sexes spent much of their time travelling outside the village buying, selling or working in Madang, only seven miles north of the village. In the other villages, walking time with the women was evenly divided between 1*a*, 1*b* and 1*c* but the men spent nearly two-thirds of their travelling time outside the village.

Subsistence Gardening.—While in the subsistence gardens, the men spent 60 per cent of their time clearing and digging and the women spent 70 per cent of their time in weeding and harvesting although in Kaiap the women did about two-thirds of all the digging that was carried out in the sweet potato gardens. In the highland villages (Mintima and Kaiap) the women spent much more time in the subsistence gardens than the men. In Oba and Bilbil, little time was spent in the subsistence gardens because in the former it was an agriculturally 'slack' period and fishing was important and in the latter the village had little gardening land and much of the food was obtained from stores.

Other Food Sources and Non-Food Gathering.—Most of this category in *Figure* 2 was accounted for by fishing in the coastal villages. The rest was mainly the collection of firewood (especially important in Kaiap) and house-building materials in the nearby forest or fallow and sago processing in Malu.

Cash Cropping.—On an average, only 37 minutes each day was spent in cash cropping activities. The major activities measured were harvesting 12 minutes, clearing and weeding 11 minutes, processing 8 minutes and care of crops 4 minutes. Generally the men did most of the clearing and weeding and the women did most of the harvesting. Pavaere, a Seventh Day Adventist village near Arawa Plantation, was the most 'modern' and cash crop orientated village and considerable areas of the village lands are planted with cocoa and coconuts. In the coconut villages, Bilbil and Oba, both sexes took part in collecting and processing the nuts but in Bilbil the men did most of the work for the women were presumably busy making clay saucepans for trade or cash. In this sense a traditional socio-economic task takes on the characteristics of a modern task. Interestingly, in Mintima much of the harvesting and processing of the coffee harvest is 'women's work', whereas in Kaiap women have very little involvement in any modern activity.

Socio-Economic Tasks.—In all villages, cooking and household tasks took up most of the time for the women, and household tasks, house-building and repairs took up most of the men's time. The main exception was in Bilbil where pot making (craftwork 5*d*) took up about 40 minutes a day for the women.

Modern Activities.—Apart from cash cropping and a little council work, the main forms of modern economic activities were boat building and boat hire in Oba, trade store operations in Bilbil and Mintima and paid work in Pavaere and Bilbil. The most important single modern non-economic activity was church-going and prayer (7*a*) which averaged 21.4 minutes per day per person. In all villages, an average of 1.5 hours per day were spent in cash cropping and 'modern' activities. In Pavaere this figure was 2.8 hours (1.3 hours in church and prayer), and the figures for the other villages were Bilbil 1.7 hours, Oba and Mintima 1.1 hours and Kaiap 0.7 hours.

CONCLUSIONS

Like Waddell and Krinks, we must come to the same general conclusion that activity patterns are essentially tradition-orientated even in the most westernised villages. Secondly, because this sample shows that men spend only an average of nine hours each day in socio-economic or 'modern' activities, it should not be assumed that this leaves plenty of time for 'new' or more cash crop activities. For a start at least 1½ hours should be added to each day's work to allow for eating and rests between tasks. Also it is inevitable that many work-days are lost because of rain, sickness and essential social activities (e.g., a death of a kinsman) and there are many socio-economic activities which are impossible to include. Among the latter we must put the decision-making processes, the craft work done at night or in the privacy of the home and marketing trips which have been combined with an overnight stay in another village. It is thus wrong to always conceive the low labour input per day as 'leisure preference' (cp. Clark and Haswell 1967, p.133). The very nature of subsistence agriculture means that the subsistence farmer can only spend a little time each day in food-producing activities because he must be his own doctor, house builder, manufacturer, landlord, priest and so on. These tasks are time-consuming because there is little specialisation and there are few economies of scale. As the period sampled was a slack time of the year, it can be assumed that the villager does not have excessive 'time on his hands'.

How then can we 'create' time so that villagers can spend more time in cash activities? Obviously if we make travel an easier and quicker process, time may be saved in travelling However, once this is done people will no doubt be tempted to spend more time in travelling but even this will increase economic opportunity and make them more reliant on a cash as opposed to subsistence economy. Secondly, we could experiment more positively in trying to make subsistence agriculture and cash cropping more efficient in terms of getting high yields from fields in close proximity to population centres. (It is fairly well documented that most primitive shifting cultivators are extremely efficient in terms of labour.) Thirdly, more 'services' (e.g., medical, water supply, education, retailing outlets) could be provided at a village level so that less time had to be spent on socio-economic activities.

Finally the greatest need is to provide sufficient incentives so that individuals are prepared to use some of their leisure and recreational time in new activities. In this context there is a real need for prices for cash crops to be reasonable yet stable and for villagers to be offered something more than trade goods at the local level.

ACKNOWLEDGEMENTS

Grateful acknowledgement must be paid to the Department of Agriculture, Stock and Fisheries for supporting the students; to Mr Brian Phillips of the Mathematics Department, University of Papua and New Guinea, who programmed the data; to Mrs Susan Pain of the Geography Department who processed most of the data and prepared the diagrams; and to Mrs Marie-Louise Ploeg, also of the Geography Department, University of Papua and New Guinea, who drew the figures. Finally my thanks go to Messrs M. Alaluku, T. Tari, N. Derr, H. Mua, J. Rutana, D. Gam and S. Kulu who collected the data and acted as gracious hosts while I stayed in their villages.

REFERENCES

ALALUKU, M. (1970). Oba hamlet. *Rural Digest, Dep. Agric. Stock Fish., T.P.N.G.*, 11(4):21-35.

BROOKFIELD, H. C. (1968). New directions in the study of agricultural systems in tropical areas. In E. T. Drake (Ed.), *Evolution and Environment* (Yale University Press: New Haven).

CLARK, L. AND HASWELL, M. (1967). *The Economics of Subsistence Agriculture*, 3rd edit. (Macmillan: New York).

CROCOMBE, R. G. AND HOGBIN, G. R. (1963). Land, work and productivity at Inonda. *New Guin. Res. Bull.*, 2.

FOUNTAIN, O. C. (1966). *Wulukum. Land Livelihood and Change in a New Guinea Village.* M.A. Thesis, Victoria Univ. of Wellington, New Zealand.

JEN-HU CHANG (1968). The agricultural potential of the humid tropics. *Geogrl Rev.*, 58:333-361.

RIMOLDI, M. (1966). Land tenure and land use among the Mount Lamington Orokaiva. *New Guin. Res. Bull.*, 11.

WADDELL, E. W. AND KRINKS, P. A. (1968). The organisation of production and distribution among the Orokaiva. *New Guin. Res. Bull.*, 24.

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RUBBER PLANTING RECOMMENDATIONS 1969-1970

ANTON J. H. VAN HAAREN*

Recommendations on choice of clones and clonal seed suited to Papua and New Guinea conditions were published in *the Papua and New Guinea Agricultural Journal*, Volume 17, No. 4. The article gave a brief description of each recommended clone, together with the price of its budwood (which is available from Bisianumu). Copies are available on request from the Director, Department of Agriculture, Stock and Fisheries, Konedobu, Territory of Papua and New Guinea.

The following notes provide revised recommendations in the light of subsequent experience. However, it should be noted that, although most of the recommended clones are now in tap locally, yield trials at Bisianumu have only recently begun producing and indications of yield potential are based mainly on overseas performance.

CLASS I—FOR LARGE-SCALE PLANTING

Clones: PR 107, RRIM 600, 623.

Clonal seedlings: Prang Besar Gough Garden No. 1, 2, 3 and 4.

Bisianumu Clonal Seed Garden (limited quantities of clonal seed will be available).

CLASS II—FOR MODERATE-SCALE PLANTING

Clones: RRIM 605, 607, 628, 701, 703, 705, 706, PB 5/51, PB 217, GT 1, LCB 1320, Ch 26.

Clonal seedlings: Prang Besar Gough Gardens No. 5 and 6.

CHANGES FROM THE PREVIOUS CLONE RECOMMENDATIONS

RRIM 513 has been withdrawn because of generally poor local performance and susceptibility to wind damage.

Ch 30 and PB 213 have been withdrawn because their performance has been generally below expectation.

PB 5/51 has been downgraded to Class II because of susceptibility to *Gloeosporium* and *Oidium* leaf diseases and above average incidence of brown bast in later years.

RRIM 703, 705 and 706 have been added to Class II because of their above average vigour and high yield in Malaysian trials.

DESCRIPTION OF RECOMMENDED CLONES

Most of the clones were described in the earlier paper and only the three newly recommended clones are described here.

RRIM 703

Average to above average in vigour. Late upright branching. Wind damage average. Average to above average susceptibility to *Gloeosporium*, but leaves are often retained. Virgin bark very thick, good but slightly bumpy bark renewal. Very precocious yielder, outyielding RRIM 605 by one third over first three years in Malaysian trials.

RRIM 705

Very vigorous, heavy crown, dense canopy, high and wide-angled branching. Stem has a tendency to bend during immaturity. Susceptible to *Gloeosporium* and *Oidium*. Virgin bark above average thickness. Yield in first year above average.

RRIM 706

Very vigorous. Late branching. Oval-shaped heavy crown with dense foliage. High incidence of stem-bending during immaturity. Average susceptibility to *Gloeosporium* and *Oidium*. Virgin bark above average thickness. Yield in first year average.

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NOTES ON THE CROWN-OF-THORNS STARFISH: ITS DISTRIBUTION IN PAPUA AND NEW GUINEA (ECHINODERMATA : ASTEROIDEA : ACANTHASTERIDAE)

REX R. PYNE*

ABSTRACT

The crown-of-thorns starfish, Acanthaster planci, *until recently regarded as a rare nocturnal marine animal, is now menacing the reef-building corals in many Indo-West Pacific areas. Notes on the taxonomy, distribution, habitat, feeding, movement, breeding, growth rate and age at maturity, natural enemies and regeneration are discussed and current methods of control are outlined.*

INTRODUCTION

THE facts are now beyond dispute and reality has replaced the once general reluctance to accept the evidence. The possible dangers of *Acanthaster planci*, commonly known as the crown-of-thorns starfish, appear greater than many researchers believed. Marine life on the reefs of many Indo-West Pacific islands is threatened by the 'population explosion' of this starfish, which was, prior to 1960, regarded as a rare nocturnal prickly starfish of no real scientific interest.

To halt predation by the crown-of-thorns starfish, scientists must first know how it lives, how rapidly it grows, how fast it moves, how it reproduces, what its spawning period is, what it feeds on, what type of coral it prefers, and what attacks it—predators and parasites. At present there is no way of predicting the silent movement of the starfish, and the reason behind the population explosion. Will it be in Papua and New Guinea that the starfish plague is reported next?

BRIEF HISTORICAL REVIEW

A. planci first became known to science in 1705 when it was described by Rumphius. It is a Linnean species. Prior to the 1960's little was heard about this species throughout the world and only few specimens were to be found in museums. An extensive collecting expedition around Mer and Murray Islands (northern end of the Great Barrier Reef, Australia) by Clark (1921) reported only three specimens being found at Mer Island, the largest being 400 mm in diameter. The Young Expedition (1928-1929) to the Great Barrier Reef reported only one specimen (Clark 1931). Clark (1931) gave the distribution of the crown-of-thorns starfish in Australian waters as, 'just enters the Australian region at the northern end of the Barrier Reef, specimens having been taken at Warrior Reef, at the Murray Islands, and at the Low Islands—apparently it may be found anywhere from Zanzibar to Hawaii.' Between 1950 and early 1960's only a small number of *A. planci* were collected on the Great Barrier Reef despite numerous expeditions to the area.

In 1963, Dr T. F. Goreau put forward the theory that predation by *A. planci* was responsible for the impoverished coral growth in the Red Sea. In 1963, destruction of corals by the crown-of-thorns starfish on the Great Barrier Reef was first noticed. In 1969, 16 islands in the U.S. Trust Territory of the Pacific Islands were visited by American scientists. At the same time the University of Hawaii surveyed the Hawaiian Islands, Johnston and Midway Islands, and three Marshall Island atolls—Kwajalein, Arno and Majuro. As a result of these surveys, serious crown-of-thorns starfish infestations were

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found at Guam, Rota and Saipan in the Marianas Islands and Palau, Truk and Ponape in the Caroline Islands.

THE BIOLOGY OF *ACANTHASTER PLANCI*

Taxonomic Description

Class ASTEROIDEA Burmeister

These are free-living echinoderms characterised by a star-shaped body, composed of a central disk and usually five arms. The arms are hollow, each arm containing a prolongation of the coelom and its contained organs. The oral and aboral surfaces are distinct, the oral surface bearing the mouth and ambulacral grooves, while the aboral surface bears the anus and madreporite.

Family ACANTHASTERIDAE

'This is a monogeneric family which Fisher considers a relic of an old and at one time a more extensive group' (Clark 1946). Due to their large size, the multiplicity of rays and madreporites, and the large articulated spines, this family is distinct from all other groups of living starfishes.

Genus ACANTHASTER Gervais

Acanthaster planci (Linnaeus) *Plate* I.

Asterias planci Linnaeus, Syst. Nat. ed. 10, 823, 1758.

Acanthaster planci Verrill, Smithsonian Inst., Harriman Ser. 14 : 364, 1914.

Acanthaster echinites Doderlein 1896a. Semon's Ast., in Jena Denkschr., Vol. 8, p.320, pl.21, figs 2 to 7.

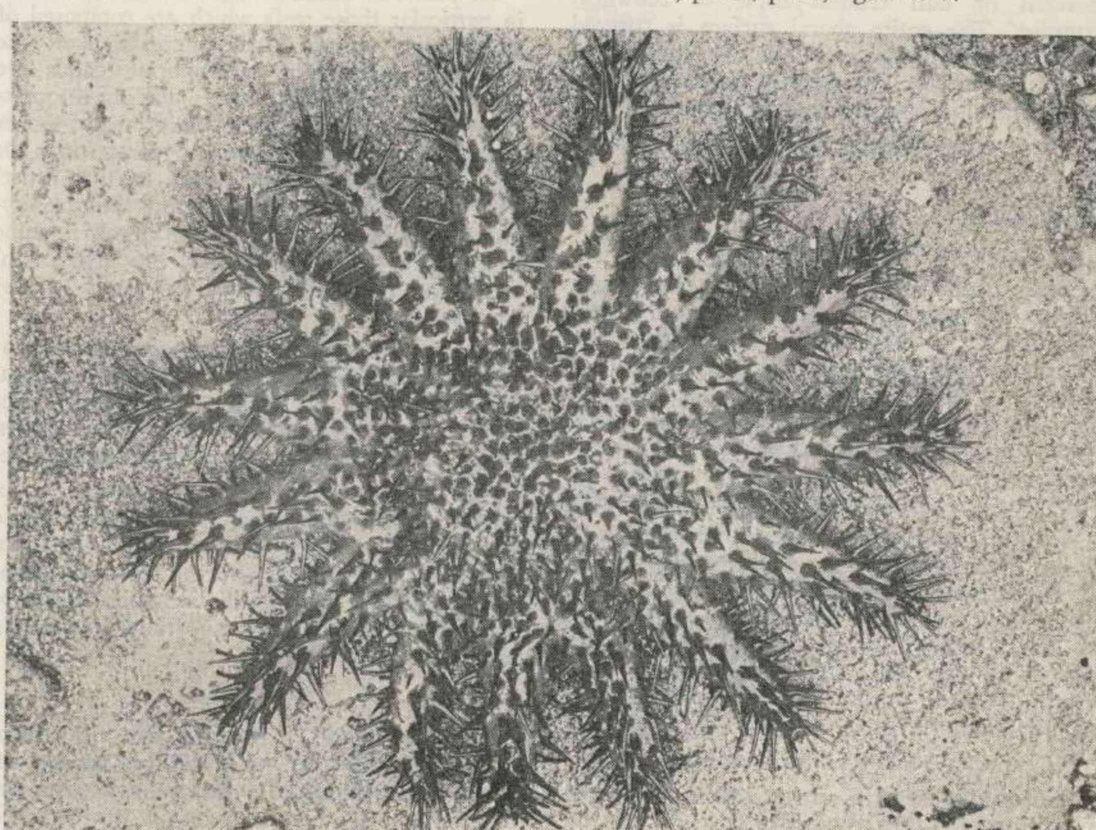

Plate I.—Crown-of-thorns starfish, *Acanthaster planci* (Linnaeus).

[Photo: D.I.E.S.]

The central disk is relatively large and flat, from which radiate many rays (13 to 18). The rays are short, approximately half the width of the disk, tapering only slightly to a blunt end. Clark (1931) gives a description of the colour in life as, 'bluish-gray with spines reddish at tips; the change from gray to red is not abrupt but gradual, apparently due to increasing amounts of rusty-red pigment in the skin. In some specimens the tips of the spines only are red, but in others the colour extends downwards towards, or even to, the base; if it spreads further into the dorsal skin, we should have red individuals, such as those Doderlein records from the Riu-Kiu Islands. The spines of the lower surface are dull reddish-purple, and the feet are white or pale yellowish. The disk, sides and upper surface of the arms basally are covered by dull reddish-purple or brownish papulae.' The entire aboral surface is covered with long thorny spines, while the small interradial spaces bear flat, heavily spatulate spines, becoming more slender near the mouth.

The crown-of-thorns starfish reaches 70 cm in diameter.

Distribution

(*a*) Indo-West Pacific Distribution

The crown-of-thorns starfish has long been known to inhabit coral reefs. In a normal reef environment, a diver would observe less than one starfish per hour. In recent years throughout the Indo-West Pacific Region a population explosion of the crown-of-thorns starfish has taken place. In an infested area, the number of starfish seen is generally more than five per hour, reaching concentrations of more than 600 per hour.

Endean (1969) defines the distribution of *A. planci* as occurring in the warm tropical waters of the Indian and Pacific oceans, ranging from the east African coast and Red Sea in the west, to the Hawaiian Islands and Tuamotu Archipelago in the east. The distribution of the crown-of-thorns starfish throughout the islands of the South Pacific is shown in *Figure* 1.

(*b*) Papua and New Guinea Distribution

No comprehensive investigation into the occurrence of the crown-of-thorns starfish on the extensive coral reefs surrounding Papua and New Guinea has been conducted. Reports of sightings and concentrations have been collated from Field Officers' Journals of the Department of Agriculture, Stock and Fisheries, and communications from interested persons (*Table* and *Figure* 2).

Commencing in June 1970 a small concentration of *A. planci* in close proximity to Port Moresby has been visited regularly by the Division of Research and Surveys, D.A.S.F. A total of 47 starfish has been collected in two visits.

Details of reported concentration are given in the Appendix.

Habitat

The destructive feeding habit of the crown-of-thorns starfish affects the thin mantle of living coral covering the complex and relatively stable reef structure.

A. planci is found living on live coral reefs, in particular those reefs which are composed of madreporian corals ('stony corals') of the *Acropora* group. The madreporian corals are the typical reef-building corals. Failing the presence of madreporian corals, the crown-of-thorns starfish, 'selects small branching coral forms, or plate, shelf and boulder corals in that order' (Barnes 1966). Barnes further adds that the alcyonarian corals ('soft corals') are largely immune to predation by *A. planci,* as are the large 'brain' corals and the smaller 'stinging' corals (*Millepora* spp.).

Against a contrasting background, the crown-of-thorns starfish is easily seen, but in its natural habitat among the various forms and hues observed on a live coral reef, the colour pattern of *A. planci* forms a very effective camouflage.

The bathymetric range of *A. planci* is not known. It has been found on coral reefs covered by only a few inches of water at low tide down to 100 ft. It is unlikely that the crown-of-thorns starfish inhabits areas of the sea-floor devoid of living corals, except when it is moving from one area to another.

Feeding

Mortensen (1931) reported that the crown-of-thorns starfish fed on corals by 'sucking off all the soft substances, leaving the white skeleton where it had been at work.' It was not until 1962, during the Israel South Red Sea Expedition (March to April 1962), that Goreau (1963), when reporting on the nature of the

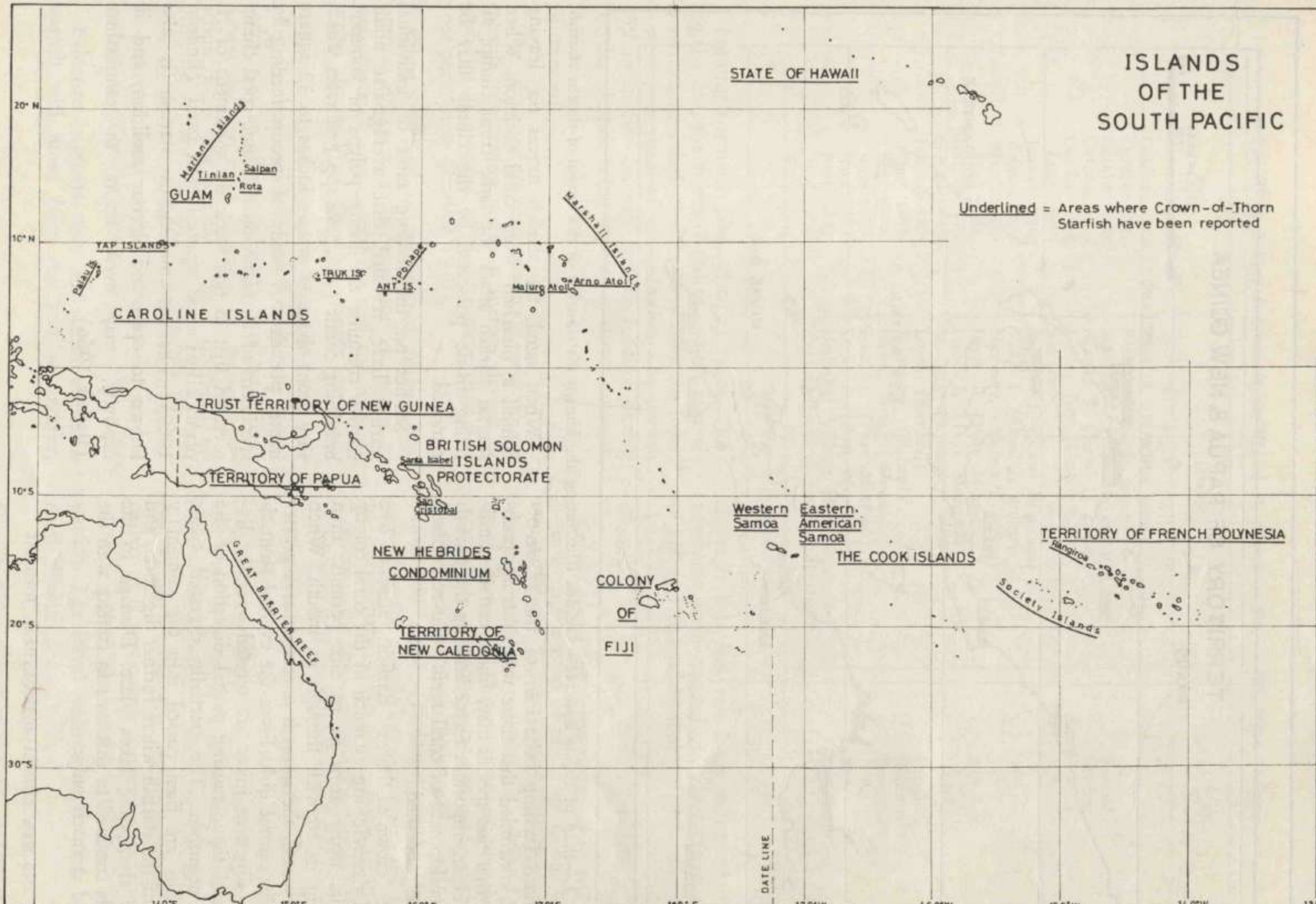

Figure 1.—Areas of reported crown-of-thorns infestation througout the Islands of the South Pacific.

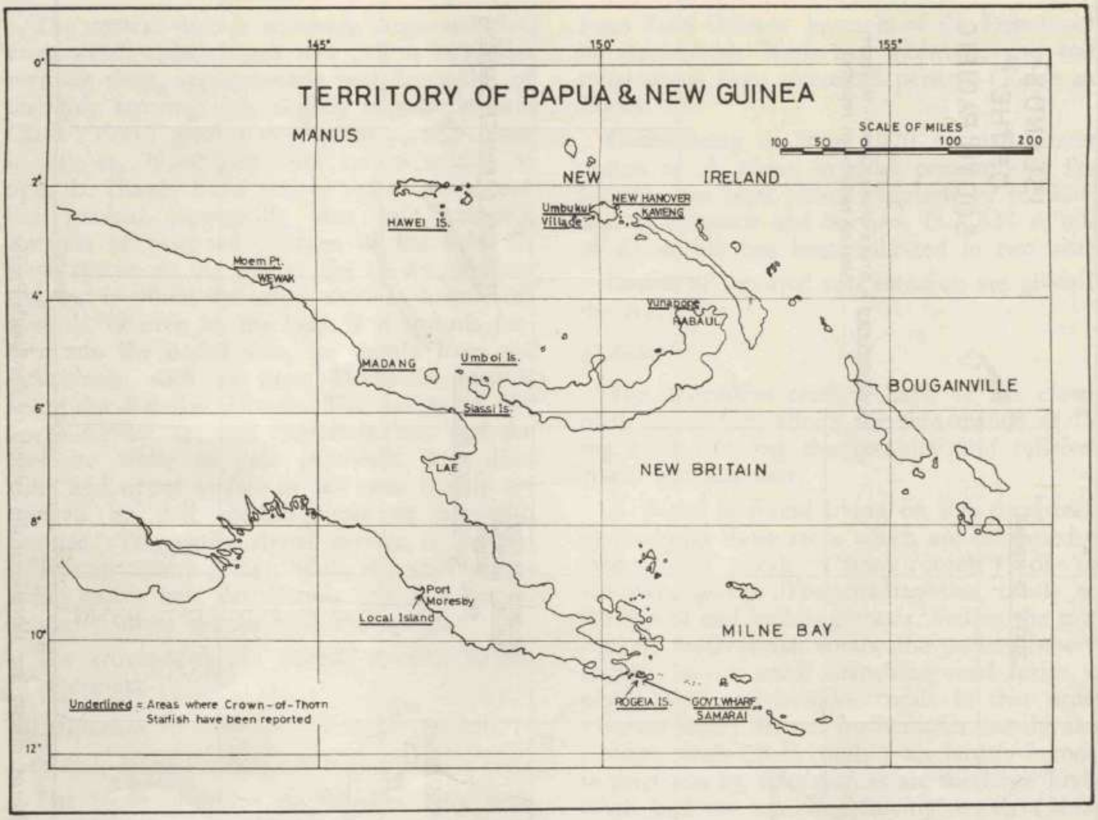

Figure 2.—Map of Papua and New Guinea illustrating the known distribution of the crown-of-thorns starfish.

specialised feeding behaviour of the crown-of-thorns, concluded that there was a 'strong probability that this species may, under certain conditions, be an important factor limiting the growth and development of coral reefs', that researchers became concerned.

The crown-of-thorns starfish attacks live coral by enveloping as much of the coral colony with its many arms as its size permits, then everting its stomach through its mouth. When fully everted, the stomach covers an area greater than the central disk. From the everted stomach lining, digestive juices are ejected over the living coral tissue causing partial digestion of the coral organism. The partially digested tissue fragments are then passed into the alimentary canal of the starfish where further digestion, and finally absorption, takes place. Damage to the coral is confined to that area in contact with the everted stomach only.

When sated, the starfish moves on, leaving behind a 'bleached' white coral skeleton. When several starfish attack the same coral clump, all living tissue possessed by the clump may be removed.

'Studies on the feeding rates of individual starfish have revealed that average-size adult starfish consume the living polyps of common branching corals (*Acropora* spp.) at rates which vary from about 17 square inches to 32 square inches per day. A study of group feeding by specimens of *A. planci* on the same coral clump revealed that in one week six specimens of *A.* planci killed seven square feet of coral' (Endean 1969). The crown-of-thorns starfish is also known to open and devour molluscs, and in captivity, may even resort to cannibalism (Barnes 1966).

Table.—Sightings and concentrations of *A. planci* in Papua and New Guinea.

Date	Location	Number Sighted
October 1966	Noru I. (Siassi Is group)	3
October 1966	Por I. (Siassi Is group)	2
October 1966	Mandok I. (Siassi Is group)	Several
October 1966	Aramot I. (Siassi Is group)	Several
October 1966	Luther Bay (Umboi I.)	Several
June 1967	Samarai	46*
January 1968	Mandok I. (Siassi Is group)	1
August 1968	Tuam I. (Siassi Is group)	32*
March 1969	Hawei I. (Manus I. group)	54*
May 1969	Local I. (Port Moresby)	12*
September 1969	Local I. (Port Moresby)	1
October 1969	Madang Harbour	1
January 1970	Logea (Samarai)	Reported
April 1970	Vunapope (Rabaul)	Reported*
May 1970	Moem Point (Wewak)	Reported*
June 1970	Local I. (Port Moresby)	27*
June 1970	Local I. (Port Moresby)	20*
June 1970	Umbukul Village (New Hanover)	Reported*
June 1970	Kavieng/New Hanover, 1968-1969	5*

*Details given in Appendix.

Feeding normally takes place at night. During the day, the crown-of-thorns starfish normally retreats into dark crevices away from the light; however, in areas of concentration, the starfish will often be observed actively feeding during the day, despite being exposed to direct sunlight.

Movement

The crown-of-thorns starfish is said to be capable of moving across a surface devoid of obstacles at a speed of slightly more than one foot per minute (Endean 1969).

When observed in numbers of plague proportion, there is a tendency for *A. planci* to congregate on one area of the reef and to move across the reef as the food supply dwindles.

'Depth was no barrier to movement, but soft substrate was avoided. Sand moved by surge action, was an effective obstacle since patch reefs surrounded by sand in areas of strong wave action were not infested. Sand provided no gripping surface for the tube feet and the seastars are easily overturned by water movement. In protected areas or during calm seas, sand is no barrier' (Chesher 1969).

Evidence suggests that the crown-of-thorns starfish will move from one reef to another, although this has not been witnessed. Prawn fishermen have trawled *A. planci* from depths of 100 feet on mud bottom.

Breeding

In *A. planci* the sexes are separate and there is an even sex ratio of one male to one female. On Australia's Great Barrier Reef the breeding season is short and well defined, lasting for one month from mid-December to mid-January. 'A ripe female of average size (35 cm in diameter) is estimated to contain between 12,000,000 and 24,000,000 eggs' (Endean 1969). Prior to spawning, the gonads increase in size and occupy the major part of the body cavity. Fertilisation is external, the sexual products (eggs and sperm) being shed into the surrounding water.

The fertilised eggs develop into free-swimming planktonic larvae, capable of being carried long distances, depending on prevailing currents and wind systems. It is interesting to note that, during the planktonic phase of the life cycle, the starfish larvae are preyed upon by coral polyps. It is particularly interesting and unusual, as coral polyps are later preyed upon by the starfish. The larval starfish finally settle on the coral growths.

Growth Rate and Age at Maturity

'The mean growth rate (described in terms of increase in diameter) of specimens of *A. planci* during their first two years is approximately one cm/month (just under $\frac{1}{2}$ in./month). Thus a specimen 6 in. in diameter is approximately 1 year old and a specimen 12 in. in diameter is about 2 years of age. Presumably this rate of growth will decrease in older specimens' (Endean 1969). Endean further believes that a breeding specimen of starfish must be at least 2 years old.

The life-span of the crown-of-thorns starfish is not known, but very large specimens are considered to be at least three years old. Chesher (1969) has estimated the maximum life span of adult starfish as eight years, but, when deprived of living coral, they starve in about six months.

Natural Enemies

(*a*) Eggs of *A. planci*—*Abudefduf sexfasciatus* or Damsel fish has been observed by Endean (1969) to feed on the eggs of *A. planci* soon after they were released. No other marine organism has been seen to prey on the drifting eggs, but it can be assumed there are many, either on the reef or in adjacent waters.

(*b*) Larval *A. planci*—perhaps the greatest mortality of the crown-of-thorns starfish takes place in the larval phase of the life history, the coral polyps being regarded as one of the main predators. Corals are zooplankton feeders, and

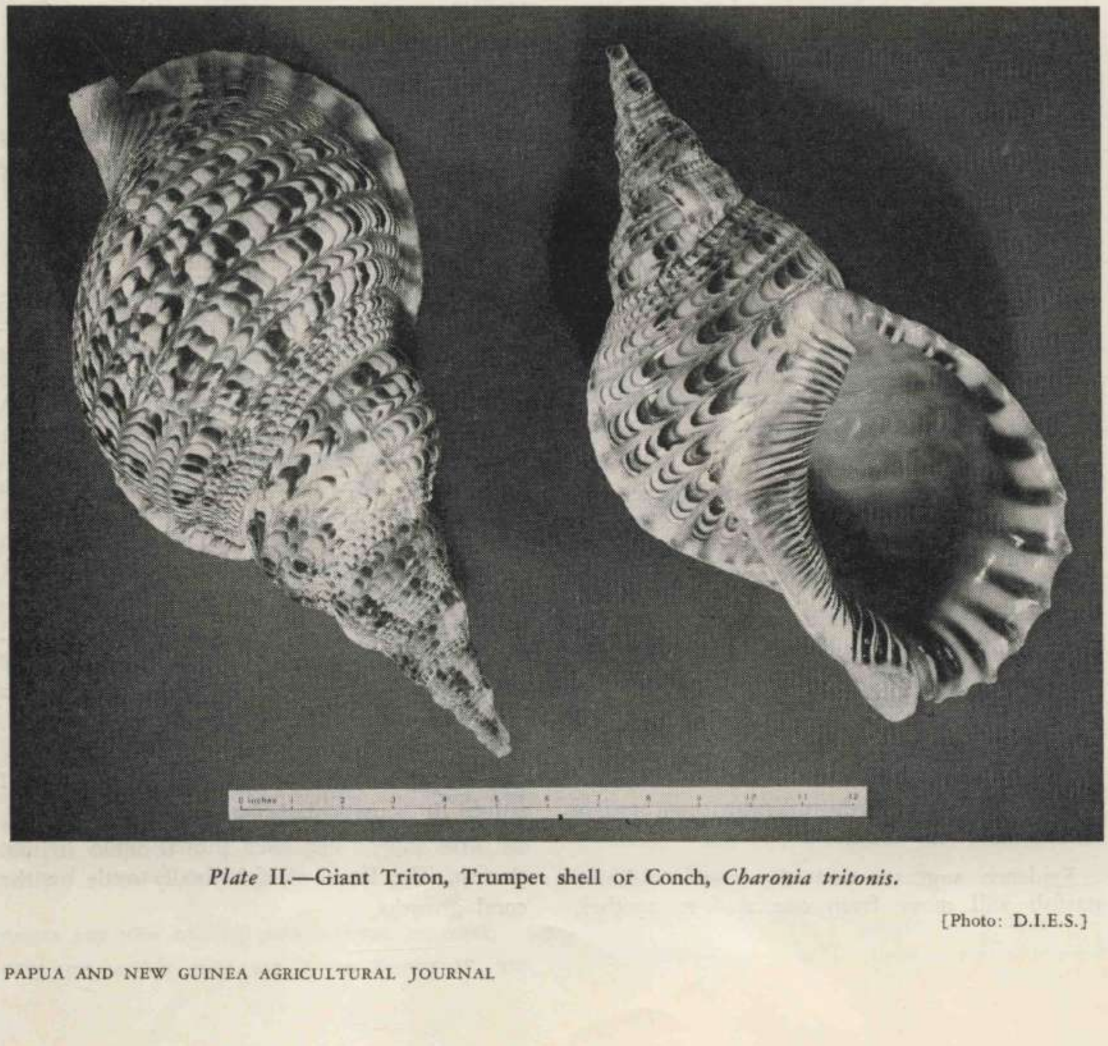

Plate II.—Giant Triton, Trumpet shell or Conch, *Charonia tritonis*.

[Photo: D.I.E.S.]

would include the larval stages of *A. planci* in their diet. Clams which are also zooplankton feeders are regarded as potential predators.

(*c*) Small juvenile *A.planci*—Endean (1969) has reported no potential predators of the small juvenile crown-of-thorns starfish as a result of investigations on the Great Barrier Reef.

(*d*) Large juveniles and adult *A. planci*—

(i) Giant Triton; Trumpet Shell; Conch Shell (*Charonia tritonis*), *Plate* II, is the second largest gastropod known in the Indo-West Pacific, reaching a length of 40 to 46 cm when fully grown.

C. tritonis is the only well known predator of the large juvenile and adult crown-of-thorns starfish. 'When feeding on *A. planci*, *C. tritonis* uses the outer lip of the shell to keep the starfish pinned to the substratum. With its radula (a flexible file-like structure bearing numerous teeth which can be protuded through the mouth) *C. tritonis* cuts the starfish into pieces. After the ingestion of the pieces of *A. planci* the sharp spines are usually regurgitated. Between 12 and 24 hours are required for an adult triton to consume an adult specimen of *A. planci*' (Endean 1969). Under normal circumstances one adult triton will consume one adult crown-of-thorns starfish per week.

(ii) Giant Helmet Shell (*Cassis cornuta*), a gastropod reaching a length of up to 35 cm. When feeding, the Helmet shell envelopes the starfish in its voluminous foot, which crushes the starfish, after which the Helmet shell proceeds to eat the soft body parts. Apparently the Helmet shell is not bothered by the sharp spines of the crown-of-thorns starfish, some of which break off and become embedded in the foot of the Helmet shell.

(iii) The Hump-head Wrasse has been observed eating the crown-of-thorns starfish; however, it is not regarded as an important predator (Endean 1969).

(iv) As a result of recent research at Magnetic Island (Brown 1970), a small crustacean (approximately 8 cm in length), tentatively named *Neaxius* sp., has been found to prey on the crown-of-thorns starfish. Seven starfish ranging in size from 21 to 44 cm were killed by this small crustacean.

(v) Painted Shrimp (*Hymenocera elegans*), has also been shown to prey on large juvenile and adult crown-of-thorns starfish (*Time*, May 25 1970). Oblivious of the poisonous spiny armour, the Painted Shrimp immobilizes the starfish by causing it to retract its tube feet. The shrimp then turns the starfish onto its back, cuts away the underside tissue with its sharp pincers, and devours the internal organs. In little more than a day of feeding, this small crustacean reduces the starfish to a small pile of gelatinous debris.

Regeneration

Most starfish have great powers of regeneration, some species being able to regenerate completely from portions of an arm. Endean (1969) expected that the crown-of-thorns starfish would be able to regenerate arms from the central disk. However, after conducting experiments in the field involving the severing of arms from the central disk, he showed that, although the wounds healed rapidly, no obvious regeneration of even a portion of an arm had occurred after a period of one month. Further, there was negligible regeneration of spines removed from areas of the central disk.

Whilst conducting feeding experiments with *C. tritonis*, Chesher (1969) reported that half a starfish escaped from being eaten and lived to regenerate all its lost parts. He stated that, 'regeneration of small functional arms required about 2 months.'

Of 47 crown-of-thorns starfish examined from a small reef off Port Moresby, more than 50 per cent of those examined showed definite signs of regeneration, up to five arms in one individual. One specimen was collected alive with only five arms present; the remainder of the arms and half of the central disk were severed. There was no evidence of regeneration in this specimen, but the cut edge of the wound was completely healed over.

Venomous Spines

The multitude of prominent orange or reddish coloured spines present on the dorsal or aboral surface of the crown-of-thorns starfish can easily inflict a painful wound when handled carelessly or trodden upon. In a specimen of approximately 12 cm in diameter, the spines average 16 mm in length and approximately 1 mm in diameter. The pedicle in such a specimen would average 3 mm in height. In general, the length of spines on any 1 specimen is nearly uniform, although, in all specimens that I have examined, there is a tendency for those near the base of the arms to be slightly larger.

The rigid calcareous core of the spine is covered with an epidermal skin, bearing fine granules and the orange and reddish colour pigments. There is no obvious venom gland associated with the spine, and it is generally regarded that the toxic symptoms which result from the penetration of a spine are a result of local reaction to the epidermis, or even a secretion from the epidermis. It has even been suggested that the toxins may be contained in the colour pigments.

Injury caused by skin punctures can result in severe local pain and numbness and may, in severe cases, be followed by protracted vomiting for several days. Medical advice recommends the wound to be bled immediately, thus releasing the poison.

METHODS OF CONTROLLING THE CROWN-OF-THORNS STARFISH

Numerous methods have been suggested as a means of controlling the crown-of-thorns starfish; some of these have already been tested, others are still in the experimental stage. No one method has yet been found effective over a large area.

(*a*) Collecting by hand—although tedious, slow and very expensive, this method is regarded as the most practical, particularly in localised areas. Once collected, the starfish can be destroyed on land, either by sun-drying, burning or burying. Merely spearing or cutting a starfish in half is ineffective because the spear wound will often heal, and the starfish cut in half may regenerate and become two complete individuals.

(*b*) Injection of various chemicals (e.g., 5 per cent Formalin) into the body of the starfish will kill it. However, every starfish must be treated individually.

(*c*) Although involving considerable expense and death of the associated corals as well, the use of granular quicklime dropped on the body surface of the starfish will kill within 12 to 24 hours. The use of a quicklime barrier has met with some success; however, a hard surface coating soon forms on the quicklime which then renders it ineffective.

(*d*) The use of copper sulphate has been suggested, but its use would have an adverse lasting effect on the reef environment.

(*e*) Tests are currently being conducted by Japanese researchers on the feasibility of using an electric gun. Again this method requires treating individual starfish.

(*f*) United States researchers have suggested the use of suction dredges in heavily infested areas. The feasibility of this method has not yet been tested.

(*g*) Biological control—researchers in Australia have suggested the possibility of increasing the population of the most commonly known predator, *C. tritonis*. However, before such a task can be undertaken, the biology of *C. tritonis* and its habits must be thoroughly investigated, and secondly, one must take into consideration what is going to happen once the population of starfish has been removed. Will researchers be faced with another plague, this time *C. tritonis*?

CONCLUSION

No single theory offered to date has explained the reason behind the starfish plague. Some researchers believe the population explosion has no unusual cause, regarding it as a natural periodic phenomenon and a passing nuisance.

Destruction of living coral reefs, however, would mean possible economic disaster for many island populations throughout the Indo-West Pacific area. The majority of inhabitants throughout this area derive almost all their protein from marine resources, and the destruction of living coral reefs would result in drastic reduction, and possible destruction, of these fisheries. Eventually, loss of living corals would allow severe land erosion by storm waves.

Many Australian researchers believe that over-collecting of the Giant Triton shell, *C. tritonis*, was the cause of the crown-of-thorns starfish population explosion on the Great Barrier Reef. United States researchers discount this theory in their area, as starfish infestations have been found in remote island areas where no serious shell collecting has taken place. 'Killing coral in the process of blasting channels or dynamiting for fish, man has perhaps altered the underwater environment in favour of the sea-stars survival', has been suggested (Sugar 1970).

Many factors are involved in the growth and development of corals, and at this stage in our knowledge it is very difficult to predict just how long it will take for devastated reefs to recover completely, if indeed they ever do. Estimates range from 10 to 50 years.

Algal growth on dead corals may contribute substantially to the diet of herbivorous fish, and could be the origin of ciguatera-type neurotoxin now present in the flesh of some species. The eating of ciguatera-bearing fish causes a distressing illness in man.

Until more is known about the biology of the crown-of-thorns starfish, it is difficult to predict where the depredation will end or what will end it. Researchers are not too hopeful that artificial control methods are sufficient to halt devastation by the starfish. It has been suggested (Dickenson 1970) that the principal hope of starfish control lies in rallying islanders throughout the areas of known infestation to protect their own reefs. On the island of Palau in the Caroline Islands, school children were led on afternoon collecting expeditions at low tide and shown how to catch and handle the crown-of-thorns starfish without being injured. Killing the starfish could become part of the islanders' educational system.

Information concerning infestations in other areas of Papua and New Guinea is urgently needed, and people sighting the starfish are requested to notify the author. Reports of normal populations as well as abnormal concentrations of starfish and the degree of coral damage are very important. Your co-operation is requested.

BIBLIOGRAPHY

AUST. ACAD. SCI. (1970). *Acanthaster planci* (crown-of-thorns starfish) and the Great Barrier Reef. *Rep. Aust. Acad. Sci.*, 11 : 19pp.

BAGLIN, D. AND MULLINS, B. (1969). *Australia's Great Barrier Reef.* (Horwitz : Sydney.)

BARNES, J. AND ENDEAN, R. (1964). A dangerous starfish—*Acanthaster planci* (Linne), *Med. J. Aust.* 1964, Vol. 1 (April 18) : 592.

BARNES, J. H. (1966). The crown-of-thorns starfish as a destroyer of coral. *Aust. nat. Hist.*, 15 (December) : 257-261.

BROWN, T. W. (1970). Starfish menaces coral reefs. *Hemisphere*, 14 (5) : 31-36.

CATALA, R. (1964). *Carnival under the sea.* (Sicard: Paris.)

CHESHER, R. H. (1969). Destruction of Pacific corals by the sea star *Acanthaster planci. Science*, 165 (3890) : 280-83.

CLARK, H.L. (1921). *The echinoderm fauna of Torres Strait: its composition and its origin.* (Carnegie Instn, Dept Marine Biology: Washington.)

CLARK, H. L. (1931). Echinodermata other than Asteroidea. *Scient. Rep. Gt Barrier Reef Exped.*, 7.

CLARK, H.L. (1946). The echinoderm fauna of Australia—its composition and its origin. *Publs Carnegie Instn*, 566.

CLELAND, J. B. AND SOUTHCOTT, R.V. (1965). Injuries to man from marine invertebrates in the Australian region. *Spec. Rep. Ser. nat. Health med. Res. Coun.*, 12.

COCHRANE, R. (1968). *Dangers of the reef and sea.* 26 pp. (Jacaranda : Brisbane.)

DICKENSON, F. (1970). Can we save the Barrier Reef? *Reader's Digest*, April 1970 : 59-65.

DIXON, B. (1969). Domesday for coral? *New Scient.*, 44 (673) : 226-27.

ENDEAN, R. (1969). *Report of investigation made into aspects of the current* Acanthaster planci *(crown of thorns) infestations of certain reefs of the Great Barrier Reef.* (Qld Dept Primary Industries, Fisheries Branch : Brisbane.) 35pp.

ENDEAN, R. (1970). 'Ban the triton shell collectors' (incl. Reports from Pacific Islands). *Pacific Islands Monthly*, 41 (2) : 37-40.

FLY, C. A. (1942). Shallow-water Asteroidea and Ophiuroidea of Hawaii. *Bull. Bernice P. Bishop Mus.*, 176.

GILLETT, K. (1968). *The Australian Great Barrier Reef in Colour.* (Reed : Sydney.) 112pp.

GOREAU, T. F. (1963). On the predation of coral by the Spiny Starfish *Acanthaster planci* (L.) in the Southern Red Sea, *Bull. Sea Fish. Res. Stn. Israel*, 35 : 23-26.

HARDING, J. (1968). The deadly crown-of-thorns, *Sea Frontier*, 14 (5) : 259-61.

HARRISON, G. G. T. (1969). The crown-of-thorns starfish. *Fisherman, N.S.W. State Fish.*, December 1969.

MORTENSEN, T. (1931). Contributions to the study of larval forms of Echinoderms. *K. danske Vidensk. Selsk. Skr.*, (9) 4 : 1-39.

NEW SCIENTIST (1969). A benign giant to save the Pacific Reefs. *New Scient.*, 44 (October 23) : 174.

PACIFIC PUBLICATIONS, SYDNEY (1970). Starfish: now a price on their head. *Pacific Islands Monthly*, 41 (4) : 28.

PACIFIC PUBLICATIONS, SYDNEY (1970). The starfish could bring 'starvation' to the Pacific. *Pacific Islands Monthly*, 41 (4) : 101.

SOUTH PACIFIC COMMISSION (1970). Crown-of-thorns starfish. *S. Pacif. Bull.*, 20 (1) : 49-50

SUGAR, J. A. (1970). Starfish threatens Pacific Reefs. *Natn. geogr. Mag.*, 137 (3) : 340-351.

TIME (1970). The starfish eaters. *Time*, May 25, 1970 : 47.

WENDT, S. (1969). Starfish is threat to Fiji food supply. *Pacific Islands Monthly*, 40 (9) : 63.

Appendix

DETAILS OF REPORTED CONCENTRATIONS OF *A. planci* IN PAPUA AND NEW GUINEA

(*a*) June 1967 (R. R. Pyne and A. G. Hinton)—on a small reef running in a south-west direction from and adjacent to the Government wharf, Samarai, 46 crown-of-thorns starfish were counted in an area 200 x 10 m, at a depth of 1 to 4½ m, in 1 hour's diving. Specimens ranged from 20 to 30 cm in diameter. Very little living coral was observed in the area surveyed.

(*b*) August 1968 (A. G. Hinton)—off Tuam Island (Siassi Is group) 32 crown-of-thorns starfish were sighted in a 100 m area of narrow fringing reef at a depth of 4½ m. Several specimens were observed feeding. Three unidentified coral species were seen to be bleached white directly beneath the feeding starfish.

(*c*) March 1969 (B. Withrington)—off Hawei Island (Manus Island group) 4 divers counted 54 crown-of-thorns starfish during a 60 minute dive over a wide area of reef. The starfish were found either under or alongside coral outcrops. No *C. tritonis* were seen in the area examined.

(*d*) May 1969 (P. Beaven)—at Local Island (Port Moresby), 12 starfish were collected in 10 minutes' diving in depths ranging between 1 and 1½ m. The starfish ranged from 20 to 30 cm in diameter.

(*e*) April 1970 (Catholic Mission, Vunapope)—a small breakwater, constructed of volcanic rock in the 1900's, was taken over by coral growth after 1945 when it fell into disuse. In 1967-1968 a plague of crown-of-thorns starfish was reported to have devastated the coral growth. About the end of 1968 the starfish disappeared and coral regeneration is reported to have commenced. Many spiny sea-urchins of the genus *Diadema* have moved into the area.

(*f*) May 1970 (B. Withrington)—an unconfirmed report that on the west side of Moem Point, Wewak, the density of crown-of-thorns starfish, on what was described as dead fringe reef, was approximately 100 starfish per acre.

(*g*) June 1970 (R. R. Pyne)—on a small reef off Local Island (Port Moresby), 4 divers in approximately 1 hour collected 27 crown-of-thorns starfish in depths ranging between 1 and 1½ m. Five starfish were observed feeding on coral (*Acropora* spp.) fully exposed to direct sunlight.

(*h*) June 1970 (R. R. Pyne)—on a small reef off Local Island (Port Moresby, 20 crown-of-thorns starfish were collected in approximately 180 minutes by 8 divers in depths ranging between 1 and 1½ m. One starfish was collected at 6 to 8 m moving across dead broken 'stag-horn' coral. All starfish were concealed beneath coral clumps. One specimen collected exhibited very marked red colouration over the entire aboral surface.

(*i*) June 1970 (E. C. Tarr)—an unconfirmed report from Umbukul Village (New Hanover) related by a village councillor stated that in 1955 a plague of *A. planci* devastated the reef off the village. A Fisheries Supervisor, diving in the area in 1969, reported finding only 4 crown-of-thorns starfish, but stated that he found no living coral.

(*j*) June 1970 (E. C. Tarr)—in the Kavieng/New Hanover area, a Fisheries Supervisor, after spending many hours diving during the 1968-1969 year, reported seeing only 5 crown-of-thorns starfish.

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