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CONTENTS

BLOOD PARASITES OF CATTLE IN PAPUA NEW GUINEA: A REVIEW

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ABSTRACT

A history is given of the occurrence of bovine blood parasites, namely Theileria *spp.,* Babesia bovis, B. bigemina, Trypanosoma theileri, Eperythrozoon *sp. and* Anaplasma marginale, *found in Papua New Guinea. Reference is made to the vectors, the epidemiology and the disease outbreaks associated with some of the parasites. The likelihood of new blood parasites entering the country is considered to be small but the presence of cattle tick (*Boophilus microplus*) and rusa deer (*Cervus timorensis*) in a few localities place at risk the maintenance of the present restricted distribution of the more important parasites and constitute a potential quarantine hazard.*

INTRODUCTION

The earliest record of a bovine blood parasite in Papua New Guinea was included in a report made by an Australian Veterinary Unit in a survey of animal diseases carried out after the close of World War 2 (Anonymous 1946). The parasite, *Theileria mutans;* was referred to as of "no pathogenic importance". Anderson (1960) and Legg (1961) referred to theileriasis in Asian cattle held in quarantine in Port Moresby *en route* from Pakistan to Australia in 1952–4. Legg stated that the parasite concerned was *T. dispar* (syn. *T. annulata*), but Gregory (1961) indicated that there was uncertainty as to whether the species involved was *T. annulata* (syn. *T. dispar*), *T. mutans* or both. Gregory (1961) and Anderson (1960) both mentioned that the same Asian cattle were shown to be carrying *Anaplasma marginale*. Other blood parasites recorded from cattle are *Babesia bovis* (syn. *B. argentina*) and *B. bigemina* (Anderson 1960, 1962–3; Egerton and Rothwell 1964), *Eperythrozoon* sp. (Talbot 1968–9) and

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reports of this species from other countries. The extent of its distribution in Papua New Guinea is not known, but it has been recorded in cattle at an unknown locality in Milne Bay Province (Anonymous 1946) and at Sogeri and Kapogere in Central Province.

REVIEW OF PARASITES

Theileria spp.

Members of the genus *Theileria* are tick-borne protozoan parasites which live in the red blood cells of ruminants, particularly cattle.

If *T. annulata* (syn. *T. dispar*) was present in the Asian cattle held in quarantine in 1952–4, it did not spread to local animals since its tick vector, *Hyalomma*, is not present in Papua New Guinea. The cattle *Theileria* found in the country, and referred to as *T. mutans*, has been observed on several occasions in cattle held at the National Veterinary Laboratory. However, there are no records of clinical pathogenicity due to this organism, even in splenectomised cattle, a result consistent with most

Trypanosoma theileri which is reported for the first time. The information presented is compiled from departmental records and reports, and from the results of published and unpublished studies carried out at the National Veterinary Laboratory.

Workers such as Uilenberg *et al.* (1977), Brocklesby (1978) and Morel and Uilenberg (1981) doubt whether the non-pathogenic species of *Theileria* outside of subsaharan Africa and a few Caribbean islands is correctly identified as *T. mutans*. Serological, morphological and transmission studies indicate that the organisms found in Britain, America and Australia are strains of another species but at present it is uncertain if its correct designation is *T. sergenti*, *T. orientalis* or *T. buffeli* (Morel and Uilenberg 1981; Uilenberg 1981). The current practice in Australia is to refer to the organism as *T. buffeli*. The parasite in Papua New Guinea has not been studied serologically but it is likely to be the same as the Australian species since virtually all imported cattle have come from Australia.

A non-pathogenic species of *Theileria* has been seen also in feral rusa deer, *Cervus timorensis* (Owen 1985). The range of the deer in Central Province coincides with cattle grazing areas but it is not known if the same species of *Theileria* infects both hosts.

Riek (1982) stated that the only recorded natural vectors of *Theileria* are ticks. However, *T. buffeli* can be readily transmitted in blood, thus mechanical transmission with a contaminated needle can also occur (Callow 1984). In Africa, *Amblyomma* is the principal vector of *T. mutans* (Brocklesby 1978) whereas in Britain, East Asia, Japan, Korea (Uilenberg *et al.* 1977) and America (Brocklesby 1978) the cattle parasite is believed to be transmitted by *Haemaphysalis*. It has long been considered that the vector in Australia is the cattle tick, *Boophilus microplus*, but attempts to prove this experimentally have been unsuccessful (Callow and Hoyte 1961; Riek 1982). According to Riek (1982) the natural vectors in Australia are *Haemaphysalis bancrofti* and *H. longicornis* but experimental transmission using the latter species has failed (Stewart *et al.* 1987a, 1987b). Stewart *et al.* (1987a, 1987b) demonstrated that another tick species, *H. humerosa*, was a more successful vector.

Six species of *Haemaphysalis* are known to occur on mammals in Papua New Guinea, including *H. longicornis*, *H. bancrofti* and *H. humerosa* (Talbot 1968–9; unpublished data). The first of these species has been seen once and only on cattle; the second is recorded from various fauna and also cattle; and the last species is reported from fauna only. The most frequently seen species of *Haemaphysalis* is *H. novaeguineae* which has been found on various hosts, including cattle in all areas where *Theileria* occurs. It has been recorded also from deer in Central Province.

Babesia bovis (syn. *B. argentina*)

This is the most important of the bovine blood parasites in Papua New Guinea. It is a protozoan that infects red blood cells and is the most common cause of the disease babesiosis (tick fever or red water) in cattle. Although the parasite was not recorded in the survey conducted after World War 2 (Anonymous 1946), outbreaks of 'tick fever' were reported subsequently in widely scattered localities where the vector, the cattle tick (*Boophilus microplus*), then occurred, including Morobe, Western Highlands, Eastern Highlands, Madang, Gulf and Central Provinces (Anderson 1962–3; departmental records). In two instances, at Wewak (East Sepik Province) in 1962 and Baibara (Milne Bay Province) in

1963, cases of babesiosis due to *B. bovis* were confirmed by means of blood films and transmission of blood into susceptible cattle. A voluntary tick eradication scheme was begun in 1950, followed by a compulsory programme of eradication which was started officially in 1955 (Anderson 1962–3). By 1966 the tick remained only in a few areas where eradication was difficult or impossible for a variety of reasons. With the elimination of the vector from most of the country, the risk of bovine babesiosis was greatly reduced.

The most significant area, with respect to babesiosis, that remained tick infested was the Port Moresby hinterland, including Sogeri, in Central Province where feral rusa deer (*Cervus timorensis*), acting as hosts, prevented eradication of the tick. Here, the compulsory eradication campaign was replaced in 1966 with a scheme of voluntary tick control. Within a few months it became clear that implementation of the control scheme by farmers was often poor and consequently babesiosis was a potential threat to the area. This was confirmed in mid 1966 by the results of complement fixation (C.F.) tests carried out in Australia on cattle sera from the locality. Later that year, a major outbreak of babesiosis due to *B. bovis* occurred near Port Moresby with a mortality of approximately 30 percent on one farm of 550 cattle (L.A.Y. Johnston, unpublished report). Most of these deaths were amongst locally bred beef cattle. There were relatively few deaths amongst dairy cattle which were generally imported from Queensland. It was concluded that the majority of the animals that died had not been exposed previously to *Babesia* infection. The outbreak was due to (1) a sudden build-up of the tick population brought about by poor cattle musters, (2) inadequate application of acaricide following the change from eradication to control of tick, and (3) a latent infection of *B. bovis* in some animals. Treatment with a babesicide, amicarbalide*, together with improved acaricide spraying, controlled this outbreak and also a smaller one on a neighbouring government farm.

By March 1967, a *B. bovis* vaccine was being produced at the National Veterinary Laboratory using splenectomised calves, and 3665 cattle on nine farms in the tick endemic vicinity of Port Moresby were vaccinated during the first year of production. The policy adopted was to vaccinate and then treat with the babesicide seven or eight days later. The programme was successful in containing the disease although, during this initial period, there were a few deaths on four farms following vaccination. For the first few years the vaccine was produced locally, however, mainly for economic reasons, vaccine has been imported from the Tick Fever Research Centre at Wacol, Queensland, since 1969, following tests to prove its efficacy against the local strain of *B. bovis*.

Since vaccination was not compulsory, not all farmers in the tick endemic area vaccinated their cattle, and generally there was little interest shown by them in the follow-up vaccination of young stock. Between 1967 and 1972 there were at least 19 confirmed outbreaks of babesiosis on eight farms, involving 66 deaths. Four of the outbreaks, at separate farms, accounted for 42 (64 percent) of these deaths and involved non-vaccinated herds. The other 15 outbreaks had an average mortality of 1.6 animals and could be attributed largely to negligence in vaccination of new stock and to a relaxation of tick control.

Information on the type, breed and age of cattle affected is too limited for meaningful comments to be made.

* Diampron; May and Baker.

With respect to periodicity, it is noteworthy that 19 of 21 outbreaks recorded between 1966 and 1972 occurred between September and January. This period coincides with the last few months of the dry season and, usually, the first month or two of the wet season in the Port Moresby area. At this time cattle often are under considerable nutritional stress, and farmers consider that tick is less of a problem than at other times. Therefore they tend to relax tick control measures. Johnston (1968) reported that most cases of babesiosis in northern Queensland occurred in winter and spring and that, at least in the coastal region, this was linked to seasonal tick infestation. Dalgliesh *et al.* (1979) found that environmental temperature, by affecting the development of the parasite in larval ticks, may also influence the incidence of babesiosis.

In the intervening period since 1972, vaccination of stock has been haphazard, and over the last few years has involved inoculating only susceptible cattle brought onto a few farms at Sogeri from outside the tick endemic area. It appears that the disease has attained a state of relative stability in the Port Moresby area since clinical cases of babesiosis are seldom reported. The last confirmed farm outbreak was in 1975 when a few animals died at one farm. (The death from babesiosis of 3 out of 107 cattle in 1982 was due to special circumstances. The cattle, from a tick-free area of Milne Bay Province, were held for several weeks prior to slaughter in a tick infested paddock near Port Moresby; their naive condition made them vulnerable to *B. bovis* carried by the ticks.)

Indirect fluorescent antibody (IFA) tests of bovine sera collected from various parts of the country between 1972 and 1974 were carried out at the National Veterinary Laboratory. The only animals, other than those from near Port Moresby and from Sogeri, which had positive reactions to *B. bovis* antigens were from Oriomo (Western Province) and Hagita (Milne Bay Province), both of which were, at the time, areas with an uncertain history of cattle tick. However, there are no confirmed reports of babesiosis from either locality. The presence of *B. bovis*, at least at Oriomo, can be linked to the introduction of cattle from the Port Moresby area in 1971. Even when kept tick-free, infected cattle can carry a latent infection of *B. bovis* for up to three years (Johnston *et al.* 1978).

Babesia bigemina

This species also infects red blood cells of cattle but is regarded as of less pathogenic significance than *B. bovis* (Johnston 1968; Rogers 1971). *B. bigemina* has the same vector, the one-host tick *Boophilus microplus*, as *B. bovis*, however, the latter is transmitted to cattle by the larval stage of the tick whereas the nymph and adult stages transmit *B. bigemina* (Callow and Hoyte 1961).

Although *B. bigemina*, according to Anderson (1962–3), was identified in blood collected from clinical cases in Port Moresby, Goroka and Mt. Hagen in 1948–9, it was not seen during the outbreak of babesiosis involving *B. bovis* in 1966 or in any of the subsequent tick fever cases. However, its presence in the country was confirmed in June 1966 when C.F. tests showed positive reactors amongst cattle in 7 of 11 farms tested from the Port Moresby hinterland. Three of these farms were located at Sogeri, an area that had been tick free for many years until mid 1965 when tick began to reappear due to the presence of feral deer.

The parasite was isolated in 1975 when pooled blood of a few cattle was injected into a splenectomised calf. The animals came from one of the farms near Port Moresby that previously had experienced babesiosis caused by *B. bovis*. No clinical cases resulting from *B. bigemina* have occurred on the farm. This is consistent with the low pathogenic significance of the parasite reported in Queensland (Johnston 1968; Rogers 1971).

It is not known if the parasite is present in cattle in any other tick endemic area but it is of interest to note that *B bigemina* was reported by Zwart (1959) to be in cattle at Merauke in Netherlands New Guinea (now Irian Jaya, Indonesia) which is located close to the border of Western Province of Papua New Guinea.

Trypanosoma theileri

T. theileri is a relatively large flagellate protozoan which is parasitic in the blood stream of cattle. It has a world-wide distribution but is seldom seen during routine blood examinations since it has a low density in the bovine host (Herbert 1964). According to Seddon (1966), it is probably common and widespread in Australia. It is not surprising, therefore, that it occurs in Papua New Guinea but, to date, it has been found only in one herd at Sogeri, Central Province. The original case in 1969 involved a young cow, one of a group imported from Australia about 12 months previously, that had died of unknown causes and which had large numbers of *T. theileri* in liver and spleen impressions. The parasite was seen in blood films and cultures of 2 of 31 other members of the herd. Pooled blood given to two calves, one entire and the other splenectomised, produced parasites in blood films of both animals within five days of inoculation. It caused a low parasitaemia in both animals that persisted for eight to ten days. Neither animal showed any clinical symtoms but a noticeable drop occurred in packed cell volume and haemoglobin levels between days seven and ten post inoculation. Eighteen months later, *T. theileri* was seen in the blood of 1 of 35 cattle from the same herd.

Nine years after the first sighting of the parasite, blood samples from 28 cows, aged one to four years, on the same farm were negative for *T. theileri* in films and culture, and when pooled blood was injected into an entire and a splenectomised calf, both remained free of the parasite. This may mean that the trypanosome failed to transfer from the original imported cattle to local stock and has not become established at Sogeri.

T. theileri is generally classified as non-pathogenic (Herbert 1964; Schlafer 1979) although it has been incriminated by many at various times as the cause of bovine trypanosomiasis (Wyssmann 1935; Carmichael 1939; Bourgeois 1941; Grunet and Andresen 1970; Mitchell and Long 1980). It is a stercorarian trypanosome and is transmitted through contamination of wounds with excreta of the vector (Callow 1984). Blood sucking arthropods such as tabanid flies are considered to be the most common vectors Herbert 1964; Schlafer 1979) but there is some evidence that certain ticks also can carry the parasite (Burgdorfer *et al.* 1973).

Anaplasma marginale

This is a tick-borne rickettsial parasite of the red blood cells of ruminants and causes the infectious disease anaplasmosis. The earliest clinical case recorded in Papua New Guinea occurred in 1954 following inoculation of splenectomised calves, especially imported from Australia, with blood from Asian cattle held in quarantine in Port Moresby (Anderson 1960, 1972; Gregory 1961). The first major outbreak of the disease in local cattle occurred on a mixed beef and dairy farm near Port Moresby in December 1969.

It is likely that the outbreak was linked to two factors. First, cattle had been imported from Australia about nine months previously. There is no record of the origin of these cattle but, as most imports come from Queensland, there is a high probability that the animals were infected with *A. marginale*. Secondly, the farm is located in a tick endemic area where a voluntary tick control programme had been in force for about three years. This control programme was not being carried out adequately at the time since large numbers of tick, particularly seed tick, were present on most of the cattle examined. Poor grazing at the end of a long dry season may have added a nutritional stress factor, although plane of nutrition does not appear to play an important part in field cases of anaplasmosis during the dry season in northern Queensland (Wilson and Trueman 1978).

The outbreak affected only adult dairy cattle and was controlled by therapy and improved cattle tick control, but not before a few deaths occurred amongst two groups of cows. Occasional relapses were recorded during the following few months but vaccination was not initiated owing to the isolated nature of the outbreak. A year later there was a smaller outbreak of anaplasmosis in a neighbouring government dairy farm which resulted in the loss of two animals. It was controlled by treatment and no further occurrence of the disease has been reported.

It is a matter of conjecture why anaplasmosis had not arisen before 1969, or appeared since, as the conditions described were not unique to that year on the affected farms and others in the vicinity. However, the sudden build-up of the tick population towards the end of that year was, possibly, a new phenomenon, at least on the farm which had the first outbreak. It is well known that adult cattle are more susceptible than young animals to severe anaplasmosis (Jones *et al.* 1968). Also, in southern Queensland there are more records of dairy than of beef herds having clinical anaplasmosis (Rogers *et al.* 1978). It is possible that the potent combination of susceptible adult cattle and sudden increases in tick populations has not appeared since 1969/1970 as there are no longer dairy cattle in the area and, subsequently, the tick control programme has allowed a sufficiently large tick population to exist to transmit the parasite to cattle while they are young and thus for immunity to develop and be maintained.

Under laboratory conditions, *A. marginale* has been transmitted to susceptible cattle by a variety of ticks and a range of blood sucking flies, as well as mechanically by means of instruments such as hypodermic needles (Yeruham and Braverman 1981). Pre-natal infections have also been reported (Callow 1984). In the field, the cattle tick *Boophilus microplus* is considered to be the most important tick vector in many countries (Thompson and Roa 1978), but it is believed that members of the dipteran family Tabanidae also can play a significant role in transmission (Wissenhutter 1975; Yeruham and Braverman 1981). Some workers such as Rosenbusch and Gonzales 1927 and Brumpt 1931, as cited by Leatch 1973, claim to have found that transovarial passage of the parasite occurs in the cattle tick, but all recent evidence indicates that *Anaplasma* is transmitted only from stage to stage (transstadial passage) and within stages in

Boophilus microplus (Connell and Hall 1972; Leatch 1973; Thompson and Roa 1978). Although *B. microplus* is a one-host tick, it is able to move from one bovine host to another during the parasitic phase. It has been shown that all three stages (larva, nymph, adult) and both sexes are capable of transmitting the parasite (Connell and Hall 1972; Leatch 1973; Thompson and Roa 1978).

In Papua New Guinea in 1969/1970, the vector of *A. marginale* was probably the cattle tick, although several species of tabanid flies (e.g. *Tabanus dorsobimaculatus* and *T. innotabilis*) occur in the Port Moresby area. The tick *Rhipicephalus sanguineus* also is present in the country. It has been implicated as a vector of *A. marginale* in Africa and, under experimental conditions, in Australia (Parker and Wilson 1979). In Papua New Guinea it is a common parasite of dogs but as the only record of *R. sanguineus* being found on cattle is contained in a report of a survey conducted after World War 2 (Anonymous 1946), it is unlikely to have had a role in transmitting *A. marginale*.

Under experimental conditions *A. marginale* has been successfully transmitted in blood from cattle to rusa deer (*Cervus timorensis*), and *vice versa*, in Papua New Guinea, but it is considered that transmission is unlikely to occur between the two hosts under field conditions (Owen 1985).

Indirect fluorescent antibody (IFA) tests on bovine sera collected between 1972 and 1976 were positive from four farms in addition to those that had the original outbreaks in the Port Moresby area, from two farms at Sogeri where tick occurs and also from locations in the country that had been tick-free for many years. Mott (1957) stated that after an acute infection of anaplasmosis, cattle usually remain carriers (and thus, presumably, have antibodies) for life. If so, the presence of positive reactors in tick-free localities can be explained by the fact that cattle from areas endemic for anaplasmosis, such as parts of Central Province, and Queensland, have been distributed to many parts of Papua New Guinea. The high percentage of reactors at Baiyer River (Western Highlands Province) can almost certainly be attributed to transfers of cattle from a government farm near Port Moresby in 1967 and from Queensland between 1966 and 1969, and at Oriomo (Western Province) to the movement of cattle from the same Port Moresby farm in 1971. *A. marginale* was recorded from cattle at Merauke in Irian Jaya, Indonesia, by Zwart (1959).

Eperythrozoon sp.

This is a rickettsial organism which parasitises the surface of red blood cells. Blood-sucking arthropods are believed to act as vectors. A member of this genus has been recorded only once in the country, in 1968, when a splenectomised calf received blood from another calf that was used at the National Veterinary Laboratory as a reservoir for *Babesia bovis* (Talbot 1968–9). The calf developed a high density of bodies in its blood which were considered to be *Eperythrozoon* sp.

DISCUSSION

All the bovine blood parasites in Papua New Guinea use arthropods as vectors. The three most important species (*Babesia bovis, B. bigemina* and *Anaplasma marginale*) utilize the cattle tick. This tick is restricted to a few localities in the southern region (parts of Western, Central and Milne Bay Provinces), and therefore the remainder of the country, where approximately 87 percent of the cattle population occurs (Densley 1980), is not troubled by these blood parasites of cattle.

In the Port Moresby area of Central Province where cattle have blood parasites, only two species (*B. bovis* and *A. marginale*) are likely to be troublesome. Even with these two organisms, the risk of a major disease outbreak occurring is low probably under the current conditions of tick control, vaccination of vulnerable stock in the case of *B. bovis*, and control of internal movement of cattle from high-risk areas. However, the potential exists for babesiosis and anaplasmosis to spread beyond their present restricted endemic locality as long as the cattle tick remains. Eradication of the tick from the Port Moresby hinterland is impractical at present due to the presence of feral deer which can act as an alternate host (Owen 1977).

Although there is a far larger population of deer carrying tick in Western Province, the situation there with respect to bovine blood parasites is of less immediate concern than in the Port Moresby area. This is because there are relatively few cattle in the province and they are located at widely scattered centres, there is no road link with other parts of the country, and no cattle or deer are moved outside the province. However a reported sighting of deer near the border of Western Province and Southern Highlands Province in 1989 is potentially a matter of concern. In contrast, there is a need for constant vigilance in Central Province to ensure tick control is being implemented satisfactorily since, if a sudden increase in tick population coincided with laxity in vaccinating susceptible cattle or with the importation of a different strain of parasite, another outbreak of babesiosis or anaplasmosis could occur. Strict adherence to quarantine procedures is necessary for animals destined to be sent from Central Province to any other part of the country in order to maintain the *status quo* of the cattle tick and tick-borne diseases.

The danger of new bovine blood parasites entering Papua New Guinea is very low probably since importation of cattle is permitted only from Australia and is under strict quarantine control. The only blood parasites occurring in Australia which have not been detected in Papua New Guinea are the rickettsial organisms *Anaplasma centrale* and *Haemobartonella bovis*. *A. centrale* is a relatively non-pathogenic form which was deliberately introduced into Australia for immunization of cattle against anaplasmosis (Seddon 1966). *H. bovis* is a pleomorphic organism which could be mistaken for anaplasms or *Theileria*. It is rarely detected in cattle blood in Australia and, apparently, is not pathogenic (Callow 1984).

Importation of cattle from two other neighbouring countries, Solomon Islands and Indonesia, is prohibited, but the entry of a disease by accident from either country could occur due to their physical proximity. With respect to the Solomon Islands, there appears to be no risk at present as no bovine blood parasites have been recorded from there; also it is free of cattle tick (de Fredrick and Reece 1980). The Papua New Guinea border with Indonesia is the most likely point of entry of exotic blood parasites. The range of cattle blood parasites in Indonesia is similar to that in Papua New Guinea but with the addition of *Trypanosoma evansi* which causes the disease surra in cattle and some other domestic animals. Surra is transmitted mechanically by biting insects and is a more serious problem in horses and dogs than in cattle.

The disease was reported to be present in Papua New Guinea during World War 2 after the Japanese occupation forces imported horses from the Philippines into Bougainville (Anonymous 1946). Japanese veterinarians diagnosed surra in horses on two occasions in 1943, when *T. evansi* was said to have been demonstrated in blood smears. The affected animals, and all horses in contact with them, were destroyed. Other animals were reported not to have had contact with the affected horses. Only a few cattle, running wild, remained on the island when a post-war survey was conducted, and tests carried out on the remaining horses in 1945–6 were negative (Anonymous 1946).

T. evansi has not been reported from the Indonesian province of Irian Jaya. However the 700km land border between that province and Papua New Guinea, which passes through inhospitable and sparsely populated country, would make it almost impossible to police the movement of animals adequately if the disease situation were to change. The fact that people on both sides of the border have strong traditional links with each other, and that the large population of deer in the southern part is free to cross the border, would add further difficulties to the task of applying quarantine measures.

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RAINFALL ANALYSIS FOR IMPROVED AGRICULTURAL PLANNING

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ABSTRACT

It is demonstrated that for a comprehensive analysis of rainfall data to give results of importance in agricultural planning, daily rainfall measurements should be used. Methods of analyses are described and illustrated using daily rainfall records for 30 years from Madang.

INTRODUCTION

In a recent paper (Abeyasekera 1987), a classification of 300 rainfall stations around Papua New Guinea was made in an attempt to provide a basis on which particular stations could be selected for further study of their rainfall patterns. Sixteen clusters of rainfall stations were identified such that patterns of rainfall were similar within clusters and different between clusters. In this paper, a single station from one of the cluster groups has been selected to demonstrate the type of analysis that is possible in order to answer important questions relating to agriculture, such as the commencement and length of the rainy season, the distribution of rainfall throughout the year and the risk of dry spells.

Related studies have been carried out by McAlpine *et al.* (1975 and 1983) and Short (1970), where the percentile distributions of rainfall amounts and a few other descriptive measures have been produced on a monthly basis. However, these have the severe drawback that they do not provide flexibility for varying the period of interest to a period other than monthly. This limits the study of the pattern of rainfall over the growing season or over the harvesting season of a crop. With access to daily rainfall records however, it is possible to obtain results of agricultural importance for any particular period in the year, and this is the subject of this paper.

MATERIALS

Daily rainfall records from 54 stations were obtained, on magnetic tape, for the period from 1956 to 1970, from the Division of Water and Land Resources at CSIRO in Australia (see Appendix). These had been collected as part of a larger study of the climate and water resources of Papua New Guinea, the results of which have been reported by McAlpine *et al.* (1983). Daily rainfall records for the period from 1971 to 1985 were obtained from the National Weather Office in Port Moresby for 10 stations (listed in the Appendix) and computerised. Rainfall records for eight of these stations were also available on the tape provided by CSIRO.

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For these stations, it was thus possible to combine the 1956 to 1970 data with the 1971 to 1985 data.

One station, Madang, having a rainfall record from 1956 to 1985, was selected for analysis. This station is located at a latitude and longitude of 5°13'S and 145°47' respectively and at an elevation of 4 metres above mean sea level. It has an annual rainfall varying from 2000 mm to 4000 mm with a heavy rainfall season occurring in the period from October to April (see Figure 1).

The software needed for the analysis has been developed by the Tropical Agricultural Meteorology Group at Reading University in the United Kingdom. This software was implemented on the Prime Computer at the University of Papua New Guinea (UPNG) by the first author.

METHODS

The statistical methodology applied in this paper is the direct method of analysis developed by Stern *et al.* (1982). The distinctive feature of this method is that for any event or characteristic of interest, each year of data provides just one number. Thus if N years of data are available and the rainfall total for a particular week is of interest, the N years would provide N rainfall totals for that week. These observations are then treated as a random sample of observations from the population of weekly totals for that week of the year. Estimates of the probability of an event can then be found, either directly from the relative frequency of occurrence or by fitting a suitable distribution to the sample values.

In this paper the application of the direct approach will be demonstrated.

RESULTS

The software for an analysis by the direct method derives information on the rainfall characteristics of interest by coding the days of the year from day 1 to day 366 (February 29th is given a zero rainfall for non-leap years) and requesting the relevant information for a specified period from day n1 to day n2 within the year. The possible analyses are described below and illustrated using the Madang rainfall data.

Amounts of rain within a period

In agroclimatic analyses, a common practice is to sum rainfall totals over periods of seven or ten days or over months, and use the totals, one from each year, to estimate the amounts of rain that can be expected, at given probability levels. If for example, the first 10 days in September are of interest (this is day 245 to day 254 inclusive), then the rainfall totals over these 10 days for each year of the record can be ordered to give empirically the 80th percentile, for example, as 58 mm. This means that the probability of receiving more than 58 mm rain in the first 10 days of September is estimated as 0.2.

An alternative approach is to fit a distribution to the rainfall totals. When periods of a month or longer are considered, rainfall totals are often found to be approximately normally distributed. A histogram of totals for January in Madang (Figure 2) shows that this is likely to be the case here. Properties of the normal distribution then provide an estimate of the 80th percentile as 437.2 mm, whereas the empirical method of ordering totals gives the percentile as 430 mm. This shows good agreement between the two methods.

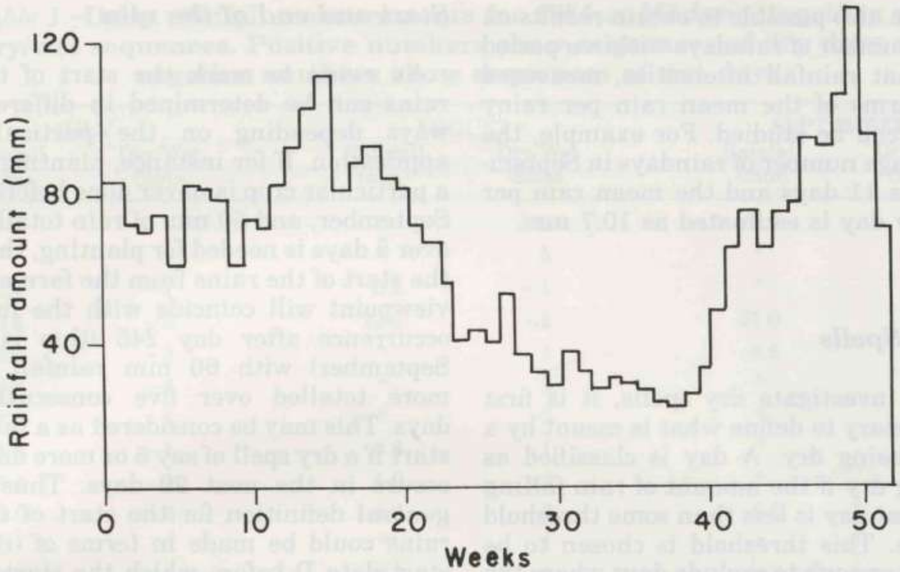


Figure 1.–**Distribution of average weekly rainfall amounts at Madang, from the first week of January to the last week of December.**

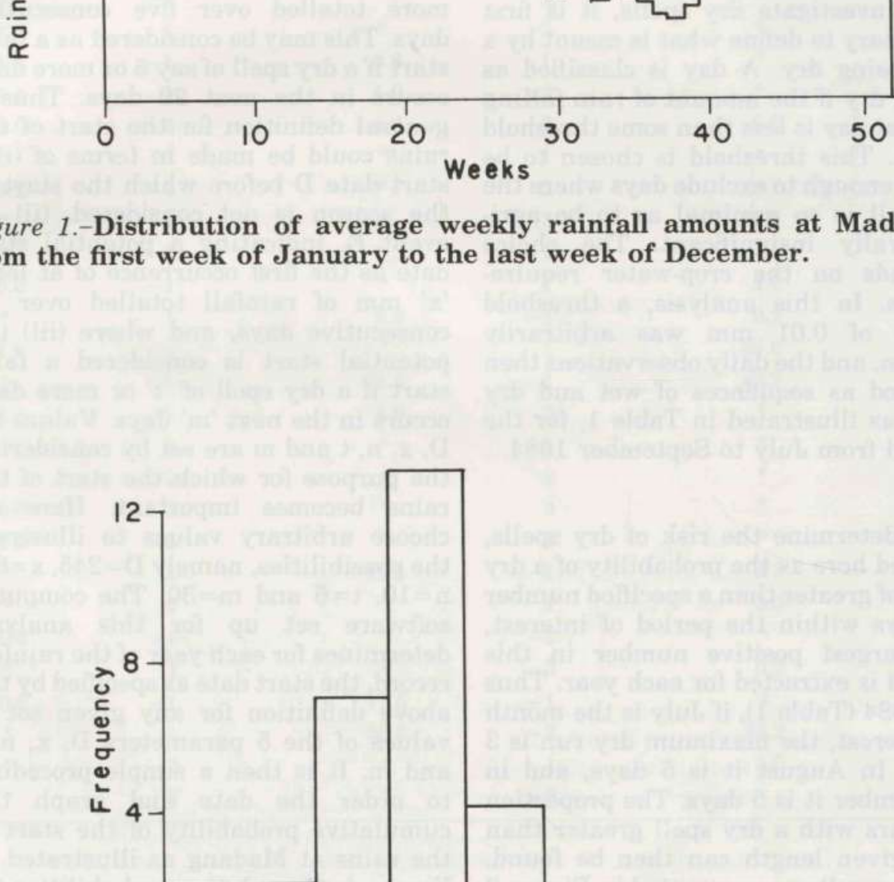


Figure 2.–**Histogram of total rainfall amounts in January (1956–1985) at Madang.**

It is also possible to obtain results on the number of raindays within a period so that rainfall intensities, measured in terms of the mean rain per rainy day, can be studied. For example, the average number of raindays in September is 11 days and the mean rain per rainy day is estimated as 10.7 mm.

Dry Spells

To investigate dry spells, it is first necessary to define what is meant by a day being dry. A day is classified as being dry if the amount of rain falling on that day is less than some threshold value. This threshold is chosen to be large enough to exclude days where the rainfall is so minimal as to be agriculturally insignificant. The choice depends on the crop-water requirements. In this analysis, a threshold value of 0.01 mm was arbitrarily chosen, and the daily observations then recoded as sequences of wet and dry days as illustrated in Table 1, for the period from July to September 1984.

To determine the risk of dry spells, defined here as the probability of a dry spell of greater than a specified number of days within the period of interest, the largest positive number in this period is extracted for each year. Thus for 1984 (Table 1), if July is the month of interest, the maximum dry run is 3 days. In August it is 5 days, and in September it is 5 days. The proportion of years with a dry spell greater than any given length can then be found. Some results are presented in Figure 3 showing the change in probabilities of dry spells throughout the year. For example, the probability of a dry spell of 7 or more days in August is approximately 0.6. This means that in 6 years out of 10 on the average, a dry spell of 7 days or longer may be expected during August.

Start and end of the rain

An event to mark the start of the rains can be determined in different ways depending on the particular application. If for instance, planting of a particular crop is never done before 1 September, and 60 mm of rain totalled over 5 days is needed for planting, then the start of the rains from the farmers' viewpoint will coincide with the first occurrence after day 245 (this is 1 September) with 60 mm rainfall or more totalled over five consecutive days. This may be considered as a false start if a dry spell of say 6 or more days occurs in the next 20 days. Thus a general definition for the start of the rains could be made in terms of (i) a start date D before which the start of the season is not considered, (ii) an event E, indicating a potential start date as the first occurrence of at least 'x' mm of rainfall totalled over 'n' consecutive days, and where (iii) the potential start is considered a false start if a dry spell of 't' or more days occurs in the next 'm' days. Values for D, x, n, t and m are set by considering the purpose for which the start of the rains becomes important. Here we choose arbitrary values to illustrate the possibilities, namely $D=245$, $x=60$, $n=10$, $t=6$ and $m=30$. The computer software set up for this analysis determines for each year of the rainfall record, the start date as specified by the above definition for any given set of values of the 5 parameters D, x, n, t and m. It is then a simple procedure to order the data and graph the cumulative probability of the start of the rains at Madang as illustrated in Figure 4. Cumulative probabilities for the end of the rains are also plotted in the same figure where the end of the rains has been defined as the first day after 3 June with the rainfall amount totalled over the previous 7 days falling below 10 mm.

Once the start and end of the rains

Table 1.-**Daily rainfall measurements for 1984 at Madang, together with dry/wet sequences. Positive numbers show sequences of dry days and negative numbers show sequences of wet days.**

JULY		AUGUST		SEPTEMBER	
Rainfall (mm)	Dry/Wet State	Rainfall (mm)	Dry/Wet State	Rainfall (mm)	Dry/Wet State
0.4	−1	*	4	2.0	−1
*	1	*	5	*	1
2.4	−1	0.2	−1	*	2
0.6	−2	22.2	−2	21.0	−1
2.0	−3	*	1	0.6	−2
0.8	−4	*	2	*	1
*	1	*	3	*	2
1.8	−1	6.8	−1	*	3
0.4	−2	1.0	−2	*	4
1.0	−3	4.6	−3	5.6	−1
*	1	*	1	*	1
0.2	−1	*	2	*	2
*	1	*	3	21.8	−1
*	2	0.2	−1	*	1
9.6	−1	*	1	4.6	−1
*	1	0.8	−1	0.2	−2
1.2	−1	*	1	23.6	−3
*	1	21.8	−1	49.2	−4
8.8	−1	4.6	−2	*	1
*	1	*	1	*	2
*	2	*	2	*	3
5.6	−1	*	3	*	4
1.0	−2	*	4	*	5
*	1	11.8	−1	3.0	−1
*	2	*	1	3.0	−2
0.4	−1	*	2	*	1
*	1	*	3	0.2	−1
10.0	−1	17.6	−1	*	1
*	1	26.6	−2	33.2	−1
*	2	*	1	5.0	−2
*	3	*	2	—	

has been suitably established, the length of the rainy season for each year can be determined by subtracting the start date from the end date. For Madang, the mean length was 266 days.

DISCUSSION

It is generally accepted that much of the year to year variation in crop yields may be due to the variability of rainfall. The results presented here

Figure 3.–**Probability of dry spells in 30-day periods, estimated as the observed proportion of years in which a dry spell of at least 4, 7 and 10 days occurred in the 30 days following each date plotted.**

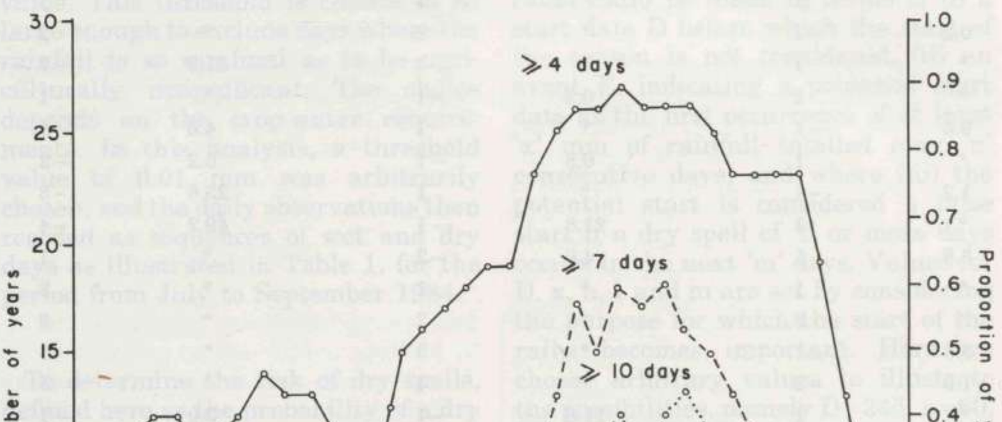
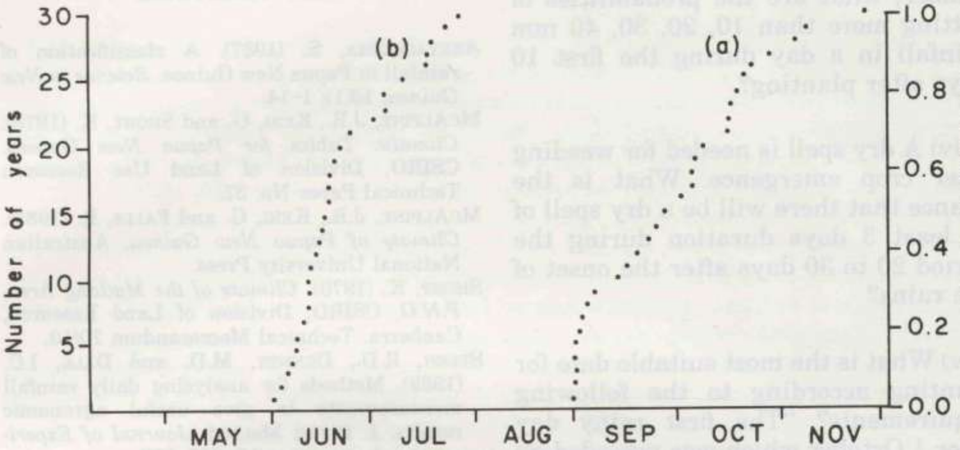


Figure 4.–**Cumulative probability of the start and end of the rains at Madang.**
(a) Start of the rains: First day after 1 September with rainfall of 60 mm or more totalled over 10 consecutive days, but with no dry spell of 6 or more days in the next 30 days.
(b) End of the rains: First day after 3 June with less than 10 mm of rain totalled over the previous 7 days.



show that many questions of agricultural importance can be studied through a comprehensive analysis of daily rainfall measurements. At least this level of detail is required to investigate many aspects of the distribution of rainfall at a site, particularly in relation to the risk of dry spells and the start and end of the rainy season. The latter is clearly of importance when a suitable planting date is to be determined for a particular crop. Farmers often plant their crops with the onset of the rains, but they should be made aware of the risks involved in planting at particular times of the year. An adequate definition for the start of the rains in terms of the crop-water requirements will allow the farmer to plant his crop at a time when the risk of inadequate rain during the initial stages of crop growth is minimal.

One prerequisite however is for agricultural researchers to appreciate the wide range of questions that can be answered, and phrase such questions precisely. Some possiblities are given below.

(i) What is the average date for the beginning of the rainy season? This event is defined as the first day after 15 October that rainfall reached 50 mm totalled over 5 consecutive days. What is the probability that this event will occur 5, 10, 15 or 20 days earlier or later than this average date?

(ii) What is the average date for the end of the rains? This is defined as the first day after 1 April with less than 20 mm rainfall totalled over 5 days, and remaining below 10 mm in the next 2 days. What is the probability that the end date will occur 5, 10 or 15 days earlier or later than the average date?

(iii) If planting is done on 1 September, what are the probabilities of getting more than 10, 20, 30, 40 mm rainfall in a day during the first 10 days after planting?

(iv) A dry spell is needed for weeding after crop emergence. What is the chance that there will be a dry spell of at least 3 days duration during the period 20 to 30 days after the onset of the rains?

(v) What is the most suitable date for planting according to the following requirements? "The first rainy day after 1 October which was preceded by 3 consecutive days having a total of more than 40 mm of rain with (a) no dry spell of 5 or more days in the next 20 days, and (b) no dry spell of 2 or more days in the flowering period from 20 October to 30 October."

These illustrate some of the questions that can be answered with access to daily rainfall records and using the computing software that has been set up on the UPNG computer. The daily records from 1956–1970 for stations listed in the Appendix are also available, and results of the type presented in this paper can be produced for interested researchers on provision of the daily records for the post 1971 period.

ACKNOWLEDGEMENTS

We sincerely thank J.R. McAlpine and his team at CSIRO, Australia, for the supply of computerised daily rainfall records, and the Tropical Agricultural Meteorology group at Reading University, United Kingdom, for supplying the software to pick specific rainfall events. Thanks are also due to the National Weather Office in Port Moresby for allowing access to their rainfall records.

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APPENDIX

(a) Stations for which computerised daily rainfall records are available from 1956 to 1970.

1. AIOME
2. AITAPE
3. AIYURA
4. AMBUNTI
5. ANGORUM
6. AWELKON
7. BAINYIK
8. BAIYER RIVER
9. BANIARA
10. BAMU
11. BEREINA
12. BOGIA
13. BULOLO
14. BWAGAOIA
15. DARU
16. DOGURA
17. ERAP
18. ERAVE
19. FINSCHAFFEN
20. GARAINA
21. GIZARUM
22. GOROKA
23. HENGANOFI
24. ITIKINUMU
25. KAIAPIT
26. KAVIENG
27. KANDRIAN
28. KEREMA
29. KIKORI
30. KIUNGA
31. LAE
32. LUMI
33. MADANG
34. MENDI
35. MENYAMYA
36. MINJ

37. MOMOTE
38. MT. HAGEN
39. NAMATANAI
40. POMIO
41. POPONDETTA
42. PT. MORESBY
43. RABAUL
44. SAIDOR
45. SAMARAI
46. SOHANO
47. TAPINI
48. TARI
49. TIMBUNKI
50. TUFI
51. VANIMO
52. WABAG
53. WAU
54. WEWAK

(b) Stations for which computerised daily rainfall records are available from 1971 to 1985.

1. ERAVE
2. JINJO
3. KAVIENG
4. KIETA
5. LAE
6. MADANG
7. MOMOTE
8. PT. MORESBY
9. RABAUL
10. VANIMO

ANALYSIS OF CATCH DATA FROM AN ARTISANAL CORAL REEF FISHERY IN THE TIGAK ISLANDS, PAPUA NEW GUINEA

PAUL J. DALZELL*† and ANDREW WRIGHT*††

ABSTRACT

For the period 1970–1982, landing records from a small-scale coral reef fishery in the Tigak Islands, northern Papua New Guinea (PNG), are summarised and analysed. Fishermen in the Tigak Islands spear, net, or handline the majority of the catch. Mugilids, carangids, lutjanids, letherinids, serranids and scarids comprise 76 percent of the total weight of the fish caught in these islands. From 1970 to 1982, 303 tonnes of reef fish caught by island fishermen were landed at a government fisheries station in Kavieng. This involved 9,131 beachside transactions. Landings of fish from the Tigak Islands increased between 1976 and 1982 and the possible reasons for this are discussed. Population size and annual rainfall did not have a significant affect on fish landings, but fish landings in two villages which owned copra plantations were negatively correlated with the mean annual copra price. As the distance from Kavieng increased, the incentive to fish decreased; more than 30 percent of the total landings for the period originated from within two kilometres of the government fisheries station. However, mean weight of landings increased with increasing distance of the source of the catch from the fisheries station. The implications of this analysis for fisheries development planning are discussed.

INTRODUCTION

The northern and eastern coasts of the main eastern and northern islands of Papua New Guinea (PNG) support extensive coral reefs. The majority of these reefs are fringing or barrier types and are among the most diverse in the world for coral species (Kojis *et al.* 1985). Associated with these reefs and the adjacent shallow water environments, which includes lagoons, seagrass beds and mangrove forests, is a rich fish fauna represented by species found throughout most of the tropical Indo-Pacific (Wright and Richards 1985). In PNG, components of this fauna have been harvested by man since pre-history (White and O'Connell 1982).

The present harvest from PNG's coral reefs has been estimated to be between 10,000 and 15,000 tonnes annually (Kearney 1975; Densely *et al.* 1977; Frielink 1983). The factors affecting fisheries production are generally unknown. Lock (1986a, b, c, d) analysed catch and effort data from the Port Moresby artisanal reef fishery and has shown that the harvest and

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catch per unit effort is inversely correlated with total fishing effort. Wright and Richards (1985) have described the catch composition and the catch rates of the Tigak Islands reef fishery in New Ireland Province and suggested that the present yields were effort limited rather than resource limited.

Wright and Richards (1985) recorded the methods of fish capture for landings of reef fish from the Tigak Islands at the Kavieng Government Fish Purchasing Centre (GFPC) during 1980–1981. A summary of these data is presented in Table 1. Fishing with nets is the most common method of fish capture in the Tigak Islands and accounts for about one-third of the total catch weight. The miscellaneous classification in Table 1 refers to fishing trips where combinations of fishing methods were used and for which detailed catch information was rarely available. The use of explosives is also common in the Tigak Islands but as this method is illegal, few fishermen attempt to sell fish obtained by bombing to the GFPC.

The composition of the artisanal catch landed at the Kavieng GFPC during 1980–1981 is given in Table 2. Wright and Richards (1985) recorded a total of 253 species of teleost fishes, representing 43 families, during this period. The catch was dominated by Mugilide which accounted for about one fifth (in weight) of the total. A further five families (Carangidae, Lutjanidae, Lethrinidae, Serranidae and Scaridae) comprised 76.1 percent of the total landed catch.

The principal method of transport from the outlying islands in the Tigak Group to Kavieng, the urban center in New Ireland, is by canoe or dinghy powered by outboard motors. These vessels are also used to transport copra from the Tigak Islands to the exporting port at Kavieng. Plantations are owned by many of the local village groups and copra has offered a regular source of cash to the island communities in the recent past.

In this paper, we examine a time series of fish landing data at a GFPC at Kavieng for the period between 1970 and 1982. The majority of the fish landed at the Kavieng GFPC

Table 1.–**Contribution by various fishing methods to the artisanal fishery in the Tigak Islands [adapted from Wright and Richards (1985)].**

Fishing Method	Percentage contribution (by weight) to the artisanal fishery
Gill netting & Beach seining	35.2
Miscellaneous (e.g. derris root poisoning or combination of methods)	31.2
Hand-lining	21.6
Spearing	6.1
Trolling	5.9

are caught in the Tigak Islands. The receipts for fish purchased by the GFPC are not designed to monitor fish landings to provide biological information relating to the dynamics of the fishery operating to the Centre, but rather to provide an economic record of the GFPC transactions. These receipts have until now been largely ignored as a useful source of information on the dynamics of small-scale fisheries in PNG. This paper presents the first attempt to use the records of a fish purchasing Center to provide information that may be useful for planning future development of PNG's coastal fisheries.

MATERIALS AND METHODS

The Study Site

The Tigak Islands (Fig. 1 and Fig. 2) lie to the west of the New Ireland mainland in the Bismarck Archipelago, between 2 ° 32 ′ S and 2° 47′ S, and 150° 30′ E and 150° 47′ E. The total population of the 24 islands in the group at the 1980 census was 1,481 (Anonymous 1983).

Many of the Tigak Islands are raised reefal limestone, whereas others consist of an atoll of reef-derived beach rock and coralline sand. The climate is tropical-monsoonal with an average annual rainfall of 3,300 mm. The average sea surface temperature is 30° centigrade with a mean salinity of 33.5 parts per thousand (Wright *et al.* 1983). The coastal vegetation fringing these islands consists of mangrove swamps bordered by either rainforest or coconut plantation.

Catch Data

Residents in the Tigak Islands catch fish which are either sold in the provincial centre of Kavieng or consumed

Table 2.–**Family composition (by weight) of Tigak Islands artisanal reef fish catch at Kavieng GFPC [adapted from Wright and Richards (1985)].**

Family	Common Name	% of Tigak Islands Catch
Mugilidae	Mullet	21.2
Carangidae	Trevally	14.0
Lutjanidae	Snapper	13.3
Lethrinidae	Emperor	10.4
Serranidae	Rock cod	9.1
Scaridae	Parrot fish	8.1
Acanthuridae	Surgeon fish	4.7
Haemulidae	Sweetlip	3.3
Scomberomoridae	Mackerel	2.7
Chanidae	Milk fish	2.3
Balistidae	Trigger fish	1.6
Siganidae	Rabbit fish	1.3
Albulidae	Bone fish	1.0
Hermiramphidae	Gar-fish	1.0
Belonidae	Needle fish	1.0
Gerridae	Biddies	1.0
Mullidae	Goat fish	1.0
Other Families		7.0

in the local villages. Fish sales in Kavieng occur through street sales, sales through the general produce market, or trade stores, or sales to the GFPC. Sales other than through the GFPC are difficult to monitor and are not considered here.

Since 1968, the government has maintained the fish purchasing facility on the Kavieng water-front. Finfish are transported to this facility from the islands by fishermen or are bought from island fishermen by GFPC staff on a collection vessel. Each purchase of fish is recorded on a produce purchase docket (PPD) which forms the basis of the GFPC accounts.

The PPDs from 1970–1982 were analyzed in an attempt to describe the history of fishing for reef fishes in the Kavieng area. The volume of catch sold to the GFPC is referred to here as the landed catch. This distinguishes it from the total catch which comprises the landed catch, and fish which are kept by the fishermen for sale elsewhere or for subsistence purposes.

As there were no data or direct measures of fishing effort, the frequency of landings were summarized by village or island with the corresponding landed catch. These summaries formed the basic data set for analysis. A data subset was selected

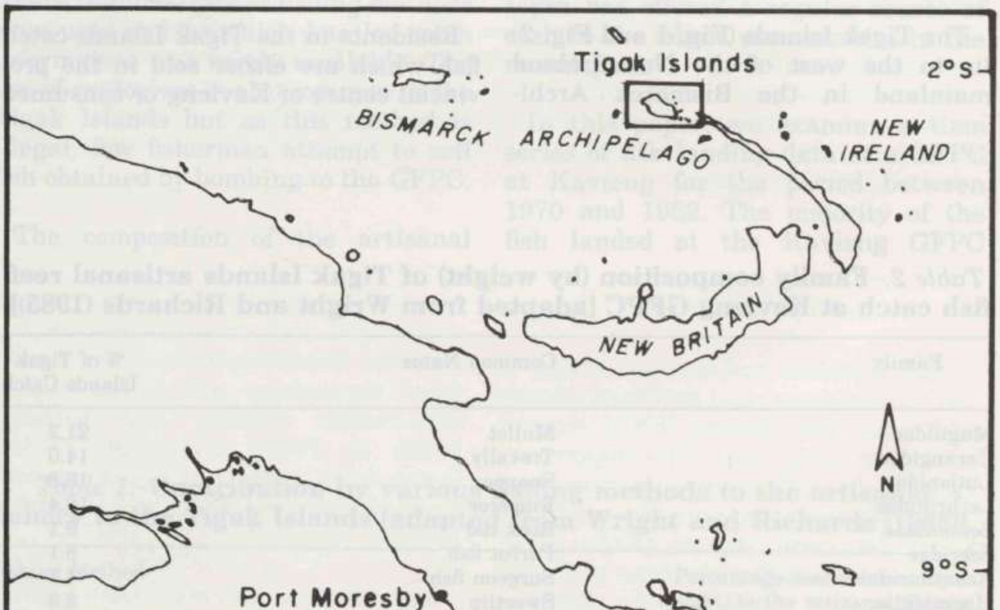

Figure 1.–**Map showing the location of the Tigak Islands in Papua New Guinea.**

for ten villages or islands that had contributed to the catch total for all years of the thirteen year study period.

RESULTS

Total Production

The total annual landed catch, number of landings and the mean weight for landings each year from the Tigak Islands between 1970–1982 are given in Table 3. Over this period, the mean annual number of landings of fish at the Kavieng GFPC was 702 landings (s.e.m. 195 landings). The mean annual landed catch between 1970–1982 was 23.3 tonnes (s.e.m. 3.0 tonnes). The average weight of the catch at each landing was 33.2 kilogrammes.

The data show that there was a considerable increase in the size of the annual landed catch in 1976 and it remained relatively constant thereafter. The average size of the annual landed catch from 1970–1975 was 14.4 t (s.e.m. 2.4 t) compared with 30.9 t (s.e.m. 3.1 t) between 1976 to 1982. Apart from 1976 when the number of landings was markedly higher, there was no corresponding rise in the number of landings after 1975. Thus after 1975 the mean size of the catch in each landing increased.

Fish production by village or island

Twenty villages or islands contributed to the total landed catch at the Kavieng GFPC between 1970 and 1982. The details of landings by

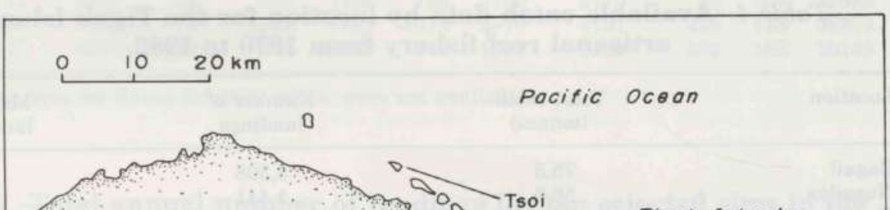

Figure 2.–**Map of the Tigak Islands and environs showing the ten villages and islands that landed fish at the Kavieng GFPC on a regular basis throughout the ten year study period. Key: 1. Kavieng GFPC, 2. Bagail, 3. Sivisat, 4. Nusa, 5. Nago, 6. Nusailas, 7. Enuk, 8. Nonovaul, 9. Butei, 10. Keton, 11. Upuas.**

Table 3.–**Total recorded annual weight of landed catch and total recorded number of landings at the Kavieng GFPC from the Tigak Islands artisanal fishery from 1970 to 1982.**

Year	Annual weight of landings (tonnes)	Annual number of landings	Mean weight of landings (kg)
1970	23.7	890	26.6
1971	7.6	387	19.7
1972	13.5	729	18.5
1973	16.8	610	27.5
1974	8.6	434	19.8
1975	16.3	869	18.7
1976*	31.4	1,522	20.6
1977	33.7	763	44.1
1978	32.8	642	51.1
1979	26.5	541	49.0
1980	22.1	447	49.4
1981	46.5	844	55.1
1982	23.3	453	51.5
Total	302.8	9,131	
Mean	23.3	702	33.2

* Excludes data for Keton which were not available.

Table 4.–**Available catch data by location for the Tigak Islands artisanal reef fishery from 1970 to 1982.**

Location	Total catch (tonnes)	Number of landings	Mean size of landings (kg)
Bagail	75.5	3,308	22.8
Nusailas	56.0	1,441	38.9
Nonovaul	34.2	895	38.2
Enuk	28.7	874	32.8
Upuas	27.5	351	78.3
Keton*	20.4	373	54.7
Butei	11.7	306	38.2
Matupit	10.8	119	90.8
Sivisat	10.2	569	17.9
Nusa	6.0	305	19.7
Utukul	4.4	26	169.2
Nago	4.2	188	22.3
Tselapiu	3.7	81	45.7
Ungan	3.2	73	43.8
Tome	2.0	90	22.2
Nusalomen	1.9	61	31.1
Bangatang	1.0	35	28.6
Nusalik	0.9	50	18.0
Noipos	0.2	8	25.0
Limalon	0.05	5	10.0

* Excluding data for 1976 which are not available.

location are given in Table 4. The landings are ranked from Bagail, with a total catch of 75.5 t for the thirteen year period, to Limallon with a total catch of 0.05 t for the same period. The correlation between number of landings and total annual catch is significant ($r = 0.94$, $P < 0.05$).

Factors affecting fish production in the Tigak Islands were examined using the data subset of the ten villages and islands that consistently contributed to the landed catch between 1970 and 1982 (Table 5 and Table 6). The catches from Nusailas, Nusa and Nonovaul followed the general trend for the fishery as a whole, with increased production after 1975. There were, however, no obvious trends in total catch or number of landings over the thirteen year period within the data subset.

The possible affect of village population size, rainfall, mean annual

Table 5.–**Total recorded annual catch (kgs) for ten selected sites in the Tigak Islands for the period 1970 to 1982 [n.a. = not available].**

Year	Bagail	Nusailas	Keton	Sivisat	Enuk	Nusa	Upuas	Nonovaul	Butei	Nago	Total
1970	5959	1700	1142	600	3704	1106	3107	717	3750		21795
1971	1687	828	554	620	1608	36	317	1395	79	118	7242
1972	3298	1558	824	2106	2112	120	1217	372	372	105	12772
1973	5951	354	492	243	1163	360	5348	720	1114	190	15935
1974	3943	1673	5	139	1536	31	902	152	52	99	8532
1975	6612	1546	42	509	1367	195	3447	781	56	596	15656
1976	18638	3434	n.a.	1140	1346	174	3419	1419	243	864	30677*
1977	4485	10433	1875	339	2128	76	1750	9932	144	45	32512
1978	8149	10844	3283	711	1120	447	1812	4018	461	414	21259
1979	5032	8378	2992	405	812	1371	349	4069	76	167	23651
1980	3745	4747	287	525	1106	753	2780	3770	12	357	18082
1981	5202	5633	6197	1892	6094	1012	2579	4151	423	113	36278
1982	2837	4914	2687	972	4602	340	1608	1889	134	162	20145

* Excluding data for Keton for 1976 which were not available

Table 6.–**Total annual number of landings for ten selected sites in the Tigak Islands for the period 1970 to 1982 [n.a. = not available].**

Year	Bagail	Nusailas	Keton	Sivisat	Enuk	Nusa	Upuas	Nonovaul	Butei	Nago	Total
1970	324	60	30	43	110	93	29	23	89		801
1971	99	48	13	51	79	4	4	62	5	5	370
1972	221	76	23	155	71	4	3	60	12	7	697
1973	324	16	15	24	33	17	78	45	36	6	594
1974	258	91	1	9	37	5	7	11	2	6	427
1975	375	121	3	50	92	12	59	54	47	22	835
1976	785	306	n.a.	92	76	16	46	133	21	42	1517*
1977	192	215	17	16	59	2	24	158	37	1	721
1978	227	143	69	25	27	18	25	55	15	13	617
1979	137	94	71	14	23	48	5	79	3	5	479
1980	114	83	7	17	38	27	31	82	3	8	410
1981	147	99	80	57	136	46	23	95	34	4	721
1982	105	89	44	16	93	13	17	38	2	2	421

* Excluding data for Keton for 1976 which were not available.

copra price and the distance of the village from the Kavieng GFPC on the catch of fish from the Tigak Islands was examined. The population figures for each village or island (Table 7) were obtained from the 1971 and 1980 Government census (Anonymous 1983). There was no significant correlation between total catch or number of landings and mean population size (P > 0.05) for the ten locations in the subset.

Annual rainfall figures for the years 1970 to 1982 were obtained from the Kavieng Weather Station, which is adjacent to the airport and about 1.5km from the town (Table 8). There was no significant correlation between rainfall and total number of landings for the 20 locations (P > 0.05).

The mean annual purchase price for copra between 1970–1972 was obtained from Copra Marketing Board

Table 7.–**Population census figures for ten locations in the Tigak Islands used as data subset [source: PNG Government Bureau of Statistics, Port Moresby].**

Location	Population	
	1971	1980
Bagail	119	127
Nusailas	80	102
Nonovaul	126	157
Enuk	97	123
Upuas	214	213
Keton	110	86
Butei	179	199
Nusa	101	110
Sivisat	30	40
Nago	5	5
Total	1,061	1,162

Table 8.–**Total annual rainfall for Kavieng, summarized from Kavieng Weather Station records.**

Year	Rainfall (mm)
1970	3,150
1971	3,014
1972	2,606
1973	3,825
1974	2,570
1975	2,756
1976	2,990
1977	3,447
1978	3,315
1979	3,147
1980	3,734
1981	3,606
1982	2,686

(CMB) records (Table 9). Two locations in the Tigak Islands, Enuk and Sivisat, are almost entirely planted with coconut. Plots of the natural logarithm of the annual number of landings against copra price for these two locations (Fig. 3) had negative slopes and both the r values are highly significant ($P < 0.005$).

The distances between Kavieng and the ten locations in the data subset were estimated from Australian Admiralty charts (Table 10). The landed catch data for Bagail, Nusa, Nago and Sivisat were grouped under the one heading of Kavieng Harbour, with a mean distance from Kavieng GFPC of 2km. There was a significant ($P > 0.05$) negative correlation between the natural logarithm of the total number of landings with distance

Table 9.–**The buying price for copra (in standard units). [source: PNG Copra Marketing Board, Port Moresby.]**

Year	Annual Copra price* (standard units)
1970	1.00
1971	0.86
1972	0.49
1973	1.20
1974	2.44
1975	0.72
1976	0.91
1977	1.49
1978	1.62
1979	2.43
1980	1.40
1981	1.09
1982	0.87

* Between 1970 and 1974 the copra price was in Australian dollars. It was changed to Kina with the introduction of the new currency in 1975. The copra price was converted to standard units based on 1.00 for 1970. The effects of inflation were accounted for by deflating the annual copra price by the consumer price index for each year.

Table 10.–**Distance (km) from Kavieng of ten locations in the Tigak Islands used as a subset for the fishery catch data.**

Location	Distance from Kavieng (km)
Kavieng Harbour (Bagail, Sivisat Nago, Nusa)	2
Enuk	11
Nusailas	12
Butei	20
Nonovaul	21
Keton	22
Upuas	32

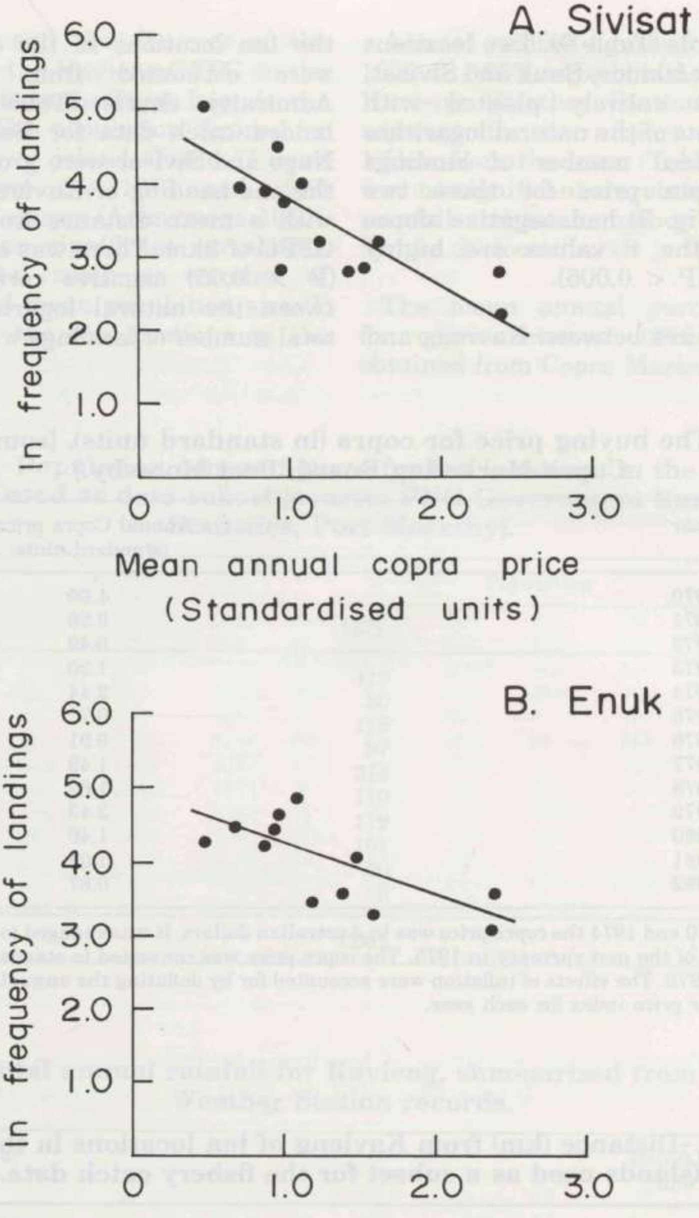

Figure 3.–**Plots showing the relationship between the annual number of landings of fish from (A) Sivisat Island and (B) Enuk Island at the Kavieng GFPC and the mean annual copra price. The copra price was converted to standard units based on 1.00 for 1970. The effects of inflation were accounted for by deflating the annual copra price by the consumer price index for each year. The regression equation for Sivisat is $y = 4.81 - 1.08x$, $r^2 = 0.62$, $P < 0.05$. For Enuk Island the equation is $y = 4.96 - 0.70x$, $r^2 = 0.55$, $P < 0.05$.**

from Kavieng (Fig. 4). A plot of the natural logarithm of the mean weight of the landed catch against distance from Kavieng is shown in Fig. 5. A significant positive correlation was obtained ($P < 0.05$).

DISCUSSION

The reasons for increased fish production after 1975 are not clear. One possibility is that the increase in buying price of fish catches at the Kavieng GFPC from 0.21 Kina/kg (Aust. $0.21 prior to 1975) to 0.45 Kina/kg in 1975 stimulated greater interest in catching and selling fish as a source of cash. As a consequence during 1976 the number of landings reached the maximum for the 1970–1982 period. Landings remained at normal levels from 1977 to 1982.

There is no evidence that fishing methods changed during the period so an apparent increase in the average weight of each unit sale from 1977 onwards could only be explained by fishermen exerting greater effort. The main motivation for this is probably related to the attractiveness of fishing for cash compared with other means of generating a cash income.

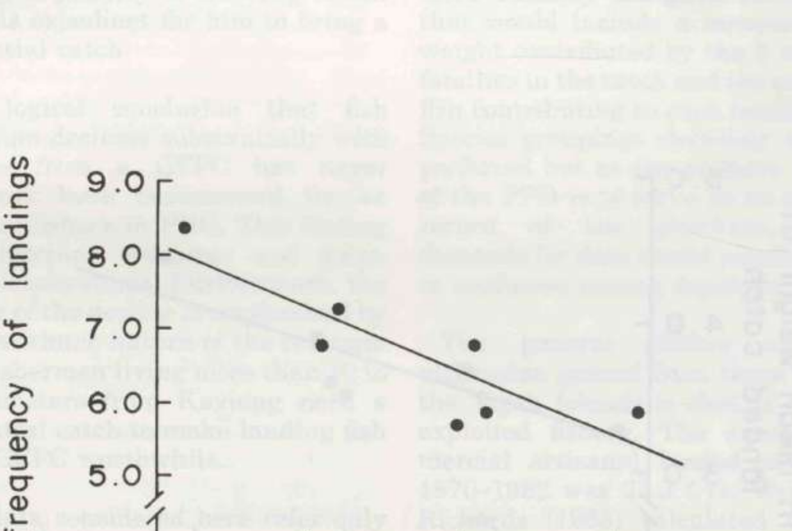

Figure 4.–**A plot showing the relationship between the number of landings of fish for the period 1970 to 1982 and the distance of the producing village from the Kavieng GFPC. The equation for the relationship is $y = 8.14 - 0.085x$, $r^2 = 0.72$, $P < 0.05$.**

Events outside the artisanal fishery may also have affected fish production from the Tigak Islands. The data relating to copra price and number of landings of fish (Fig. 3) by Sivisat and Enuk villagers at the GPFC suggest that when the price of copra is low more effort is put into fishing. Other villages also have access to large plantings of copra but the same relationship between copra price and fish landings is not evident. However, these other villages also benefit from a number of other income sources including fertile vegetable producing land and royalty payments for timber logging operations. These may also influence fishing effort.

In June 1975 royalty payments were commenced to Tigak Islands' residents for the use of traditional fishing areas as a source of live bait, by the domestic pole-and-line tuna fleet. Royalty payments were based on 2.5 percent of the value of the tuna catch taken by the tuna boats which baited in the traditionally-claimed shallow reef-associated lagoons throughout the Tigak Group.

Unfortunately, accurate records of royalty payments were not kept, but it is estimated that they amounted to between 25,000 and 30,000 Kina/yr. The influx of this money into the Tigak Islands between 1975 and 1981 may

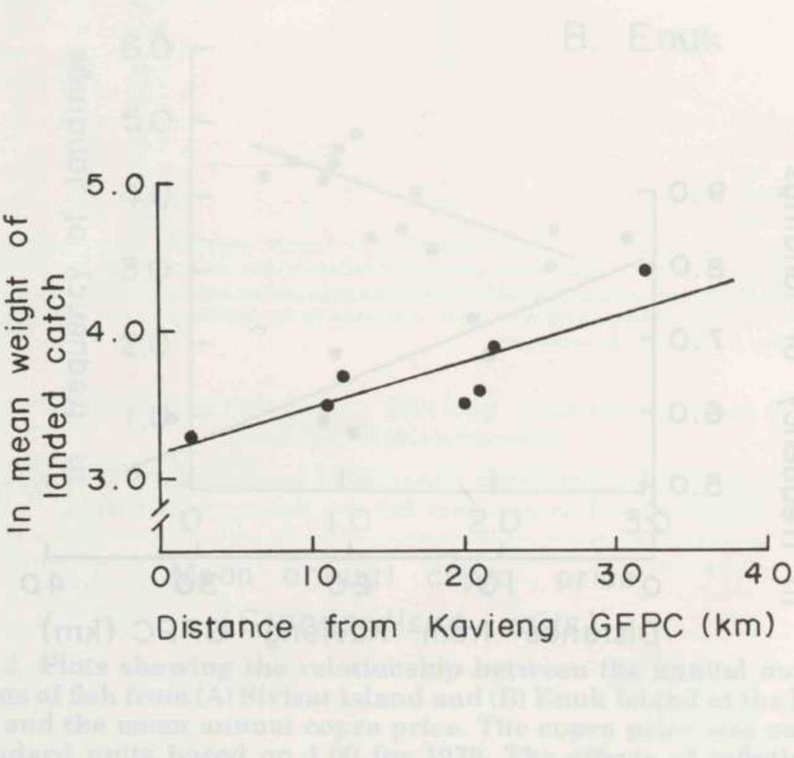

Figure 5.–**A plot showing the relationship between the mean weight of the catch per landing at the Kavieng GFPC and the distance of the producing village from the GFPC. The equation for the relationship is $y = 3.16 + 0.032x$, $r^2 = 0.72$, $P < 0.05$.**

have permitted the acquisition of more outboard motors and fishing equipment which led to increased fish production after 1975, although this reason for increased fish production cannot be substantiated.

As they are, the PPD records are useful and can provide an insight into the dynamics of an artisanal fishery. Within the Tigak Islands reef fishery, several factors have affected fish production between 1970 and 1982. Approximately one third of the total landings of the Tigak Islands fishery come from the immediate proximity of the Kavieng GFPC. Fishing effort, at the least that directed to commercial fishing, declines markedly within the 2–10 km distance from Kavieng GFPC. For a fisherman living far from Kavieng to journey to Kavieng to sell fish, it is expedient for him to bring a substantial catch.

The logical conclusion that fish production declines substantially with distance from a GFPC has never previously been documented for an artisanal fishery in PNG. This finding has important economic and sociological implications. Furthermore, the severity of the decline is emphasized by the logarithmic nature of the relationship. Fishermen living more than 10 to 15 kilometers from Kavieng need a substantial catch to make landing fish at the GFPC worthwhile.

The data considered here refer only to finfish and not to invertebrates. Certain villages such as Tome are known to produce large quantities of cockles (*Anadara* sp.) and mudcrabs (*Scylla serrata*), although they produce very little finfish (Table 4). Wright *et al.* (1983) estimated that 8.4 t of spiny lobster (*Panulirus* spp.) and 7.6 t of mudcrab are harvested annually from the reefs and mangrove areas adjacent to Kavieng. Fish production may therefore be affected by the harvesting of other marine resources which offer a better economic return.

A major problem with a study of an artisanal reef fishery is the lack of estimates of catch per unit of effort (CPUE). Average CPUEs for various gears used in the Tigak Islands have been estimated independently by Wright and Richards (1985). Station records do not detail the number of fishermen contributing to the catch, the period spent fishing or the fishing gear used.

For fisheries analysis, catch per unit effort (CPUE) would be a much more appropriate statistic than the size of the landed catch for assessing changes within the fishery. Collection of these data, therefore, would mean adopting a more suitably designed receipt book that would include a measure of the weight contributed by the 5 main fish families in the catch and the number of fish contributing to each family group. Species groupings obviously would be preferred but as the primary function of the PPD is to serve as an economic record of the purchase, further demands for data would possibly result in confusion among depot staff.

The general picture of finfish utilization gained from these data for the Tigak Islands is that of a lightly exploited fishery. The average commercial artisanal landed catch from 1970–1982 was 23.3 t/yr. Wright and Richards (1985) calculated the subsistence production for the Tigak Islands as 12.4 t/yr which gives a total accountable finfish production of 35.7 t/yr. The size of the catch sold at the Kavieng Market or trade stores is unknown. The total reef area of the Tigak Islands to a depth 30 m is 20,765 hectares and virtually the entire artisanal and subsistence catch comes from within these depths (Wright *et al.* 1983; Wright and Richards 1985). The yield of finfish during the years 1970 to

1982 was approximately 1.72 kg/ha. This is very small when compared with the Daugo Island reef fishery in Port Moresby where yields approach 80 kg/ha (Lock 1986a, b and c).

However, the present yields from the Tigak Islands fishery are likely to be more typical of reef fisheries throughout PNG. The observed generally large size of fish in all species groups and the high proportion of predators in the catch suggests that the fishery is still exploited at low levels and that production from the Tigak Islands is effort limited rather than resource limited.

ACKNOWLEDGEMENTS

We thank Mr Yarang Kurtama who summarized the original raw data, the Copra Marketing Board which provided the information on copra prices, the PNG Government Bureau of Statistics for other data and Mr John Hampshire for the advice on economic analysis. We are also grateful to Mr Graeme Brown of the South Pacific Commission for statistical advice and to two anonymous referees whose comments contributed significantly to the final form of the paper.

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GERMINATION OF CASSOWARY EGESTED AND MANUALLY DEFLESHED FRUIT

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ABSTRACT

The germination of seed of seven tree species collected from the droppings of the dwarf cassowary, Casuarius bennetti picticollis, *was compared with the germination of fresh fruit and manually defleshed seed of the same species. For four species,* Flacourtia zippelii, Garcinia latissima, Cryptocarya *sp. and* Prunus *sp., removal of the flesh, either manually or by passage through the gut of the cassowary, significantly enhanced germination of the seed compared with intact fruit. No germination was recorded for any of the seed or fruit of the three* Elaeocarpus *spp. tested. The implications of these results are discussed in terms of rainforest regeneration following logging.*

INTRODUCTION

For plants dependant upon seed dispersal by animals, satisfactory dispersal is achieved through dependable animal visitation and removal of fruit, non-injurious treatment of the seed by the animal vector, and evacuation or regurgitation of the seed at some distance from the parent plant (McKey 1975). Seeds adapted for animal dispersal should germinate poorly unless passed through a vertebrate digestive tract (McKey 1975). Very few studies have compared germination of fresh seeds with those evacuated by a dispersal agent (Krefting and Roe 1949; Rick and Bowman 1961; Noble 1975; Stocker and Irvine 1983). One difficulty is the collection of faecal material from a known source.

Cassowaries, which are large flightless frugivorous birds found in the rainforest of New Guinea and northern Australia, produce sizeable, readily identifiable droppings. The dwarf cassowary, *Casuarius bennetti picticollis*, which inhabits mainly montane rainforest in New Guinea, eats fleshy fruits, the seeds of which are evacuated intact soon after they are consumed (Pratt 1983). Working on Mt. Missim, in the Bulolo-Wau area, Pratt identified 36 species of fruit from seeds in cassowary droppings. Certain species appeared to depend on the cassowary for dispersal away from the parent tree (Pratt 1983).

Very little is known about the germination of seeds after passage through the cassowary gut, although Stocker and Irvine (1983) have shown that seed viability is retained after passage through the cassowary digestive tract. In this study, the germination of seeds from dwarf cassowary droppings collected in April 1984 is compared with that of fresh fruit of the same species. A further collection of fruit of several of these species was made to test germination of fruit from which the flesh had been removed manually.

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METHODS

Twenty-one droppings were collected from a number of sites between 1600 m and 2600 m above sea level (a.s.l) on the western slopes of Mt. Missim, to the east of Bulolo and Wau, during the week of 7th to 13th April 1984. Seeds in the droppings were identified at the time of collection, and fresh fruit of these species were collected from the ground below fruiting trees at the same site. An additional collection of fresh fruit for some of the species was made in May 1984 between 1600 m and 2300 m a.s.l. Each species was collected from the same altitude as that of the first collection. This second collection of fresh fruit had the flesh removed manually using only the thumb and fingers, in order to minimise the chance of damaging the seed coat. In the case of two species, recorded as *Elaeocarpus* sp. A and *E.* sp. B, this involved soaking the fruit in water for 18 hours before the flesh could be removed.

For each species, the size of fruit and seeds was measured. Fresh fruit, seeds from droppings, and seeds from which the flesh had been removed manually were sown in batches of one to ten (depending on size) on one percent water agar, in plastic petrie dishes (Table 1). In this way, seed development could be observed with minimum disturbance. The covered dishes were placed in plastic bags, which were then sealed to prevent the agar from drying out, and placed on a laboratory bench at 25 °C. Germination was checked at approximately weekly intervals at which time petrie dishes were taken from the plastic bags for aeration.

RESULTS

Seven plant species were identified from seeds in the twenty-one droppings. These are listed in Table 2 which also shows the sizes of fruit and seed. Six droppings contained a single fruit

Table 1.–**Sample size for faecal, fresh and defleshed seeds.**

Species	Faeces	Fresh	Defleshed
	a[1] b[2]	a[1] b[2]	a[1] b[2]
Elaeocarpaceae			
Elaeocarpus sp. A	4 × 2 5 × 2	4 × 2 3 × 2	5 × 2
Elaeocarpus sp. B	4 × 3	4 × 3	5 × 4
Elaeocarpus sp. C	20 × 2	20 × 4	20 × 2
Flacourtiaceae			
Flacourtia zippelii	10 × 4	10 × 2 9 × 2	10 × 9
Guttiferae			
Garcinia latissima	2 × 1 1 × 1	1 × 5	4 × 1 3 × 2 2 × 2
Lauraceae			
Cryptocarya sp.	10 × 4	11 × 2 10 × 2	—*
Rosaceae			
Prunus sp.	6 × 2	7 × 2	—*

a[1] = Number of seeds per petrie dish
b[2] = Number of replicates
* = Fresh fruit not available at second collection.

species, five of these contained only *Flacourtia zippelii* seed and one contained only *Elaeocarpus* sp. C seed. These species were not found in conjunction with others in the remaining droppings which contained two or more species.

After 28 weeks, no germination was recorded for the three *Elaeocarpus* spp. For the four other species, percentage germination of seed taken from the faeces was greater than percentage germination of fresh fruit (Figure 1). For the two species tested (*F. zippelii* and *G. latissima*), the percentage germination of seed from faeces was similar to that for defleshed seed (Figure 1).

Seeds which had passed through the cassowary digestive tract, and manually defleshed seeds germinated more quickly and had a higher germination than those of fresh fruit. For *F. zippelii*, the first germination of egested and manually defleshed seeds was recorded within 12 days of sowing. Although germination of fresh fruit for this species was also good (42 percent by the twelfth week after sowing), it was relatively slow, with the first germination being recorded at day 32 (Figure 1a). For *G. latissima*, both egested and manually defleshed seeds commenced germination by day 26, but there was no corresponding germination of fresh fruit (Figure 1b). For *Cryptocarya* sp. and *Prunus* sp. only egested seeds and fresh fruit were available (Table 1). Very rapid germination took place for egested *Cryptocarya* sp. seed, and 72.5 percent of seed germinated in the first 12 days after sowing. Fresh fruit of *Cryptocarya* sp. showed poor germination (eight percent at 28 weeks after sowing), and two of the three fruit which germinated had had the flesh partly removed prior to collection (Figure 1c). All the egested *Prunus* sp. seeds germinated by day 32, whereas no fresh fruit germinated during the 28 weeks following sowing (Figure 1d). The flesh of all fresh fruit was in poor condition by week 28 since it had been broken down by insects which were present in the fruit at the time of collection, and by saprophytic micro-organisms.

DISCUSSION

The results indicate that for those species which germinated in the trial, viability was not lost by the passage of seeds through the cassowary digestive tract. On the contrary, germination was enhanced when compared with fresh fruit. The effects of passage through the cassowary gut could be reproduced *in vitro* by the manual removal of flesh from fresh fruit. The dwarf cassowary as a dispersal agent thus fulfilled at least one of McKey's

Table 2.–**Fruit species in dwarf cassowary droppings from Mt. Missim, and the dimensions of fruit and seed collected from the droppings.**

	Fruit (mm)	Seed (mm)
Elaeocarpus sp. A	40–45 × 30–33	35 × 22
Elaeocarpus sp. B	45–50 × 30	33 × 22
Elaeocarpus sp. C	12–15 × 9–12	9–12 × 7–9
Flacourtia zippelii	25–30	15–25
Garcinia latissima	55–70 × 50–60	45–50 × 35
Cryptocarya sp.	23 × 15	15 × 12
Prunus sp.	35	25

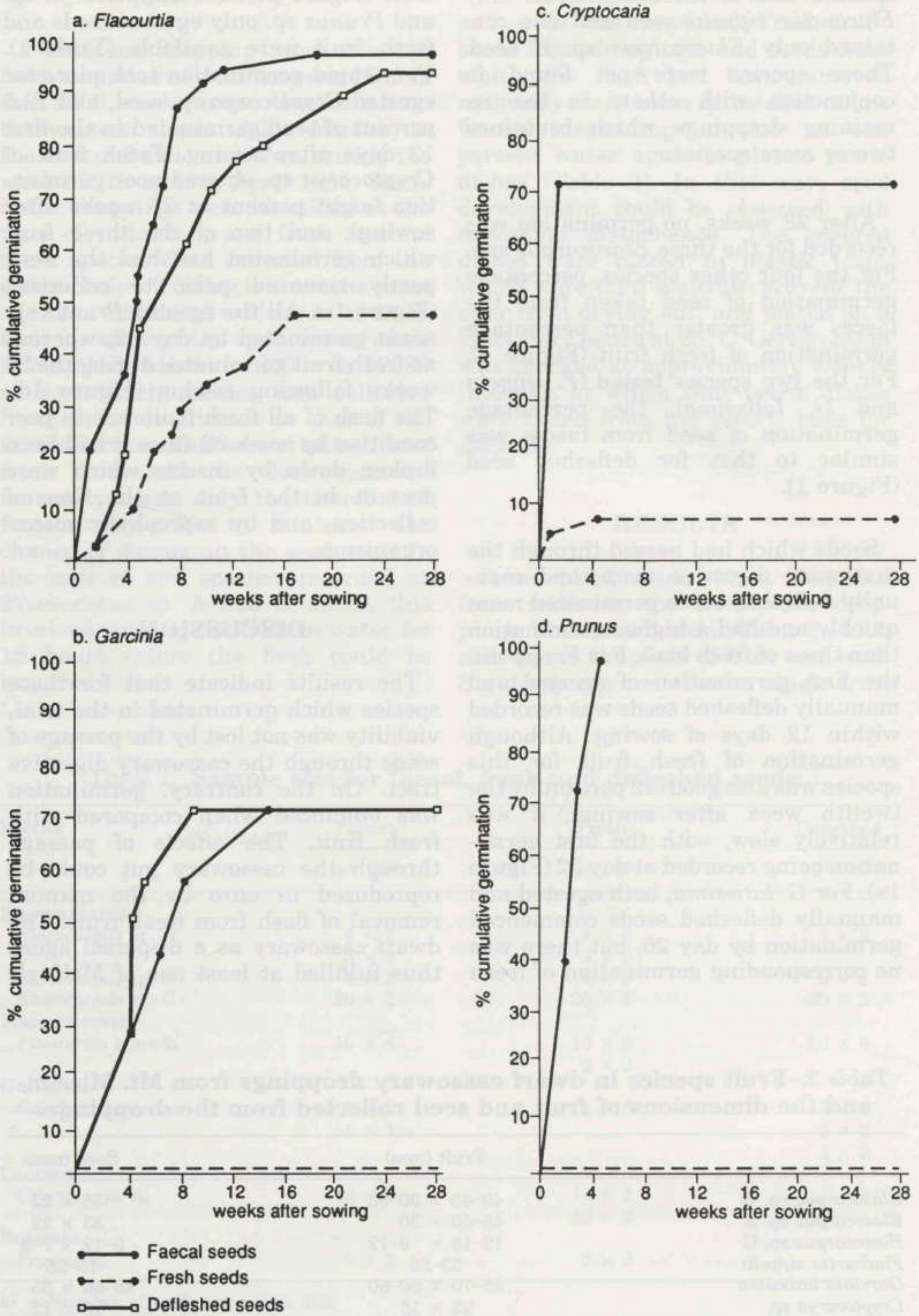

Figure 1.-**Germination of fresh, faecal and defleshed seeds of 4 species.**

(1975) postulates, namely the non-injurious treatment of the seed by the animal vector. Because enhanced germination appeared to depend simply on the physical removal of the flesh from the fresh fruit, agents other than the cassowary, such as insects, other small invertebrates, and microorganisms, may produce the same effect, although this has not been tested. As well as enhancing germination, the cassowary also disseminates seeds away from the parent tree (Pratt 1983). As tropical seeds of mature stage forests may quickly lose their viability (Hopkins *et al.* 1976), timing may also be a critical factor with regard to the removal of the flesh.

Two species which were identified in this study, *Prunus* sp. and *Flacourtia zippelii*, are new food records for the dwarf cassowary. They were not recorded by Pratt (1983) although Stocker (1983) identified *Prunus tunerana* as a species in the diet of the double-wattled cassowary (*C. casuarius*) in North Queensland. The size of Pratt's (1983) study site (6 ha) may have precluded him finding some species which were present on the transect from 1600 m to 2600 m a.s.l in this study.

Stocker (1983) stated that the germination of manually defleshed seeds appeared to be similar to the germination of cassowary egested seeds, as was the case in the present study. However, he did not state whether the germination of fresh fruit was tested. The poor germination which Stocker (1983) recorded for two *Elaeocarpus* species and the good germination for *Prunus tunerana* accords well with the results obtained in this study. De Vogel (1980) has similarly reported poor to fair germination for several *Elaeocarpus* species, and the absence of any germination of the *Elaeocarpus* seed in this study may reflect a long dormancy period.

Current forestry research in Papua New Guinea includes the study of regeneration after logging. The implications of this and other studies (see McKey 1975 for review) are clear. For certain secondary regrowth and many mature phase rainforest plant species, dispersal and germination depend on vertebrate agents such as birds. Hopkins *et al.* (1976) imply that 50 or more years after logging are necessary before mature phase species regeneration becomes effective. The adjacent rainforest or seed source must, therefore, be sufficiently large to maintain a viable breeding population of known dispersal agents over such a period of time. In Papua New Guinea, very little work has been undertaken to identify either the tree species dependent on animal vectors, or the animals which disperse their seeds, although some work has been done by Diamond *et al.* (1977). Accordingly investigations into these aspects of dispersal should be a part of current research on natural regeneration after logging, so that logging techniques can be modified if animal vectors are found to play a significant role in the regeneration of the New Guinea rainforest.

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EFFECT OF TARO LEAF BLIGHT ON LEAF NUMBER

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ABSTRACT

*Leaf blight (*Phytophthora colocasiae *Racib.) of taro (*Colocasia esculenta *(L.) Schott) causes a reduction in leaf number compared with healthy control plants. The proportional reduction in leaf number provides a partial disease index if the time when the disease becomes established in the crop is fixed. The reduction in leaf number, after equilibration, is directly proportional to the number of leaves on healthy plants, which varies over the crop cycle. This has implications for the design of disease management strategies involving intervention during the growing season.*

INTRODUCTION

Taro (*Colocasia esculenta* (L.) Schott) is important as a staple subsistence food crop in many of the lowland areas of Papua New Guinea. It is commonly grown in traditional gardens following a long bush fallow (5–25 years) and may be inter-cropped with many other species. Purchased agricultural inputs are rarely used. Leaf blight, caused by the fungus *Phytophthora colocasiae* Racib., is a serious disease of taro in Papua New Guinea, although the annual loss of yield which may be attributed to it is not yet known.

Previous work at the Lowlands Agricultural Experiment Station (LAES) in East New Britain (Cox and Kasimani 1988) has clearly demonstrated that taro leaf blight can be effectively controlled by fortnightly sprays with 0.3 per cent Ridomil plus 72WP (12 per cent active ingredient metalaxyl, 60 per cent active ingredient copper; Ciba-Geigy AG). The use of Ridomil plus in this way should not be dismissed simply because it is a purchased input. The ability to control taro leaf blight is a useful tool for research purposes: to help identify taro cultivars with differences in resistance to the disease (by being able to grow taro in the presence and absence of leaf blight); and to explore the way in which the yield loss caused by leaf blight is caused (by being able to regulate the amount of the disease in the crop at different stages of crop development).

The measurement of leaf area has been an important aspect of previous work on taro leaf blight (*e.g.* Jackson *et al.* 1980) since the effect of leaf blight on yield has been interpreted in terms of a reduction in leaf area. Chapman (1964) showed that the area of a *Xanthosoma sagittifolium* leaf could be estimated by the relationship:–

$$y = c_1 + c_2ab^2 \qquad (1)$$

where y = leaf area

a = distance from the sinus to the leaf tip

b = distance from the sinus to the tip of the basal lobes

c_1, c_2 are constants.

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This method was used by Jackson *et al.* (1980) in their study of the effect of fungicides on the development of leaf blight. It was also used by Caesar (1980) in his study of the growth and development of *Xanthosoma* sp. and *Colocasia* sp. under different light and water conditions. The method is slightly different for *Colocasia esculenta* because the leaf sinus and the point of insertion of the petiole are not coincident. Either may be used as a reference point for leaf measurements. Nevertheless, the equation is dimensionally inconsistent: the left hand side has the dimensions of area (L^2), but the right hand side is a volume (L^3).

Bourke *et al.* (1976) have pointed out that the area of a taro leaf can be estimated from the square of the single linear dimension "a" of equation (1) above, and this procedure has been used by Bourke and Perry (1976) in their study of the influence of sett size on the growth and yield of taro. There is little evidence of allometric growth. The use of a single measurement appreciably reduces the amount of work involved in leaf area estimation and thus the cost of measurement.

Gollifer and Brown (1974) attempted to define a disease index for taro leaf blight using a field assessment key for estimating the percentage of the leaf area damaged by the disease. The amount of disease was assessed on each fully expanded leaf and the mean disease rating for each plant was calculated by dividing the sum of the assessments for each leaf by the total number of leaves examined.

Leaves are produced at the top of the plant axis and appear to move down it as they are displaced by new ones. The severity of the disease on each leaf increases as it ages and the longer it has been exposed to the fungus. It can be misleading to average the disease scores on different leaves unless there is a constant proportional relationship between the severity of the disease at different levels within the plant canopy, and a constant number of leaves per plant in each sample. This is because if any plant has more leaves than the others, its mean disease score will be disproportionately weighted by leaves at the bottom of the plant axis which are more severely affected by the disease.

It may be possible to assess the disease on a single specified leaf (*e.g.* the second fully-expanded leaf, counting from the top). However, the index suggested by Gollifer and Brown (1974) omits consideration of the most important effect of the disease: the total loss of leaves at the base of the plant. A disease score summed over all the available leaves would underestimate the level of disease in severely affected plants since they have fewer leaves.

The total number of leaves lost at the bottom of the plant is more directly related to yield loss than partial loss of effective leaf areas further up the axis, although the latter could be used as a proxy variable. The relationship between the two would need to be determined by experiment for each cultivar (since different cultivars have different numbers of leaves) in the same way that the leaf area model has to be calibrated for each cultivar because leaves of different cultivars have slightly different shapes.

Previous attempts to define a disease index for taro leaf blight have thus been either excessively elaborate (estimation of total leaf area using an overparameterised model, and correction for areas damaged by blight) or trivial (because the index can not be related to variation in yield). In this paper, the effect of leaf blight on the number of leaves which the taro plant can support is examined.

MATERIALS AND METHODS

Setts of the taro cultivar 'K264' were planted at 0.8 m × 0.8 m spacing in a randomized complete block design with five replications of four treatments (30 plants/plot). The site was newly-cleared secondary bush at LAES. Growth and yield data were recorded on the central 12 plants of each plot. An additional guard row of *Xanthosoma sagittifolium* ("kongkong" or "singapore" taro), which is a more vigorous plant species not affected by taro leaf blight, was used to separate the plots. This helped to restrict the movement of inoculum between plots.

Damage by taro beetle (*Papuana* sp.) was partly controlled using two applications of Lindane granules (6 per cent hexachlorocyclohexane, HCH), at planting and at 49 days after planting (DAP) (1 g/plant). No fertilizer was applied. The plants were sprayed twice with 0.5% Ridomil plus 72WP, at 48 DAP and at 55 DAP to eliminate any natural blight infection. When the plants were assessed at 69 DAP none showed any blight symptoms.

The four treatments were labelled "A", "B", "C" and "D". Treatments A, B and C were inoculated with a zoospore suspension of *P. colocasiae* at 78 DAP, 105 DAP and 133 DAP respectively. Treatment D was an uninoculated control plot. Treatments B, C and D were sprayed fortnightly after planting with 0.3% Ridomil plus 72 WP, except that the final spray of treatments B and C preceding inoculation was omitted. Treatment B was sprayed once, treatment C three times, and treatment D nine times.

The plants were scored for the number of leaves on the main stem and the presence or absence of blight (+/−) approximately every 3 weeks starting at 43 DAP. On each occasion, the top leaf of each plant was tagged with a loop of string so that the rate at which new leaves were produced, and old ones lost, could be determined. The main corms were harvested at 235 DAP.

RESULTS

In general, the number of leaves per plant in each of the plots increased at a similar rate until spraying with fungicide was stopped and the plants were inoculated (see Table 1). Following inoculation, the number of leaves

Table 1.–**Mean number of taro leaves per plant (n=60) at different days after planting. The treatments are different times of inoculation with taro leaf blight.**

Days after planting	Days after planting until inoculation (no. leaves/plant)			
	78	105	133	no inoculation (1)
43	2.69a (2)	2.78a	2.82a	2.73a
69	3.58a	3.50a	3.39a	3.57a
89	3.44b	4.30a	4.06ab	4.38a
110	3.14b	4.42a	4.25a	4.27a
131	2.48bc	2.38b	3.17ac	3.50a
152	2.41b	2.30b	2.65ab	2.97a
174	2.45b	2.35b	2.63b	3.65a
196	2.27b	2.12b	2.35b	3.02a
216	1.85b	1.93b	1.97b	2.53a

(1) Uninoculated plots were sprayed with 0.3% Ridomil plus 72 WP at fortnightly intervals
(2) In each row, means followed by a common letter are not significantly different (P > 0.01) using Duncan's Multiple Range Test

per plant declined until an equilibrium rate of leaf loss was achieved within 3–6 weeks. After the equilibration period, the number of leaves per plant in all treated plots was similar irrespective of the time of inoculation, and significantly below that for the control plots.

The effect of leaf blight was to reduce the number of older leaves at the bottom of the plant axis (see Table 2). Leaf blight had no effect on the rate of leaf production. The reduction in the number of leaves caused by blight (y) at different times during the crop cycle is directly proportional to the number of leaves which a healthy plant has at that time (x):

$$y = -0.28 + 0.33x \quad (2)$$
$$(r = 0.72, n = 7, P < 0.05)$$

At harvest, the yield was significantly reduced ($P < 0.01$) in all the inoculated plots (see Table 3). The yields from inoculated plots were not significantly different from each other,

Table 2.–**Comparison of the number of top and bottom leaves in unsprayed and leaf blight diseased and ridomil sprayed taro plants. Top leaves are those higher on the plant axis than a tag attached three weeks previously; bottom leaves are those below and including the tagged leaf.**

	Leaves	Days after planting until inoculation (no. leaves/plant)							
		69	89	110	131	152	174	196	216
Sprayed	total(1)	3.57	4.38	4.27	3.50	2.97	3.65	3.02	2.53
	top	3.31	2.20	2.24	2.17	1.58	2.03	1.70	1.25
	bottom	0.32	2.28	2.00	1.35	1.37	1.64	1.32	1.29
Diseased	total(1)	3.58	3.44	3.14	2.48	2.41	2.45	2.27	1.85
	top	3.26	2.26	2.41	2.12	1.66	1.97	1.57	1.22
	bottom	0.39	1.28	0.78	0.46	0.79	0.48	0.71	0.66
(sprayed − diseased)	top	0.05 ns(2)	−0.06 ns	−0.17 ns	0.05 ns	−0.08 ns	0.06 ns	0.13 ns	0.03 ns
(sprayed − diseased)	bottom	−0.07 n.s.	1.00 ***	1.22 ***	0.89 ***	0.58 ***	1.16 ***	0.61 ***	0.63 ***
% reduction		—	23	29	25	20	32	20	25

(1) The sum of the top and bottom leaves may not equal the total number of leaves as some leaves above the tag were dead.
(2) ns = non-significant ($P > 0.05$; *** = $P < 0.001$

Table 3.–**Mean yield of taro corms following inoculation with taro leaf blight at different times.**

Time of inoculation (DAP)	Mean corm weight (g)	Yield (t/ha)
78	260	4.1
105	260	4.1
133	300	4.7
no inoculation(1)	392	6.1
L.S.D. (P = 0.01)	73.4	1.1

(1) Uninoculated plots were sprayed with 0.3% Ridomil plus 72 WP at fortnightly intervals.

although the yield from plots inoculated at 133 DAP was higher than the yields from plots inoculated at 78 DAP and 105 DAP.

DISCUSSION

The present experiment demonstrates the value of leaf number (rather than leaf area) for monitoring the progress of the disease. Leaf blight increases the rate at which older leaves disappear. Leaf number is easier, and thus less costly, to estimate than total leaf area (whether or not this is corrected for the loss of effective area around leaf blight lesions), and it is a direct measure of the major component of leaf area affected by the disease. The proportional reduction in leaf number per plant provides a partial disease index which is neither elaborate nor trivial.

The total number of leaves on healthy plants reflects the balance between the rate of leaf production at the top of the plant axis (dependent on intrinsic morphogenetic patterns and crop nutrition) and the rate of natural senescence. The rate of destruction of leaves by leaf blight depends on the age structure of the leaf population and the susceptibility of the host tissue to attack by leaf blight (both of which may vary between cultivars), and the presence of weather patterns (high rainfall, high humidity) favouring pathogen development.

However, it is clear from Table 1 that, following inoculation of a single cultivar at different times, the reduction in leaf number rapidly equilibrates. At harvest time, it is not possible to distinguish different disease progress curves simply from the number of leaves remaining.

The equilibrium rate of leaf fall was achieved within 3–6 weeks of inoculation. The very rapid rate of equilibration in leaf number per plant at the reduced level following inoculation at 105 DAP (treatment B), the drop in leaf number per plant in treatment C prior to inoculation, and the reduction in leaf number per plant in the control plots between 120 DAP and 160 DAP all appear to have been related to heavy rainfall which occurred between 107 and 126 DAP. Some contamination from adjacent infected plots probably occurred slightly before C plots were inoculated, and at 131 DAP some plants in the sprayed (control) plots were also infected by leaf blight. By 152 DAP, the C treated plants had equilibrated at the lower leaf number and the disease in the control plots had been eliminated by the routine spray regimen. Leaf number per plant in control plots did not recover however until 174 DAP. Although this temporary loss of control in the experiment might have reduced slightly the apparent rate of yield loss generated by the disease, it does serve to emphasise the intrinsic stability of the taro-leaf blight system.

The high correlation between the number of leaves lost to blight and the number of leaves on plants kept free from disease by routine application of Ridomil plus has important implications for the design of disease management strategies involving intervention during the growing season, for example through the use of fungicides.

During the first two months of the crop cycle, there are few leaves (from zero to three) and there is little blight damage. Leaf numbers then rapidly increase and remain high throughout the main part of the season, subsequently declining as the crop approaches maturity. Thus, the potential rate of yield accumulation is greatest during mid-season when leaf numbers are highest. The potential for reduction in leaf number caused by blight is also highest at that time.

In areas where taro leaf blight is endemic, pesticide use should be concentrated in the period of maximum leaf number (2–5 months after planting in a 7 month crop). Treatment before two months will have little effect if the crop becomes infected later. Treatments applied during the last two months of the crop cycle will also have a comparatively slight effect on yield because (1) the potential rate of yield loss accumulation is much lower during this period, and (2) the final sprays applied during the main part of the growing season will have a residual protective effect. Restriction of fungicide cover to the middle of the growing season will reduce the total number of spray applications required to achieve a worthwhile yield response, although the final level of disease in the crop at harvest may be indistinguishable in treated and untreated plots.

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CONTROL OF TARO LEAF BLIGHT USING METALAXYL: EFFECT OF DOSE RATE AND APPLICATION FREQUENCY

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ABSTRACT

*Metalaxyl (as Ridomil plus 72WP) was used to control leaf blight (*Phytophthora colocasiae *Racib.) of taro (*Colocasia esculenta *(L.) Schott) using a knapsack sprayer. A quadratic dosage-response curve is suggested. The technical optimum response occurs at 0.2 per cent Ridomil plus, using a fortnightly spray regimen. Five applications of 0.3 per cent Ridomil plus, at 3-weekly intervals during the middle of the growing period, can more than double the yield. The responses of yield to dose rate and application frequency are interpreted in terms of (1) the effect of Ridomil plus on the number of leaves per plant, (2) the proportion of plants exhibiting symptoms of blight, and (3) a phytotoxic effect.*

INTRODUCTION

Taro (*Colocasia esculenta* (L.) Schott) is an important staple subsistence food crop in many lowland areas of Papua New Guinea. Taro leaf blight (TLB), caused by the fungus *Phytophthora colocasiae* Racib., is one of the most serious of the diseases of taro in Papua New Guinea (Cox and Kasimani 1990).

Previous work at the Lowlands Agricultural Experiment Station (LAES) in East New Britain (Cox and Kasimani 1988) has shown clearly that TLB can be effectively controlled by fortnightly sprays of 0.3 per cent Ridomil plus 72WP (12 per cent active ingredient metalaxyl, 60 per cent active ingredient copper; Ciba-Geigy AG). We used this dose rate in our initial experiment because it was the same as that recommended in Papua New Guinea for controlling black pod in cocoa which is caused by a similar organism, *Phytophthora palmivora*. In this paper, we describe the effect of varying (1) the dose rate, and (2) the application frequency of Ridomil plus.

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MATERIALS AND METHODS

Two field plot experiments were carried out at LAES. Setts of the taro cultivar, K264, were planted at 0.8 m x 0.8 m spacing in a randomized complete block design with five replications of four treatments (30 plants per plot). Growth and yield data were recorded on the central 12 plants of each plot. An additional guard row of *Xanthosoma sagittifolium*, which is not affected by *P. colocasiae*, was used to separate the plots.

The progress of the disease was followed at 3-weekly intervals by (1) counting the number of leaves on the main stem, and (2) noting the presence or absence of leaf blight lesions on each plant.

Experiment 1: effect of dose rate

All plants in all plots were inoculated by spraying with a zoospore suspension of *P. colocasiae* at 36 days after planting (DAP). Metalaxyl (as Ridomil plus 72WP) was applied at three dose rates: 0.1, 0.2 and 0.3 per cent product (0.15, 0.30 and 0.45 kg per hectare active ingredient metalaxyl). The fourth treatment was an unsprayed control. Cittowett spreader/sticker (BASF) was added to the tank mixture at 3 ml per 12 litres. All sprays were applied using a hand-pumped knapsack sprayer with a fine nozzle. The taro was sprayed at 2-weekly intervals starting at 38 DAP. The plants were scored starting at 35 DAP. The main corms were harvested at 246 DAP.

Experiment 2: effect of application frequency

All plants were inoculated by spraying with a zoospore suspension of *P. colocasiae* at 41 DAP. The treatment plots were sprayed with 0.3 per cent Ridomil plus 72WP using a knapsack sprayer with a fine nozzle. Cittowett spreader/sticker (BASF) was added to the tank mixture at 3 ml per 12 litres. Treatment A was sprayed twice (at 49 and 56 DAP); treatment B was sprayed 5 times (49, 70, 92, 112 and 134 DAP); treatment C was sprayed 7 times (49, 63, 77, 92, 105, 119 and 134 DAP); D plots were not sprayed (untreated control). The plants were scored starting at 48 DAP and the main corms were harvested at 259 DAP.

Partial control of taro beetle (*Papuana* sp.) was achieved using three applications of Lindane granules (6 per cent hexachlorocyclohexane, HCH; 1 kg active ingredient per hectare) at planting, 41 DAP and 134 DAP. A top-dressing of nitrogen (225 kg N per hectare as urea) was applied at 58 DAP.

RESULTS

Experiment 1

An analysis of variance (ANOVA) of the harvest data demonstrated a significant effect of treatment with Ridomil plus ($P < 0.001$) but failed to distinguish between the different dose rates ($P > 0.05$) (see Table 1). However, if the rate effect is decomposed into linear and quadratic components, both are significant ($P < 0.001$). The data suggest the existence of a quadratic dosage-response curve.

This relationship was explored using multiple regression analysis. The mean corm weight (Y) was related to the dose rate of Ridomil plus (X) by the second order polynomial:–

$$Y = 309 + 4105\,X - 10525\,X^2, \quad R^2 = 0.98$$
$$\text{S.E.:}\quad (26)\quad (417)\quad (1330)$$

The increase in corm weight following application of Ridomil plus to diseased plants was associated with an increase in leaf number (see Table 2). Although plots treated with 0.2 per cent Ridomil plus had slightly greater mean cumulative leaf number per plant throughout the later stages of crop growth (after the disease had become established in the crop), the differences between the Ridomil treatments were not significant ($P > 0.05$). The reduced efficacy of 0.1 per cent Ridomil compared with the higher dose rates is shown by the greater proportion of infected plants (see Table 3).

Experiment 2

This experiment again demonstrated the significant effect ($P < 0.05$) on the yield of taro of Ridomil plus treatment in the presence of leaf blight (see Table 4). The relationship was explored using multiple regression analysis.

Table 1.–**Mean corm weight of taro (n=60) following application of Ridomil plus 72WP at different dose rates at fortnightly intervals (Experiment 1).**

Treatment	Mean Corm Weight (g)
unsprayed control	303
0.1% Ridomil plus	632
0.2% Ridomil plus	691
0.3% Ridomil plus	599
S.E.D.	46.8

Table 2.–**Effect of the application rate of Ridomil plus (per cent) on the mean number of leaves per plant (n=60) at different times during the crop cycle (Experiment 1).**

	Ridomil plus dose rate				
DAP*	0	0.1%	0.2%	0.3%	LSD
35	2.3	2.7	2.8	2.7	0.46
56	3.2	4.3	3.9	3.8	0.61
77	3.1	4.4	4.1	4.2	0.76
98	2.5	4.7	4.7	4.6	0.61
140	3.3	4.0	4.2	4.1	0.27
161	2.2	4.2	4.6	4.4	0.60
182	2.9	3.4	3.6	3.5	0.51
203	2.7	3.4	3.4	3.1	0.70

* Days after planting
LSD = Least Significant Difference (P = 0.01)

Table 3.–**Effect of the application rate of Ridomil plus on the percentage of taro plants showing blight symptoms (n=60) at different times during the crop cycle (Experiment 1).**

DAP*	Dose Rate: 0	0.1%	0.2%	0.3%
35	2	7	0	0
56	82	7	2	2
77	100	18	0	0
98	100	37	3	2
140	90	15	0	0
161	100	38	5	0
182	63	25	2	7
203	70	20	0	0
Mean	76	21	2	1

* Days after planting

The mean corm weight (Y) was related to the number of fungicide applications (X) by the third order polynomial:–

$$Y = 269 + 36.4\ X^2 - 4.45\ X^3, \quad R^2 = 0.997$$
$$\text{S.E.:}\ (15.8)\quad (2.75)\quad (0.387)$$

The exclusion of the linear term from this equation is theoretically justified because of the uneven pesticide cover achieved with the use of only two sprays close together, compared with five or seven equally spaced applications

As in Experiment 1, the increase in mean corm weight following Ridomil plus application to diseased plants is associated with an increase in leaf number (see Table 5), and a reduction in the proportion of plants showing symptoms of leaf blight (see Table 6).

DISCUSSION

These experiments confirm the previous work by Cox and Kasimani (1988) on the effectiveness of Ridomil plus application using a knapsack sprayer for the control of taro leaf blight. As they suggested, it appears that the dose rate of Ridomil plus can be reduced from 0.3 per cent to 0.2 per cent (using a fortnightly spray regimen) whilst maintaining effective control of the disease. The data presented here support the theoretical notion of a quadratic dosage response curve which reflects diminishing marginal returns to increasing dose rate, with negative marginal returns above a dose rate of about 0.2 per cent. The technical optimum dose rate, obtained by differentiation of the regression equation, is close to 0.2 per cent (0.195 per cent).

Although the overall response to Ridomil plus application is associated with an increase in leaf number per plant, in accordance with our present understanding of the principal effect of leaf blight on the taro plant (Cox and Kasimani 1990), this does not account for the distinct curvature of the response surface in the neighbourhood of the technical optimum. The lower yield of plants receiving 0.1 per cent Ridomil plus can be explained by the greater proportion exhibiting symptoms of leaf blight. Although sufficient to prevent loss of leaf number, the lower dose rate is not sufficient to prevent infection and the concomitant reduction in the effective area of the leaves that remain. The reduction in yield to the right of the technical optimum, although again associated with a non-significant reduction in leaf number per plant, may be evidence of a direct phytotoxic effect.

Thus using Ridomil plus at 0.2 per cent is better than 0.3 per cent (lower direct costs, greater yield response) using a 2-weekly spray schedule. Fine tuning of the dose rate between 0.1 per cent and 0.2 per cent does not appear to be feasible given the variation in potential yield, levels of leaf blight and uniformity of spray cover which might be expected under normal field conditions. Dose rates below 0.1 per cent are unlikely to work effectively because of the substantial reservoir of inoculum remaining even using 0.1 per cent Ridomil plus.

It is clear from Experiment 2 that, in the presence of leaf blight, the mean corm weight of taro can be doubled by as few as five applications of 0.3 per cent Ridomil plus 72WP. The timing of these applications is important. The use of only two sprays was partly successful in that a low level of disease was achieved for a short time: 36 days after the second spray, there was still no significant reduction in leaf number per plant compared with plots receiving additional spray applications (treatments B and C), although the percentage of plants exhibiting symp-

Table 4.–**Effect of the number of applications of 0.3 per cent Ridomil plus 72WP on the mean corm weight (n=60) of taro (Experiment 2).**

Number of sprays	Mean Corm Weight (g)
0	260
2	391
5	618
7	528
L.S.D. (P=0.05)	214

Table 5.–**Mean number of leaves per plant (n=60) at different times during the crop cycle in relation to the number of applied sprays of 0.3 per cent Ridomil plus 72WP (Experiment 2).**

DAP*	Number of sprays				LSD (P = 0.01)
	0	2	5	7	
48	4.0	4.3	4.0	3.9	1.3
69	2.7	3.5	3.4	3.3	0.36
92	2.1	3.3	3.6	3.7	0.58
111	2.3	2.6	3.2	3.4	0.63
134	2.5	3.1	4.2	4.1	0.82
175	2.7	2.7	3.3	3.3	0.60
195	2.3	2.3	2.1	2.2	0.74
217	2.4	2.4	2.2	2.4	0.32

* Days after planting

Table 6.–**Effect of different numbers of Ridomil plus applications on the percentage of taro plants exhibiting blight symptoms (n=60) at different times during the crop cycle (Experiment 2).**

DAP*	Number of sprays			
	0	2	5	7
48	60	80	83	85
69	90	8	33	10
92	93	65	40	5
111	7	40	10	0
134	93	95	0	0
175	92	95	67	50
195	85	85	75	62
217	85	72	80	70
Mean	84	68	49	35

* Days after planting

toms of leaf blight was much higher. Similarly, the number of leaves per plant following cessation of spraying in B and C plots was still significantly greater than in control plots 41 days later even though by this time (175 DAP) the proportion of plants with blight was increasing rapidly. The protective effect on leaf number lasted for at least 5-6 weeks. It may be longer in large plots where plants are not in the immediate vicinity of a reservoir of inoculum.

The differences between the percentage of infected plants in B and C plots suggest that the disease was more rapidly brought under control using a fortnightly rather than a 3-weekly spray regimen, and it increased more slowly following the withdrawal of pesticide cover. The total amount of Ridomil plus applied to C plots, which received seven sprays, was 40 per cent higher than the amount applied to B plots, which had five sprays.

Differentiation of the regression equation relating yield of taro to the number of spray applications indicated a turning point (the technical optimum) at about 5.5 spray applications. The curvature of the response surface to the left of the technical optimum (i.e. the lower yield of plants receiving two sprays compared with those receiving five) can be interpreted in terms of the effect of blight on leaf number after cessation of spraying. The reduced yield to the right of the optimum (plants receiving seven sprays) may be evidence of a direct phytotoxic effect. There is less disease in these plots as estimated by the percentage of infected plants but this is not translated into an increase in corm weight. This result is analogous to the reduced yield obtained in Experiment 1 using a 0.3 per cent solution when sprays are applied routinely according to a 2-weekly regimen. The existence of this effect also means that previous estimates of the potential yield loss associated with leaf blight (Cox and Kasimani 1988) need to be revised upwards slightly: in these experiments, leaf blight is shown to be capable of causing at least a 58 per cent reduction in taro corm weight.

There appears to be little value in inserting a sixth spray during the hypothetical 3-month critical period for spray application Cox and Kasimani (1988) as the technical optimum lies between five and six sprays, and by six applications the marginal productivity of further sprays is already negative. Also, the application interval has an integer quality: a spray interval which was not a multiple of a week would be hard to implement. Similarly, reduction of the number of sprays to four is probably unwise because (1) use of five applications is to the left of the technical optimum, (2) the third order nature of the response function indicates that the curvature of the response surface is very pronounced in the region between two and five applications, (3) the integer quality of the application interval is removed, and (4) even with five sprays, there is a substantial reservoir of inoculum. However, the equation is based on only four treatments. The interval between two sprays and five sprays is large, and the way in which the two sprays were applied (close together) was different from the way in which the five and seven sprays were applied (equally spaced).

An economic optimum cannot yet be defined for either the number of spray applications to use (i.e. the number which equates marginal revenue with marginal cost), or for the dose rate, because of lack of information about the valuation of subsistence output and the opportunity costs of labour and capital in subsistence production. However, if a farmer wishes to spray his taro crop with Ridomil plus on the basis of his own perception of the potential yield response and his own valuation of inputs and outputs, five applications of a 0.3 per cent solution at 3-weekly intervals during the early-middle part of the growing season, or fortnightly applications of a 0.2 per cent solution, can be suggested in areas where the disease is endemic. It should be noted that late infection, although not contributing substantially to yield reduction, might have other effects: (1) it is suggested by some farmers that leaf blight spoils the eating quality of the corm giving it a "bitter" taste, (2) it may contribute to the development of corm rot either in the ground or in storage, and (3) it means that the planting setts will be carrying over inoculum to infect the succeeding crop. These may justify additional measures for the management of the disease.

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t – tonne
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ml – millilitre
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m – metre
a.s.l – above sea level
yr – year
wk – week
h – hour
min – minute
s – second
K – kina
n.a. – not applicable or not available
n.r. – not recorded
var – variance
s.d. – standard deviation
s.e.m. – standard error of mean
s.e.d. – standard error of difference
d.f. – degrees of freedom

Levels of significance:
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★ – $0.01 \leq p < 0.05$
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