A REVIEW OF THE WORK ON PREDATORS, PARASITES AND PATHOGENS FOR THE CONTROL OF *ORYCTES RHINOCEROS* (L.) (COLEOPTERA: SCARABAEIDAE) IN THE PACIFIC AREA

by

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MISCELLANEOUS PUBLICATION No. 7
COMMONWEALTH INSTITUTE OF BIOLOGICAL CONTROL

COMMONWEALTH AGRICULTURAL BUREAUX
FARNHAM ROYAL, SLOUGH SL2 3BN, ENGLAND
OCTOBER 1974

First published in 1974
by the
Commonwealth Agricultural Bureaux
Farnham Royal, Slough SL2 3BN, England

Price £2.50

ISBN 0 85198 332 4.

This publication can be obtained
through any major bookseller
or direct from
Commonwealth Agricultural Bureaux, Central Sales, Farnham Royal,
Slough SL2 3BN, England

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INTRODUCTION

This review aims to summarise the literature on the biological control work carried out by Pacific Territories and Pacific-based organisations. The various control agents that have been introduced are evaluated and those recorded agents which have not been utilised but which appear promising, are noted for future study and perhaps introduction.

Since many of the reports on biological control work are in cyclostyled form, this review provides a guide to the available literature which is not found in abstracting journals. Some information has also been found in the correspondence files of the UN/SPC Rhinoceros Beetle Project.

SPREAD OF *ORYCTES RHINOCEROS* (L.) IN THE PACIFIC WITH NOTES ON EARLY ERADICATION CAMPAIGNS AND ATTEMPTS TO CONTROL IT

1910: Samoa

The Indian rhinoceros beetle, *O. rhinoceros*, was discovered in Apia, Western Samoa, having probably been introduced in 1909 in soil and vegetable refuse packed around rubber trees imported from Ceylon. No immediate attempt was made to exterminate the pest when it was first discovered and it soon spread over Upolu, Savai'i and to American Samoa, both Tutuila and Manu'a. Early attempts at control were by collecting larvae and beetles and by trapping beetles.

Ref. Doane, 1913.

1921: Keppel Island (Niuatoputapu)

The infestation on Keppel Island (area 6 sq. miles) was eradicated by 1929 as a result of a vigorous sanitation programme. It was believed by some people that the beetle was deliberately introduced to Keppel.

Ref. Dumbleton, 1952; Catley, 1965c.

1931: Wallis Island

Early attempts to eradicate *O. rhinoceros* by collection of larvae and destruction of breeding sites were unsuccessful. Little copra is exported from Wallis.

Ref. Cochereau, 1965.

1942: Palau Islands

O. rhinoceros was probably introduced by Japanese wartime shipping from South-east Asia. During the war it spread rapidly, palms killed by bombing and gunfire providing abundant breeding sites. A sanitation programme was not initiated until 1950.

Ref. Gressitt, 1953.

1942: New Guinea

O. rhinoceros was introduced into the Gazelle Peninsula of New Britain and parts of New Ireland during the Japanese occupation. It later spread to the Manus Islands.

1953: Tonga

O. rhinoceros was first discovered on Vava'u. It had probably been introduced in 1951 or earlier. An eradication campaign comprising the elimination of breeding sites, trapping and collecting beetles was promptly initiated but was not successful. The beetle became established in Tongatapu about 1960, and in the Ha'apai group in 1971.

1953: Fiji

The beetle was first discovered in Viti Levu in 1953 although it had obviously been present for some time since it had spread 70 miles in an east-west direction from Suva and 20 miles inland. It is possible that the beetle was introduced from Tonga as there were no quarantine regulations for ships from Tonga similar to those enforced for ships from Samoa. By 1959 the whole of Viti Levu was infested and some of the offshore islands also, in spite of vigorous quarantine aimed at preventing the beetle from spreading to the main coconut growing islands of Vanua Levu and Taveuni. By 1969 the beetle was on Taveuni and in 1971 it had spread to Rambi. In 1972 the beetle was found on Vanua Levu, and investigations revealed damaged palms in several widespread localities. The Fiji campaign illustrates the extreme difficulty of preventing the spread of the beetle between islands with frequent shipping connections.

Ref. O'Connor, 1953, 1955, 1957; Swaine, 1966.

1963: Tokelau Islands

O. rhinoceros was found at Nukunonu in July 1963. Although efforts were made to confine the infestation to the islet on which it was discovered the beetle has since spread to all islets in Nukunonu Atoll.

Ref. Anon., 1968b.

ATTEMPTS AT BIOLOGICAL CONTROL OF *O. RHINOCEROS* BY PACIFIC TERRITORIES

Samoa

1913: K. Friederichs travelled through the Eastern Tropics and Madagascar to find out why the rhinoceros beetle was not a severe pest in these areas. He concluded that lack of breeding sites due to sanitation was the main reason although in Ceylon the type of palm grown seemed resistant to the beetle.

Friederichs found *Metarrhizium anisopliae* (Metsch.) Sorokin in his beetle cultures in Samoa and he experimented with this pathogen as a field control by sprinkling spores on specially prepared compost heaps. He considered it to be a good controlling agent. He reported attempts to introduce the European mole, hedge-hog and *Carabis* sp. to Western Samoa. Although he noted that pigs were useful predators of grubs he did not consider natural enemies to be important controls. He thought that parasitic wasps and elaterid larvae were useful enemies and suggested the introduction of the parasitic wasps *Scolia carnifex* Coq. and *Scolia oryctophaga* Coq.

Ref. Friederichs 1913, 1918, 1919, 1920.

1939: H.W. Simmonds visited Java, Malaya and Mauritius to collect enemies of *Oryctes*. He found the carabid *Catascopus fascialis* Wied. under the bark of rotting rubber logs in Malaya and although he considered that *Catascopus* adults rarely penetrated into the wood deeply enough to come in contact with *Oryctes* grubs he sent 180 adults to Samoa of which 122 survived to be released. No recoveries have been made subsequently. He noted that *Oryctes* damage was severe where breeding sites were abundant and local officers were of the opinion that sanitation was the only measure holding this pest in check in Malaya.

In Mauritius and Madagascar Simmonds collected many

S. oryctophaga and 36 *Elis romandi* Sauss. He also collected a few *Scolia ruficornis* F. during a call at Zanzibar and, after testing it on *O. rhinoceros* in Malaya, considered it to have potential value as a control agent. Simmonds had difficulty in finding *Oryctes* grubs in Madagascar and correlated this with the presence of scoliids. However, he was there only one month. Simmonds sent 180 *S. oryctophaga* to Samoa by air and 150 survived to be released. Of another 216 wasps travelling by ship 62 were released together with one *E. romandi*. He suspected that *S. oryctophaga* might not establish in Western Samoa because of the lack of a cool season and indeed no recoveries of *S. oryctophaga* were ever made.

Simmonds also obtained a culture of *Metarrhizium* from Dutch scientists in Java and sent this culture to Samoa where it was spread on specially prepared heaps.

Ref. Simmonds, 1940, 1941; Lever, 1939.

1945: H.W. Simmonds went to Zanzibar and collected 465 adult female *S. ruficornis* for introduction into Samoa. In 1949 the parasite was recovered at one locality and has been found in restricted localities since then.

Ref. Simmonds, 1949.

American Samoa

Pachylister chinensis (Quens.) was sent from Western Samoa in 1956 and became established. *Bacillus popilliae* Dutky was distributed in 1958 against *Oryctes* and *Adoretus*.

Wallis Island

1952: A strain of *M. anisopliae* was introduced from the Argentine.

1959: F. Cohic placed about 130 *S. ruficornis* cocoons from the Palaus in specially prepared compost pits. A few wasps were seen flying at a later date. Cochereau (1965) reported that *S. ruficornis* was definitely established and he also noted a number of sick larvae possibly infected with *Metarrhizium*. He found that the two most important controlling agents of *O. rhinoceros* in Wallis were a "blue disease" and a lucanid beetle *Figulus foveicollis* Boisd. which would eat *O. rhinoceros* eggs and 1st instar larvae in the laboratory.

In 1965-66 Cochereau introduced the elaterids *Alaus montraveli* Montr. and *A. farinosus* Montr. from New Caledonia to Wallis. They have not been recovered.

Ref. Cochereau, 1965, 1970.

Palau Islands

1947 - 48 - 50: H. Compere, F.X. Williams and R.T. Abbott sent a total of 175 *S. ruficornis* from Zanzibar and East Africa, to the Palau Islands.

Ref. Gressitt, 1953; Pemberton, 1957.

1946 - 1948: T.R. Gardner went to Thailand, the Philippines and Malaya. He studied *Scolia patricialis* Burm. This would sting and paralyze *O. rhinoceros* in the laboratory and was assumed to be a parasite of the beetle. Gardner sent 110 female *S. patricialis* to the Palaus but only 2 survived to be released. No recoveries were recorded.

Ref. Gardner, 1947, 1948a, 1948b, 1953, 1957; Anon., 1963a.

1951: N.L.H. Krauss sent 25 adults of the histerid beetle *Placodes ebeninus* Lew. from Tanganyika to the Palaus. The beetles were collected from decaying sisal bases feeding on larvae of the sisal weevil. Krauss also sent 600 *S. ruficornis* from Zanzibar, of which 126 survived. The histerid was never recovered, but in 1953 R.P. Owen found evidence that *S. ruficornis* was established.

Ref. Krauss, 1951-52; Pemberton, 1957.

1951: L.J. Gressitt spent six months in the Palaus and one month in Western Samoa studying the ecology of *O. rhinoceros*. He studied the morphology and biology of the beetle, and its ecology in various breeding sites. The elaterid *Alaus depressicollis* Schwarz and *Scolopendra* centipedes were common predators in logs in the Palaus.

Gressitt's work was published in a monograph which included an extensive review of the literature on the ecology and control of *Oryctes*.

Ref. Gressitt, 1953.

1952: H.W. Simmonds sent over 100 *P. chinensis* from Western Samoa to the Palaus where it became established. *Pachylister* was released in Samoa and Fiji as a predator of houseflies, but larvae and adults were also found associated with *O. rhinoceros* under split log traps and in compost.

Ref. Gressitt, 1953; Pemberton, 1957; Simmonds, 1958;
Hoyt, undated b.

New Guinea

1952: G.S. Dun introduced *S. ruficornis* and *S. oryctophaga* from Zanzibar and Mauritius, into New Guinea.

1953: The Mauritius Department of Agriculture sent about 1,000 female *S. oryctophaga* to New Guinea.

1953-54: *P. chinensis* from Fiji and histerids of the genus *Hololepta* and elaterids of the genus *Pyrophorus* collected by C.I.B.C., Trinidad were introduced into New Guinea. Both *Pachylister* and *S. ruficornis* became established and the latter is now common around sawmill sawdust heaps. *S. oryctophaga*, *Hololepta* spp. and *Pyrophorus* have not been recovered.

1960-65: Local parasites and predators of dynastids were studied, but none showed much promise as control agents for *O. rhinoceros*. The large scoliid *Triscolia saussurei* Grib. would not attack *O. rhinoceros* grubs in captivity. The effects of the predatory histerid, *Plaesius ellipticus* Marseul, and dynastid, *Oryctoderus coronatus* Bates, are not known, but these beetles seem too rare to be of much consequence.

Ref. Anon., 1963b, 1965b; Dun, 1953, 1955, undated;
Smee, 1965.

Fiji

1953: N.L.H. Krauss and others sent 5,000 histerids of the genus *Hololepta* (= *Leionata*) - *H. marginepunctata* Mars. (= *H. colombiana* Mars.), *H. quadridentata* (F.) and probably a third species - and 125 elaterids (*Pyrophorus pellucens* Esch. and two other species) from Trinidad to Fiji. The histerids were found in decaying banana and coconut logs and the luminous elaterids were caught as adults at night.

1954: H.W. Simmonds introduced 60 *Mecodema spinifer* Broun, a large ground carabid, from New Zealand to Fiji.

1954: The Mauritius Department of Agriculture sent 750 *S. oryctophaga*, mostly females, to Fiji.

1954: Further shipments of histerids and elaterids from Trinidad to Fiji made up totals of 16,000 histerids and 2,700 elaterids released during the campaign. None of these insects appears to have become established in Fiji. A reported recovery of *Pyrophorus* sp. by Swaine (1966) proved to be erroneous (Swaine in litt., 1967).

1958: *S. ruficornis* was introduced from the Palau Islands. It became established.

1971: V.P. Rao of C.I.B.C. Indian Station introduced further carabid predators of the genus *Pheropsophus*.

Ref. Anon., 1956a, 1957, 1958, 1959; O'Connor, 1953, 1955, 1957, 1964; Swaine, 1966; Simmonds, 1959a, 1959b; Rao, 1972.

WORK OF THE SOUTH PACIFIC COMMISSION PROJECT

Soon after the rhinoceros beetle was discovered in Fiji the Fiji Government requested the South Pacific Commission to undertake research into methods of control of the pest. The work done during this period has been summarised by O'Connor (1964) who gave details of the releases of biological control agents. A more concise review is given below.

1954-1956: R.A. Cumber studied the ecology of *O. rhinoceros* in Western Samoa. He trapped beetles with split log traps and used these traps to make observations on beetle behaviour, longevity and population size. Cumber also carried out trials with chemical attractants and bacterial pathogens but none proved effective.

Ref. Cumber, 1956, 1957.

1954-1957: T.V. Venkatraman studied biological control agents in India and Ceylon and also spent one month in East Africa and six months in Madagascar. He listed many potential *Oryctes* predators which occurred in palm logs and he considered that the elaterids *Lanelater fuscipes* (F.) and *Alaus speciosus* (L.) were useful control agents. He found *Hypoaspis* mites eating the eggs of *O. rhinoceros* in Ceylon and a *Cordyceps* fungus on *Oryctes* larvae in Madagascar. Small shipments of *Alaus* and *Lanelater* were sent from Ceylon to Western Samoa, and *S. oryctophaga* from Madagascar to Fiji. The elaterids became established but *S. oryctophaga* did not.

Ref. Venkatraman, 1954, undated a, undated b, undated c, 1956a, 1956b, 1958; Anon., 1956b, undated; O'Connor, 1964.

1955-1960: P. Surany worked on the diseases of *Oryctes* in Samoa, Fiji, New Guinea, Asia, East Africa, Madagascar, Seychelles, Mauritius and Reunion. He considered the most important diseases of *Oryctes* to be "histolytic disease" and "blue disease". (K.J. Marschall, who worked as Surany's assistant, and Kreig and Huger at Darmstadt (Franz, 1961) have since shown that these conditions are not caused by pathogens but that "histolytic disease" is due to faulty diet and "blue disease" to rupture of the gut by mechanical injury.)

Surany also mentioned mites as predators of the eggs of *Oryctes* and considered these to be an important mortality factor.

In 1957 Surany sent *Rhabditis* nematodes from Ceylon and Madagascar to Fiji. These nematodes can kill larval and adult *Oryctes* in the laboratory, but there is some doubt that they are primary mortality factors in the field. The nematodes were later distributed to Western Samoa, American Samoa and the Wallis Islands. They have been recovered in Fiji.

Ref. Surany, 1958, 1960, undated; Anon., 1956b, 1958; Marschall, 1960, 1963; Franz, 1961; O'Connor, 1964.

1957: C.P. Hoyt spent five months in Madagascar searching for biological control agents. In logs he found elaterids and a reduviid, but these were never numerous. He sent a shipment of the scaritid *Scarites madagascariensis* Dej. to Fiji and 129 were released. Further shipments were collected by the Madagascar Department of Agriculture and liberated in Fiji in 1957 and in Wallis in 1959. *Scarites* was found mainly in heaps or rubbish. It does not seem to have become established. It was suggested that the giant toad may have eaten the beetles in Fiji.

Ref. Hoyt, 1957, 1958; O'Connor, 1964; Anon., 1958.

1958-1960: J. Lepointe, supervised by R. Paulian, studied the factors controlling *Oryctes* in Madagascar. He considered that the "blue disease" (as described by Surany) was the most important controlling factor. He concluded that parasites and predators could not be responsible for the control of *Oryctes* in Madagascar, though he suggested that elaterids were suitable for introduction into the Pacific.

Lepointe and Paulian considered that *Oryctes* was controlled in the natural forest habitat but not in the coconut plantations. They thought that a comparative study would reveal different mortality factors in the two habitats. Lepointe concluded that "blue disease" was only half as effective in coastal areas as in the primary forest. In fact his data suggest that in badly infested plantations *Oryctes* breeding sites were plentiful and this produced the high damage levels. Breeding sites were not abundant in forests. O'Connor (1960) criticised some of the techniques and conclusions in Lepointe's report and these criticisms appear to be valid.

Ref. Lepointe, 1960; Paulian, 1958.

1959-1960: C.P. Hoyt worked in Sierra Leone for five months and in Nigeria for twelve months. He collected over 4,000 adults of the large carabid *Neochryopus savagei* Hope and these were released in Fiji, New Guinea, Western Samoa, American Samoa and Tonga. *N. savagei* was found mainly in the debris which collects in the leaf bases in the crowns of oil palms. It feeds on *Oryctes* and other larvae breeding in this debris. Hoyt also sent 14 adults of the large carabid *Ochryopus gigas* Schio. and 12 survived to be released in Fiji. *Scolia* wasp cocoons sent to Fiji produced few adults, and these died during attempts to rear them in the laboratory.

Hoyt noticed that *Oryctes* were prevented from breeding in logs lying on the ground because of predation by "driver" ants *Dorylus nigricans* Ill. He found elaterid larvae uncommon (only 25 in over 500 palm logs), but frequently found *Hypoaspis* mites associated with *Oryctes* eggs. Hoyt considered that the main limiting factor on the *Oryctes* population in West Africa was the number of available breeding sites.

Ref. Hoyt, 1959a, 1959b, 1960, 1961, 1963b, undated c, undated d; O'Connor, 1961, 1964.

1959: F.A. Bianchi spent several months searching for biological control agents in Central America and Brazil with little success. He sent 20 elaterid larvae from Panama to Fiji, but they died during attempts to rear them in the laboratory.

Ref. Bianchi, 1959; O'Connor, 1964.

1960-1964: The Institut für Biologische Schädlingsbekämpfung, of Darmstadt (West Germany) undertook research on the pathology of *Oryctes*. Their conclusions on Surany's "blue" and "histolytic" disease supported those of Marschall. Attempts to infect *Oryctes* with rickettsiae and viruses of *Melolontha* failed. Other pathogens were tested but only *Beauveria* and *Metarrhizium* showed promise.

In 1963 Huger spent several months in Malaya, Fiji and Western Samoa. In Malaya he discovered a virus disease in *O. rhinoceros* larvae which appeared to reach epizootic levels (Huger, undated). He called the disease "Malaya disease".

Ref. Franz, 1961, 1963, 1965; Huger, undated.

1961-1962, 1963-1964: The Commonwealth Institute of Biological Control in India carried out investigations on biological control agents of *O. rhinoceros* in India. The most common breeding medium for *O. rhinoceros* in India is cow manure and most of the predators and parasites found by the Indian workers lived in this medium. Although high incidence of predators in the heaps was associated with low *O. rhinoceros* larval numbers, these predators did not prevent *O. rhinoceros* from breeding in the heaps and the actual degree of predation was undetermined. Nematodes, mites and various "diseases" were also found associated with *O. rhinoceros* in manure heaps.

In 1962, 339 scaritids (*Scarites dubiosus* Andr. and *Scarites* sp.) were sent for releases in Fiji, Tonga, Western Samoa and American Samoa, and the carabids *Pheropsophus hilaris sobrinus* Dej. and *Oxylobus punctatosulcatus* Chaud. were released in Fiji, Tonga and Wallis. Fifteen *Campsomeris azurea* Christ. were released in Fiji and a few *Scolia quadripustulata* Magr. were released in Fiji and Tonga. No recoveries of these insects were reported. The numbers of insects released in Tonga were fewer than reported by O'Connor (1964) due to losses during shipping.

Ref. Rao, undated a, undated b; Rao and Manjunath, 1964; Manjunath *et al.*, 1969; O'Connor, 1964; Catley, 1965c.

1961-1962: C.P. Hoyt went to Zanzibar and Kenya for twelve months, primarily to study the reduviid predator *Platymeris laevicollis* Dist. which had been recorded earlier (Vanderplank, 1958) as a useful predator of *Oryctes* adults in palm crowns. Several large shipments of *P. laevicollis* were sent to the Pacific in 1963-1964 by both Hoyt and the Zanzibar Department of Agriculture. Many further releases of laboratory reared animals have been made. *Platymeris* were released in Fiji, Tonga, Western Samoa, American Samoa, Wallis, Palaus, and New Britain. Although thousands of *Platymeris* of all stages have been released in many countries it has never become established.

During his stay in East Africa Hoyt found nematodes associated with the reproductive organs of *Oryctes monoceros* Ol. These were never found in unmated females and thus seemed to be transmitted during copulation (see work by Mariau and Poinar). Hoyt also found the mites *Hypoaspis* sp. and a large *Caloglyphus* sp. on the eggs of *Oryctes*. He thought that the *Hypoaspis* sp. did not kill the eggs but were attracted to eggs that had died from other causes but the *Caloglyphus* mite seemed to be able to kill viable eggs.

Ref. Vanderplank, 1958; Hoyt, 1962, undated d, undated e; O'Connor, 1964.

1962: Hoyt spent four months in New Guinea, New Britain and New Ireland looking for predators and parasites of dynastids. He found nematodes associated with the reproductive organs of various dynastids, but not *O. rhinoceros*. Occasionally rotting logs which had been rendered unsuitable for *Oryctes* breeding by fungi or bacterial invasion were found but no promising biological control agents were discovered.

Ref. Hoyt, 1963a, undated f.

1963: Hoyt spent seven months in Malaya and the Philippines investigating parasites and predators of *Oryctes*. Elaterids were occasionally found, and *Scolopendra* centipedes were common, but seemed to have little effect on *Oryctes* larvae. The parasite *Scolia procer* Ill. was found parasitising *Chalcosoma atlas* L. and *O. rhinoceros* in and under logs. *C. atlas* was a primary host and *O. rhinoceros* a secondary one. Hoyt and B.J. Wood of the Chemara Research Station sent *S. procer* cocoons to the Palaus and New Guinea. Unfortunately, most of the cocoons were dead on arrival and only one live female was released in each country (Owen, in litt. 1964; T.P.N.G. Dept. Agric. Stock Fish., Ann. Rep. 1963-64). In the Philippines no predators or parasites were found. *O. rhinoceros* larvae were abundant in some areas.

Ref. Hoyt, 1964, undated g.

1963: A. Catley went to Nigeria to collect further shipments of *Neochryopus savagei*. Of the 14,490 beetles dispatched 8-9,000 survived and were released in Fiji, New Guinea, American Samoa, Western Samoa and Tonga. *Neochryopus* was recovered in New Guinea in the crowns of some oil palms cut down in 1965 and in Fiji an adult was found in a compost heap (J.A. Ulvinaceva, pers. comm. 1972). *Neochryopus* may still be established in these territories but there have been no further reports.

Ref. Catley, 1963a,b,c, undated; O'Connor, 1964; Anon., 1968a.

WORK OF THE UN/SPC RHINOCEROS BEETLE PROJECT

1964-67: A.D. Hinckley (Ecologist - Project Area)

Hinckley studied the ecology of *O. rhinoceros* in Samoa. He also worked in Tonga, Fiji, Tokelaus and the Palaus, and in 1967 spent two months in Malaya, Thailand and the Philippines. Hinckley studied the associates of *O. rhinoceros* in breeding and feeding sites in Western Samoa. *Scolopendra* centipedes, the introduced elaterids *Alaus* and *Lanelater* and the native elaterid *Simodactylus* sp. would all eat *O. rhinoceros* larvae in the laboratory. *Hypoaspis* mites were occasionally found associated with dead *O. rhinoceros* eggs in the field, but it was not known whether they were the primary cause of the egg mortality. Hinckley (1967b) concluded that in Samoa *O. rhinoceros* was virtually free from predation and competition.

In South-east Asia Hinckley found *Oryctes* damage on the average less than in the Pacific but where breeding sites were abundant damage was severe. (Sanitation is widely practised in Malaya). Compared with Samoa, termites and other beetle larvae were common in rotting logs and millipedes rare. *Scolia patricialis* was common on Carey Island in Malaya but there was no sign of *S. ruficornis* which "had been released in a very unsuitable area". Hinckley thought that the damage levels observed in Malaya cast doubts on the efficiency of *Rhabdionvirus* as a self-spreading controlling factor. (See Huger's work.)

Ref. Hinckley, 1965a, 1965b, 1966a, 1966b, 1967a, 1967b, undated.

1964-67: A. Catley (Entomologist - Project Area)

In 1965 Catley searched for parasites and predators previously released in Samoa, Fiji and Tonga. *S. ruficornis* was found in Samoa and Fiji and the two elaterids *Alaus speciosus* and *Lanelater fuscipes* were recovered in Samoa; *Alaus* inside logs and *Lanelater* in sawdust and in rotten logs.

In 1965 a colony of *Platymeris laevicollis* was set up and releases made. Releases were continued till 1969. A collection of 150 *S. ruficornis* cocoons and some adults were sent to H.W. Simmonds for release in Fiji. Catley considered that *Scolia* was only a useful parasite in very restricted habitats. He thought that compost heaps to encourage *Scolia* would probably produce more beetles than wasps. *Lanelater* and *Alaus* did not appear to him to be contributing greatly to the control of *Oryctes* larvae. Both species had spread about 20 miles to the west of Apia, and four miles to the east. In 1966 attempts were made to rear *S. ruficornis* in the laboratory to provide stocks for introduction into Tonga but these attempts failed. A small consignment of 32 *Lanelater* larvae and a large number of *Platymeris* were released in Tonga in 1967. In Western Samoa no recoveries of *Platymeris* were made during searches of palm crowns and light trapping. The ants *Technomyrmex* sp., *Pheidole megacephala* F. and *Odontomachus* sp. were observed attacking *Platymeris* nymphs soon after release. Ants appeared to be the major factor preventing their establishment in Western Samoa. For future releases it was suggested that late instar *Platymeris* be released.

In 1967 and 1969 Catley published papers briefly discussing past and current work on *Oryctes* control.

Ref. Catley, 1965a, 1965b, 1965c, 1966, 1967a, 1967b, 1967c, 1968, 1969a, 1969b; Hoyt and Catley, 1967.

1966-71: G.O. Bedford

April 1966 - April 1967 (Entomologist - Africa)
May 1967 - November 1967 (Entomologist - Project Area)
January 1968 - 1971 (Insect Ecologist - New Guinea)
1971 - (Insect Ecologist - Fiji)

In 1966-67, Bedford searched for predators and parasites of *Oryctes* in Madagascar and the Comores Archipelago. He found that where breeding sites were abundant damage to palms was heavy. In most of the big plantations dead palm wood was removed to prevent *Oryctes* breeding. Scoliids, gregarines, *Metarrhizium* and *Cordyceps* fungi, and mermithid nematodes were found parasitising *Oryctes* but none was common. Predatory elaterid larvae were occasionally found but did not appear to be of much importance. Bedford concluded that the major factor limiting *Oryctes* populations was the number of suitable breeding sites available.

Larvae infected with oxyurid nematodes in the fermentation chamber, gregarine cysts, *Cordyceps* and *Metarrhizium* fungi, were sent to Western Samoa. Catley failed to infect *O. rhinoceros* larvae with the gregarine parasites and infected larvae were sent to Huger at Darmstadt, where the life-cycle and pathogenicity were studied. Marschall failed to infect *O. rhinoceros* larvae with the *Cordyceps* fungus (pers. comm., 1971). Oxyurid nematodes were later found by Bedford in the fermentation chamber of *O. rhinoceros* in Samoa.

Ref. Bedford, 1967a, 1967b, 1967c, 1968c, undated; Tuzet *et al.*, 1967; Catley, 1967b.

In 1967-68, Bedford worked in Western Samoa. *Platymeris* nymphs and adults were released in Samoa and Tonga. A few recoveries were made one month after a release in Samoa. No recoveries were made in Tonga.

Ref. Bedford, 1967c.

In January 1968, Bedford went to New Guinea and began work on the ecology of dynastids on the Gazelle Peninsula. Damage by *Scapanes* and *Oryctes* was severe in some areas. No *Platymeris* were recovered during a search of various release areas. A predatory ant *Oecophylla smaragdina* F. was common, and it was considered that this ant could have killed the *Platymeris*.

Passalid larvae and adults and large millipedes found in the British Solomon Islands were suggested as possible competitors of *Oryctes*, as these were very active in breaking down coconut wood. Passalid adults and millipedes were sent to Western Samoa for evaluation. They were placed in boxes with coconut logs. The millipedes died, but the passalid adults rapidly riddled the coconut wood with tunnels (Zelazny, pers. comm., 1971). No releases were made. Bedford (1971a) concluded that the *O. rhinoceros* population in New Guinea was limited by the availability of breeding sites. In New Guinea *Oryctes* larvae were well hidden from all predators except elaterids, which were rare. *O. rhinoceros* did not compete with the local dynastids for breeding sites.

In 1969, Bedford and Marschall went to Malaya to assess the effects of *Rhabdionvirus* on the *O. rhinoceros* population. They found few virus infected grubs in the field and beetle damage was heavy in some areas. They concluded that *Rhabdionvirus* alone was not capable of controlling *O. rhinoceros* below an economic level in this country.

Ref. Bedford, 1968a, 1968b, 1969a, 1969b, 1970, 1971a, 1971b; Marschall, 1971.

1965-66: R.W. Paine (Entomologist - South-east Asia)

Paine spent three months in Malaya searching for predators and parasites of *Oryctes* and made shorter visits to Timor, Borneo, Singapore, Maldive Islands, New Guinea, Southern India and Ceylon. He considered that as a whole Malaya suffered more damage from *Oryctes* than Ceylon or Southern India. India suffered the least damage, and this was due to the comparative lack of *Oryctes* breeding sites.

Mites, especially *Hypoaspis*, were commonly found on *Oryctes* adults in all areas. In some cases they were extremely abundant. A *Caloglyphus* mite was found associated with the eggs of *O. gnu* Mohn in Malaya and Sabah. Paine considered that this mite could only develop on damaged eggs (cf. Hoyt in East Africa). *S. patricialis* was seen in fair numbers in Malaya, but it seemed to be a parasite of *Xylotrupes*. *Scolia ruficeps* Sm. was found on one occasion in a palm trunk and although it was proven to attack *O. rhinoceros* Paine considered that it was more naturally associated with species of Cetoniidae. The elaterids *Lanelater aequalis* Cand., *L. fusiformis* Cand. and *Alaus lacteus* F. were occasionally taken in coconut trunks in South-east Asia. In captivity they destroyed few *Oryctes* grubs. In Ceylon *L. fuscipes* and *A. speciosus* were found. The larva of a mydaid, *Mydas carmichaeli* Brun., was found in palm trunks in Malaya and Sabah. It readily ate *Oryctes* grubs. It was never found in coconut trunks. Nematodes in the reproductive organs of *O. gnu* and *O. centaurus* Sternb. did not appear to affect the fecundity of the females.

Paine concluded that the role played by predators and parasites in the control of *O. rhinoceros* in Asia was insignificant. Only the elaterids and *Mydas* could be safely introduced into the Pacific. The main controlling factors in Asia, apart from those of a purely ecological nature, were the competitors for larval food supply: termites (which were very abundant) and other coleopterous larvae.

Ref. Paine, 1965, 1966, undated.

1967: D. Mariau (I.R.H.O., West Africa)

Mariau did research on parasites, predators and diseases of *Oryctes* on the Ivory Coast. He found the invertebrate inhabitants of rotting palm logs, the main breeding site of *O. monoceros*, were mainly scarabaeid and cetoniid larvae, termites and ants. Rotting forest logs contained a much richer fauna. Mariau considered that the only enemies to show some promise for *Oryctes* control were *Hypoaspis* mites and nematodes (*Oryctonema genitalis* Poinar) associated with the reproductive organs.

Mariau estimated that mites cause 20-30% mortality of eggs in the field. In the laboratory only 24% of eggs laid by mite-infested beetles hatched compared with 73% in the absence of mites.

A comparison between females infested with nematodes and those without nematodes in the reproductive organs showed that nematode infection had no effect on the fecundity of the beetles or on the viability of eggs.

Mariau sent samples of *Hypoaspis* sp. to Western Samoa and *O. monoceros* adults infected with nematodes to Hurpin at the Station de recherches de lutte biologique et de biocoenetique, La Miniere, France. Specimens of the mites from Western Samoa and the Ivory Coast were sent to Dr. M. Costa, who specialises in the study of *Hypoaspis*. Costa considered that the Samoan mites were *Hypoaspis rhinocerotis* Oudms., and were different from the Ivory Coast *Hypoaspis* sp. However, later the situation became confused as both types of mites were found on beetles in Western Samoa (Costa, in litt. 1969). The taxonomy of the mites has not been resolved; the differences between the two types described by Costa were very slight. The Ivory Coast mites were released on Nukunonu Atoll, Tokelau Islands, in November 1968.

At La Miniere Hurpin infected *O. rhinoceros* with nematodes in the reproductive organs of *O. monoceros* by reciprocal matings (Hurpin, pers. comm., 1971). A culture of infected *O. rhinoceros* was set up in Western Samoa (see work by Stelzer).

Ref. Mariau, 1967a, 1967b, 1968a; Catley, 1968.

<u>1968-69: M.J. Stelzer (Entomologist - Project Area)</u>

In 1968 Stelzer released large numbers of *Platymeris* nymphs and adults in Samoa and Tonga, and consignments of eggs and adults were sent to Ceylon and India. A single female *Platymeris* adult was recovered in an area where adults had been released some ten months previously. It seems that on the basis of this recovery Catley (1969b) reported *Platymeris* to be established in Samoa. However, in Fiji it was found that *Platymeris* adult females could survive for 264-452 days in the laboratory (Anon., 1965a) and thus it is possible that the female recovered was a survivor from the original release.

Stelzer tried to breed the nematode-infected *O. rhinoceros* sent by Hurpin but the culture died out without any males becoming infected (Stelzer, pers. comm., 1972).

Ref. Stelzer, 1968; Catley, 1969b.

<u>1965-71: Institut für Biologische Schädlingsbekämpfung, Darmstadt, Germany. A.M. Huger, E. Müller-Kögler, A. Krieg</u>

In 1965, Huger began work on the symptoms, isolation, identification, and transmission of the virus he had discovered in Malaya (1966a). Huger named the virus *Rhabdionvirus oryctes*, erecting a new genus for the species.

Experiments to test virus survival in sawdust showed that after ten days the virus had lost most of its virulence. The virus did not lose virulence after long storage at sub-freezing temperatures. In experiments to test germinative transmission of the virus low doses of virus were given to *Oryctes* larvae. Some of these larvae survived to become adults, and of their fourteen progeny two died from Malaya disease (Huger, 1966a). Huger (1969b) was reasonably certain that transovarian transmission of the virus could occur (but see Zelazny's work). Further experiments on this aspect were spoiled by extraneous diseases.

In 1967 and 1968 Huger investigated two gregarine parasites of *Oryctes*. One (probably *Didymophyes gigantea* Stein) occurred in *O. nasicornis* L., and the other (*Stictospora kurdistana* Theod.) was found by Bedford in Madagascar. Huger concluded that neither was sufficiently pathogenic to be useful in the biological control of *O. rhinoceros*.

Müller-Kögler (1967) carried out infectivity and viability tests with *Metarrhizium* and found that low spore concentrations were effective and that although 66% of the *Metarrhizium* spores stored in rotten sawdust were dead after one month some survived for as long as two years at 20-24°C.

Krieg (1968) attempted to infect *O. rhinoceros* with *Sericesthis* iridescent virus (SIV). Infection was successful but the virus was not sufficiently virulent to cause regular fatal infections. Bacteria reported by Lal in India to cause 90% mortality of *O. rhinoceros* did not have any effect when fed orally to *O. rhinoceros* at Darmstadt.

In 1969 Huger confirmed by electron microscopy that the diseased larvae recovered in the field in Samoa contained *Rhabdionvirus*. He stated (1969a) that the virus in Samoa could create a situation comparable to that in certain areas of Malaysia where, together with cultural and other control methods, enzootic and epizootic mortalities by *Rhabdionvirus oryctes* had obviously contributed to markedly ameliorate the rhinoceros beetle problem. This conclusion was partly based on findings from a series of shipments of *O. rhinoceros* larvae from Malaysia in some of which all of the larvae died from virus infections that "developed from a latent to a fatal state" (but see discussion on *Rhabdionvirus*).

In 1969-70 diagnostic studies, and studies on the pathology and histology of *Rhabdionvirus* were continued. Huger found that *Rhabdionvirus* was associated with nuclear polyhedra similar to those of *Borrelinavirus*.

Ref. Huger, 1965, 1966a, 1966b, 1966c, 1967a, 1967b, 1967c, 1968, 1969a, 1969b, 1970, 1971; Müller-Kögler, 1967; Müller-Kögler and Huger, 1967; Krieg, 1968.

<u>1964-71: K.J. Marschall (Insect Pathologist - Western Samoa)</u>

Upon arrival in Western Samoa, Marschall made a field survey of diseases of *O. rhinoceros* and found *Metarrhizium anisopliae*. Laboratory work on the growth, transmission and virulence of *Metarrhizium* was begun.

In 1965, experiments to test methods of application of *Metarrhizium* to heaps of *Oryctes* breeding material in the field were made. Application of spores gave 60-100% *Metarrhizium* infection with some residual effect.

In 1966 Marschall visited Huger in Darmstadt, Germany, to work on the newly discovered virus disease, Malaya disease, and the virus was sent to Samoa in October 1966. Mixtures of macerated virus-infected larvae and rotten sawdust were applied to ten rotten log heaps on Savai'i and two heaps on Manono and *Metarrhizium* spores and virus material were distributed in the Tokelau Islands in 1967.

The "Fagaloa Field Trial" was set up in 1967 in an attempt to assess the effects of extensive field distribution of *Metarrhizium* on the *O. rhinoceros* population. Heaps of rotten coconut logs were set up and half the heaps were sprayed with *Metarrhizium* spores. The other heaps served both as controls and to detect the spread of *Metarrhizium*. Mortality from *Metarrhizium* occurred in both treated and control heaps but there was no significant spread of *Metarrhizium* to control heaps. The larval population in all heaps dropped during the period of trial. Marschall noted a "conspicuous reduction" of damage to palms in Fagaloa, and considered that the *O. rhinoceros* population had been effectively suppressed by *Metarrhizium* (but see discussion on *Metarrhizium*).

In late 1968 *Rhabdionvirus* was recovered from many sites in Western Samoa. Heavy infection of field sites in many areas was initiated using an improved "release heap" with the aim of starting an epidemic in the *O. rhinoceros* population.

In 1969 a control programme using *Metarrhizium* was begun in Tonga. *Metarrhizium* spores were "mass produced" and spread on natural and artificial release sites. This programme was evaluated by Young (1971b) and the programme was stopped.

In general Marschall's work is difficult to evaluate because of inadequate description of methods in the reports and lack of controls in the experiments. The high mortalities attributed to *Rhabdionvirus* and *Metarrhizium* by Marschall (1970) were based on bulk collections where cross contamination between the field-collected grubs probably occurred.

Ref. Marschall, 1965a, 1965b, 1966a, 1966b, 1967, 1968a, 1968b, 1969a, 1969b, 1970a, 1970b, 1970c.

<u>1968: I.M. Hall (Consultant in Insect Pathology)</u>

In July, I.M. Hall spent ten days in Apia as a consultant Insect Pathologist advising on the *Metarrhizium* trial at Fagaloa Bay and the field release of *Rhabdionvirus*. Hall was pessimistic about the effective use of *Metarrhizium* because of the extreme difficulty of getting the infective conidial spores to the zone where the larvae lived and also because the fungus had been in the ecosystem of the beetle for many years without controlling the beetle population. He thought that *Rhabdionvirus* showed most promise and he recommended that increased effort be put into establishing the virus in the field.

Ref. Hall, 1968.

<u>1968-69: G.O. Poinar (Nematologist)</u>

Poinar studied the nematodes associated with the reproductive organs of *Oryctes* in Papua, New Britain, Malaysia and the Ivory Coast. He confirmed that nematodes are not found in the bursa copulatrix of *O.*

rhinoceros, but that they occur widely in *O. monoceros*. Poinar (1970a) named the nematode in *O. monoceros*, *Oryctonema genitalis*. Another nematode was found in the colleterial glands and aedeagi of *O. monoceros*, *O. boas* F., *O. owariensis* P. de Beauvois., *Xylotrupes gideon* (L.) and *Scapanes australis* Boisd. Poinar (1971) named this nematode *Rhabditis adenobia*. Neither nematode seemed to have any obvious deleterious effect on the infected beetles (see Mariau's work).

Ref. Poinar, 1968, 1970a, 1970b, 1971, 1972.

<u>1969-71: B. Zelazny (Entomologist - Western Samoa)</u>

Surveys of *Rhabdionvirus* and *Metarrhizium* infected larvae in the field in Western Samoa in early 1970 showed that less than 2% of larvae were infected by either pathogen. Larvae were collected and held individually, precautions being taken to avoid contamination of healthy larvae by diseased larvae. Dead larvae, or larvae which died after being held in the laboratory, were fed to healthy larvae to confirm the cause of death.

Extensive surveys in 1970-71 revealed that about 8% of *O. rhinoceros* breeding sites contained virus infected larvae and *Metarrhizium* occurred in 2-8% of sites. It was found that *O. rhinoceros* adults were also infected by *Rhabdionvirus* and surveys indicated that a high proportion of adults in the field were infected. Virus infected beetles died sooner and infected females laid fewer eggs than uninfected ones. Infected adults could contaminate the medium in which they were held and also contaminated the tissue in the palms of crowns from which they were collected, suggesting two possible means of virus dispersal.

Zelazny estimated that *Rhabdionvirus* could cause a total reduction of 50% of one generation of *O. rhinoceros* through its effects on larvae and adults. It is not known how this reduction would affect final population size.

Ref. Maddison and Zelazny, 1970; Zelazny, 1971a.

<u>1970-71: E.C. Young (Project Manager)</u>

In 1970-71, Young evaluated the *Metarrhizium* release in Tonga begun by Marschall in 1969. He found that there had been little spread of *Metarrhizium* from the release heaps to natural sites. Palms near the release heaps were still severely damaged, so the control programme was considered ineffective and was abandoned.

A *Rhabdionvirus* release programme was begun in Tongatapu in November 1970. Virus was added to release heaps similar to those used in Western Samoa and Fiji. In February and March 1971, Tongan Agriculture Officers sent dead larvae from natural sites to Western Samoa. Most of these larvae proved to be virus diseased, showing that virus had spread quickly from the release heaps to natural sites, probably by contamination of beetles which had visited the heaps. In April 1971 an extensive survey showed that 19% of the breeding sites in the release area were virus-infected. Agriculture officers had found a few virus-infected sites 5-6 miles from the release area.

Ref. Young, 1971a, 1971b.

DISCUSSION OF PREDATOR, PARASITE, AND PATHOGEN GROUPS, ATTEMPTS TO USE THEM IN CONTROL PROGRAMMES AND EVALUATION OF THE REASONS FOR THEIR SUCCESS OR FAILURE

PREDATORS

COLEOPTERA

<u>Elateridae</u>

The two species of elaterid introduced into Western Samoa have both become established and have spread from their release sites on Upolu. They are both occasionally found associated with *O. rhinoceros* breeding in coconut logs.

The *Pyrophorus* spp. introduced into Fiji and New Guinea from Trinidad have not been recovered. In Trinidad the larvae of these elaterids are occasionally found in the axil debris in the crowns of coconut palms (F.D. Bennett, C.I.B.C., Trinidad, pers. comm., 1971). The larval habitats of the different species are not known, since only adults were collected. It is possible that these species were not ecologically suited to prey on *Oryctes* larvae.

Larvae of *Lanelater* spp. and other elaterids have been found throughout Asia and Africa in logs inhabited by *Oryctes* spp. In the Palaus Gressitt (1953) recorded *Alaus depressicollis* as a common predator of *O. rhinoceros*. Most authors considered that because elaterids were uncommon they could have little effect on *Oryctes* populations. The advantage of elaterids over other larval predators is their ability to penetrate logs and attack *Oryctes* grubs in these sheltered habitats. There is some evidence that the adults search out logs containing beetle larvae or other suitable food sources for oviposition (Venkatraman, 1954). The experience with the elaterids introduced into Western Samoa suggests that they are easy to colonise, even using low numbers. The disadvantages of elaterids are their lack of specificity (not so important in the Pacific Islands where alternative xylophagous coleoptera are relatively scarce), very slow growth rate (and thus potential rate of increase) and the difficulty of rearing them in the laboratory. The rarity of elaterid larvae in the field also makes their collection somewhat tedious. Once established elaterids provide a constant predatory pressure on *Oryctes* populations.

Histeridae

Two histeridae, *Pachylister chinensis* and *Plaesius javanus* have been widely introduced into the Pacific, *Pachylister* against houseflies and rhinoceros beetles and *Plaesius* against the banana weevil borer. Both predators have been found associated with *O. rhinoceros* larvae in Western Samoa, *Pachylister* in compost and under split log traps (Gressitt, 1953) and *Plaesius* in papaya stems (Hinckley, 1967b).

The *Hololepta* spp. from Trinidad, and *Placodes* from Zanzibar probably found no suitable habitat in the Pacific. *Hololepta* was found in banana stems and *Placodes* in sisal bases. Their ecology was not well known and it is possible that they were not adapted to Pacific niches.

Carabidae

The family Carabidae contains many predators of soft bodied insects. The larger species are not found in the tropics, but many species are capable of feeding on eggs and early stage instars of *Oryctes* both as larvae and as adults.

The large ground carabids introduced from Europe and New Zealand were probably not adapted to the Pacific climate. *Catascopus fascialis* introduced from Malaya, with limited potential as an *Oryctes* predator, seems to have failed to establish. Perhaps some food requirements were missing in the restricted Samoan log fauna. The species of *Pheropsophus*, *Oxylobus* and *Scarites* introduced from India were collected in manure compost, an uncommon habitat in the Pacific. Species of *Pheropsophus* from India have been established in Mauritius (Manjunath *et al.*, 1969) but they have not spread from the manure heap in which they were released and do not prevent *O. rhinoceros* from breeding extensively in this heap (J. Monty in litt., 1971).

Neochryopus savagei was found primarily in the debris in the crowns of oil palms in West Africa. This debris was so abundant that *Oryctes* and other beetles bred in it and these larvae were preyed upon by *Neochryopus*. The crowns of coconut palms in the Pacific contain little axil debris and the crown fauna is sparse. It is unlikely that *Neochryopus* could find many habitats in the Pacific Islands although it may have established in New Guinea and Fiji. *Ochryopus gigas* faced a similar situation to *Neochryopus* and the small numbers released also made establishment unlikely. *Scarites madagascariensis* preyed on beetle larvae living in rubbish and compost. Such environments are rare in the Pacific.

It is unlikely that the above carabids would survive if they were released among rotten coconut logs which are the most common breeding site of *O. rhinoceros* in the Pacific. *Oryctes* larvae are probably a very minor item in the natural diet of most of these beetles. The general disadvantage of carabids as predators of *Oryctes* is that they can penetrate only relatively friable *Oryctes* breeding sites.

HEMIPTERA

Reduviidae

Platymeris laevicollis

Vanderplank (1958) thought that *Platymeris* was a useful predator of *Oryctes* because he found large numbers of *Oryctes* larvae in compost heaps near plantations that had little *Oryctes* damage. *Platymeris* was the only natural enemy which could have protected the palms since *Scolia ruficornis* parasitised less than 10% of the larvae in the heaps. However, Hoyt (undated d) determined that the species breeding in the compost was *O. boas*, and this species was not found attacking coconut palms. *O. monoceros* was the only species taken in palm crowns and this species bred in dead palm wood. Hoyt's surveys of palm damage in East Africa showed widespread high damage levels where dead coconut wood was abundant. Wheatley (1961) did not think that *Platymeris* had any effect on *O. monoceros* numbers in Kenya. Thus, although *Platymeris* undoubtedly may attack *Oryctes* adults in palm crowns, there is some doubt as to its efficiency as a control agent.

Platymeris does not seem to have become established anywhere it was introduced (cf. Catley, 1969b) and this is probably due to predation of the young nymphs by ants. It is also possible that some requirement for the young nymphs is not available in the Pacific and in Asia. Greenslade (1968) discussed the ecology of ants in Africa and the Solomon Islands and concluded that the same species of ants could be more predatory in the Pacific than in Africa where they rely on honeydew from homoptera to a greater extent. Thus *Pheidole* ants may tolerate *Platymeris* in Zanzibar but will prey on the nymphs and eggs in the Pacific. Adult *Platymeris* are able to survive in the Pacific and this probably explains several claims for establishment of the bug. Releasing adults does not overcome the problem of predation of the nymphs.

Other Reduviidae:

Reduviids have been found under the bark of rotting logs and in compost in Africa and Asia. These ate *Oryctes* larvae in captivity but they were never common in the field.

Hoyt (1963b) tested the large reduviid *Platymeris biguttata* Stal. against *O. owariensis* adults but the bug showed no interest in them. Nymphs and adults of *P. biguttata* were found frequently in the tops of standing rotten oil palm trunks. Hoyt (undated d) records *Platymeris erebus* Dist. in the crowns of coconut palms in Kenya, but it was not common.

CHILOPODA

Scolopendridae

Large *Scolopendra* centipedes have been recorded as predators of *Oryctes* by Gressitt (1953), Lepointe (1960) and Hinckley (1967b) but evidence for this is largely circumstantial. Centipedes are often found associated with *O. rhinoceros* larvae in and under well rotted logs and in compost. Because they sometimes bite humans, centipedes are usually killed on sight by Pacific people.

CRUSTACEA

Hermit crabs and other crabs are often found in and under logs near the sea. These crabs may attack *O. rhinoceros* larvae living in exposed situations.

VERTEBRATES

Rats, mice, shrews, squirrels, lemurs, monkeys and flying squirrels have been reported as predators of *Oryctes* larvae and adults. Domestic pigs root for larvae in compost and rotten logs.

Large monitor lizards, *Varanus* spp., are reported to eat *Oryctes* larvae in Asia, and it is possible that some of the small lizards found under logs also eat larvae.

Various birds, including wild and domestic fowls, are reported to search out *Oryctes* larvae. Owls probably take some adults. Wood (1969) has a photograph of the remains of a beetle eaten by an owl.

The giant toad (*Bufo marinus* L.) may feed on *Oryctes* grubs but it has also been claimed that it destroyed biological control agents released against *O. rhinoceros* in Fiji. *Bufo* is often found in and under rotten coconut logs in Fiji and American Samoa.

Vertebrates are notoriously unreliable as biological control agents and few have been seriously suggested for introduction against *O. rhinoceros*. Friederichs (1913) suggested the European mole, hedgehog, badger and shrew as potential enemies of *O. rhinoceros* larvae. He also thought that the African elephant shrews and the Madagascan Tenrek (*Centetes ecaudatus*) would be suitable for introduction. The mole and hedgehog were introduced into Western Samoa but they could not survive in the tropical environment.

PARASITES

HYMENOPTERA

Scoliidae

Many attempts have been made to introduce scoliid parasites of *Oryctes* to countries where they do not occur. *Scolia oryctophaga* and *S. ruficornis* have been widely introduced in substantial numbers. *S. ruficornis* has established in many countries but *S. oryctophaga* only in Mauritius, where it is reported to give good control of *Oryctes tarandus* Ol. However, there is some doubt as to whether *C. tarandus* was ever a major pest and the degree of control is not really known (Moutia and Mamet, 1946). Workers in Java found that *S. oryctophaga* had a pupal diapause, adapted to the cool wet season in Madagascar, and thus it is not adapted to the mild Pacific climates. *S. oryctophaga* has not prevented *O. rhinoceros* from becoming a major pest of coconuts in Mauritius.

S. ruficornis is limited as a parasite of *O. rhinoceros* because it does not parasitise larvae in coconut logs, the main breeding site of *O. rhinoceros* in the Pacific. This parasite would be more useful in countries where *Oryctes* breeding in compost is a major problem. In its country of origin (Zanzibar) parasitism of *O. boas* by *S. ruficornis* is usually less than 10% (Vanderplank, 1958) and this would support Catley's (1966) view that any attempts to encourage *S. ruficornis* by providing suitable breeding sites would produce more *Oryctes* than *Scolia*.

It should be noted that Simmonds (1941) considered that scoliids controlled *Oryctes* in Madagascar and that *S. ruficornis* gave good control of *O. rhinoceros* in Fiji (Simmonds, 1964). There was little evidence to support these claims.

As shown in Table 1, *S. patricialis*, *S. procer*, *Elis romandi*, *S. quadripustulata* and *Campsomeris azurea* had little chance of establishing in the Pacific because of the small numbers introduced or because they were not ecologically suited to parasitise *O. rhinoceros*. Hoyt (1964) suggested that as *Chalcosoma atlas* seems closely related to the New Guinea *Scapanes*, *S. procer*, a parasite of *Chalcosoma*, should be introduced into New Guinea in the hope that it might control *Scapanes* and/or *O. rhinoceros*. No successful shipment has been made.

Africa and Madagascar have been extensively searched for suitable scoliids and there seems little hope of an effective parasite being found there. In Malaya Corbett's record of *Scolia ruficeps* as a parasite of the second instar larvae of *O. rhinoceros* was confirmed by Paine (1966) but Paine considered that *S. ruficeps* was more naturally associated with cetoniids. *S. ruficeps* appears to be uncommon. In India Kurian (1969) recorded *Scolia cyanipennis* Fab. as "common in Kerala associated with the breeding sites of *Oryctes* particularly in decaying coconut logs". On one occasion *S. cyanipennis* was found parasitising an early stage *O. rhinoceros* larva. This species was not noted by Venkatraman (1958) or Manjunath *et al.* (1969).

Other Hymenoptera

Hoyt (undated a) listed the known parasites of dynastids. *Pimpla instigator* F. (Ichneumonidae) on *O. nasicornis* L. and *Ipobracon* sp. (Braconidae) on *O. monoceros* are reported but they do not seem to be common.

DIPTERA

Dipterous parasites of dynastids were also listed by Hoyt (undated a). Catley (1967a) mentioned that attempts were made to obtain *Microphthalma europaea* Egg., and *M. numidica* (Tachinidae) parasites of *O. nasicornis* for introduction into Western Samoa. No further record of this attempt was made. *M. europaea* is a natural parasite of the dynastid *Phyllognathus silenus* (F.) in Algeria. In the laboratory it could develop on *O. nasicornis* and many other lamellicorns (Hurpin and Fresneau, 1964). However, the mature *M. europaea* larvae had difficulty in penetrating the integument of second instar *Oryctes* larvae to escape to pupate, and is thus not well adapted to parasitise this genus.

Hoyt (1963b) found predatory tabanid larvae associated with *O. monoceros* in West Africa and once found a tachinid larva inside a dead *O. boas* larva. Both flies were very rare. Paine (1966) found a predatory mydaid larva associated with *Oryctes* in Malaya. It seemed restricted to damp *Corypha* palm logs and was not found in coconut logs. Large tachinid puparia were found in Timor. Paine suggested that the rutiline tachinids of Indonesia and the Melanesian Sub-Region could be investigated for possible value against *Oryctes*.

ACARINA

Laelaptidae

Hypoaspis

Hypoaspis (= *Coleolaelaps*) mites have been found on *Oryctes* eggs, larvae, pupae and adults in all countries where *Oryctes* naturally occur. *Hypoaspis rhinocerotis* Oudms. was described from India, but, as previously discussed, the taxonomy of these mites is confused and it is possible that more than one species exists. Most authors agree that the mites cause no damage to larvae or adult *Oryctes* but there is some debate about their role as egg predators. Venkatraman (1958), Surany (?) (1960) and Mariau (1967a, 1967b, 1968a) report that *Hypoaspis* mites can kill newly laid eggs. Hoyt (1963b), Hinckley (1967b) and Zelazny (pers. comm., 1971) are undecided whether the mites destroy viable eggs or whether they scavenge inviable or dead eggs. Mariau (1967b) reported that mites at all stages of development were found on eggs enclosed in the protective cell built around the egg by female *O. monoceros*. The mites probably left the ovipositing female and stayed on the egg. It was estimated that 70% of the eggs laid in the field were attacked by mites. Mariau's (1968a) experiments showed that in the laboratory *Hypoaspis* sp. from the Ivory Coast caused significant egg mortality. These mites were released on the Tokelau Islands.

The taxonomic problems and role of *Hypoaspis* as a predator in the Pacific have not been resolved. It is not known whether *Hypoaspis* mites occur in Fiji, Wallis, Tonga or American Samoa. From the literature it seems that they are more commonly found on *Oryctes* in Asia and Africa than in Western Samoa.

Caloglyphus

Caloglyphus mites have been recorded by Hoyt (undated d) feeding on *Oryctes* eggs in Kenya, Zanzibar and Madagascar. Hoyt considered that this mite could probably kill viable eggs. Paine (1966) found a *Caloglyphus* sp. associated with the eggs of *O. gnu* in Malaya and Sabah but he found that they could only develop on damaged eggs. *Caloglyphus* mites are also recorded by Hoyt (undated a) on *O. nasicornis* and by Manjunath *et al.* (1969) on *O. rhinoceros* in India.

Other Mites

Venkatraman (1958) reported unidentified mites feeding on freshly laid *Oryctes* eggs. These may have been *Caloglyphus*. Goonewardena (1958) has a photograph of an *O. rhinoceros* egg damaged by the mite *Parasitum helicorpridis* Oudms. Surany (1960) recorded a mite in the atria of the spiracles of *O. boas* in such numbers that the spiracles were nearly blocked. No further information on any of these mites is available.

NEMATODA

Rhabditidae

Two species of rhabditids have been found associated with the reproductive organs of *Oryctes*. The beetles become infected during copulation.

Oryctonema genitalis

Hoyt (undated d) discovered this nematode in the bursa copulatrix of female and the aedeagus of male *O. monoceros* in Kenya. Later Paine (1966) and Mariau (1967a) found it in *O. monoceros* from the Seychelles and Ivory Coast respectively. The nematode was studied and named by Poinar (1970a). The nematode also occurs in *O. gnu* in Malaysia (Paine, 1966) and similar nematodes were found by Bedford (1969a) in *O. gigas* Lap., *O. blucheaui* Fairm. and *O. insularis* Coq. in Madagascar. According to Mariau (1967b) *O. genitalis* has no effect on fertility or viability of eggs of *O. monoceros*. These nematodes have been successfully introduced into *O. rhinoceros* in which they have never been found naturally but no study of their effect on this beetle has been made.

Rhabditis adenobia

Nematodes have been found commonly in the colleterial glands and aedeagi of *O. rhinoceros*, *O. monoceros*, *O. boas*, *O. owariensis*, *Xylotrupes gideon* and *Scapanes australis* (Poinar, 1971). Poinar (1971) named the nematode from *O. monoceros*, *Rhabditis adenobia*. In Asia 30-100% of mated female *O. rhinoceros* are infested with *R. adenobia* (Paine, 1966). It does not appear to have any obvious deleterious effect on its host, but this has not been studied in detail.

Rhabditis spp.

Surany (1960) sent *Rhabditis* nematodes from Ceylon and Madagascar to the Pacific. In the laboratory these nematodes killed all the infected larvae. They were distributed to Samoa and Wallis from Fiji. Nematodes killing the larvae were found in the mass-rearing cultures during the virus release programme in Fiji and probably were the released *Rhabditis* spp. It is possible that these only kill larvae which are weakened by some other stress, such as being held in the laboratory. They do not appear to cause any mortality in the field.

Other Nematodes

Surany (1960) and Bedford (1968c) found large mermithid nematodes in the body cavity of *Oryctes* larvae and adults. This parasite seems to be fairly rare.

In India C.I.B.C. has investigated the nematode *Neoaplectana carpocapsae* strain DD-136, which can infect and kill *Oryctes* larvae (V.P. Rao, in litt., 1970). This nematode could be used as a biological insecticide to treat compost as it has a fairly long survival period in the field. However, Reed and Carne (1967) have shown that host parasite relationships must be considered in the use of DD-136 and their work suggests that DD-136 may not be suitable for controlling *O. rhinoceros*.

PROTOZOA

Gregarinidae

The two gregarine parasites of *Oryctes* studied by Huger did not have any obvious pathogenic effects on the infected larvae and beetles (Huger, 1967c, 1968). It has not yet been shown that *S. kurdistana* can infect *O. rhino-*

ceros. Catley failed to achieve infection in Samoa. The *Didymophyes* sp. which infects *O. nasicornis* and *O. rhinoceros* has more promise as a control agent. It seems that the infective stages can be spread by the adults. Although this gregarine does not kill *O. rhinoceros* larvae and adults no studies have been made to find the more subtle effects, if any. There are no data on the abundance of *Didymophyes* in natural populations of *O. nasicornis*. *S. kurdistana* was rare in Madagascar (Bedford, 1968c). Gregarines have been observed in *O. rhinoceros* larvae in Western Samoa (Marschall, pers. comm., 1971) but these have not been studied.

PATHOGENS

FUNGI

Metarrhizium anisopliae

History of the use of *Metarrhizium* to control *O. rhinoceros*

The earliest attempted use of *Metarrhizium* to control *O. rhinoceros* was by Friederichs in Western Samoa (Friederichs, 1913, 1918; Friederichs and Demandt, 1922). Friederichs experimented with *Metarrhizium* which he found naturally infecting *O. rhinoceros* in his laboratory culture. He applied *Metarrhizium* to specially prepared heaps and found that all larvae hatching in the heaps were subsequently killed by the fungus. However, by 1922 this method of control had been abandoned (Friederichs and Demandt, 1922) because it was considered too expensive to keep the traps in use (Hopkins, 1927).

In Ceylon, Bryce (1915) tried to duplicate Friederich's results. *Metarrhizium* spores sent from Samoa would not grow in culture and so the Philippine and Malayan strains were used. Bryce found that these could kill young *O. rhinoceros* larvae but not "well-grown" larvae. Friederichs also found that "Samoan *Metarrhizium*" would not kill "large" larvae in Ceylon (Friederichs, 1919, as cited by Surany, 1960). It is possible that the Ceylon *O. rhinoceros* populations were resistant to the overseas strains of *Metarrhizium*, as suggested by Hopkins (1927). Bryce (1923) concluded that *Metarrhizium* would only be effective when conditions favoured the fungus and were unfavourable to the insect and he did not recommend its use against *O. rhinoceros*. Friederichs (1920) also noted that under laboratory conditions many insects could be infected with *Metarrhizium* but in the field the same hosts were immune unless a particularly virulent form of the fungus was produced.

Lester-Smith (1936) found a strain of *Metarrhizium* naturally affecting *O. rhinoceros* in Ceylon and he recommended its use in compost traps in a similar method to Friederichs'. Cherian and Anantanarayanan (1939) obtained *Metarrhizium* from Ceylon and confirmed its virulence to *Oryctes*. They pointed out that its use in traps was limited by the extent to which the beetles bred elsewhere. Simmonds (1941) obtained a culture of *Metarrhizium* from scientists in Java who were using it in compost traps to control *O. rhinoceros*. He thought that field dissemination of *Metarrhizium* would not have any lasting effect on the natural level of the fungus. He also cautioned that artificially constructed breeding sites require constant careful supervision if the desired effect is to be achieved.

In India *Metarrhizium* was studied at the Madras Agricultural Department field stations from 1939 to 1945. The fungus effected complete control of *O. rhinoceros* larvae in small-scale trials in pots and pits but in extensive field trials control was limited (Nirula *et al.*, 1955). The symptomatology and epizootology of *O. rhinoceros* and *Metarrhizium* were studied by Nirula *et al.* (1955) and Nirula (1957). They found that the disease was particularly prevalent during the monsoon period and they concluded that it appeared likely that epizootics of *Metarrhizium* could be initiated by artificial dissemination of the fungus during favourable periods (e.g. the monsoon period).

Kurian (1969) reported trials in which *Metarrhizium* spores were added to cowdung pits in India and 100% mortality of *O. rhinoceros* grubs was obtained after 25 days.

Work on the biology of *Metarrhizium* and its use in the control of *O. rhinoceros* grubs was begun by Marschall (1965a, 1965b, 1966b, 1967) under the Rhinoceros Beetle Project in Western Samoa. In 1968 a field trial was planned to test the effects of extensive dissemination of *Metarrhizium* on the population of *O. rhinoceros* in a relatively confined area (Marschall, 1968a). Mr. G.A. McIntyre of the Division of Mathematical Statistics, CSIRO, Canberra advised on the design of the trial and analysed the results. Dr. I.M. Hall of the University of California was consulted on the design of the trial from the insect pathology point of view (Hall, 1968). The trial aimed at answering the following questions:

1. To what extent does an artificial addition of *Metarrhizium* raise the natural level of infection?

2. Does the higher rate of infection spread into neigh-

bouring areas?

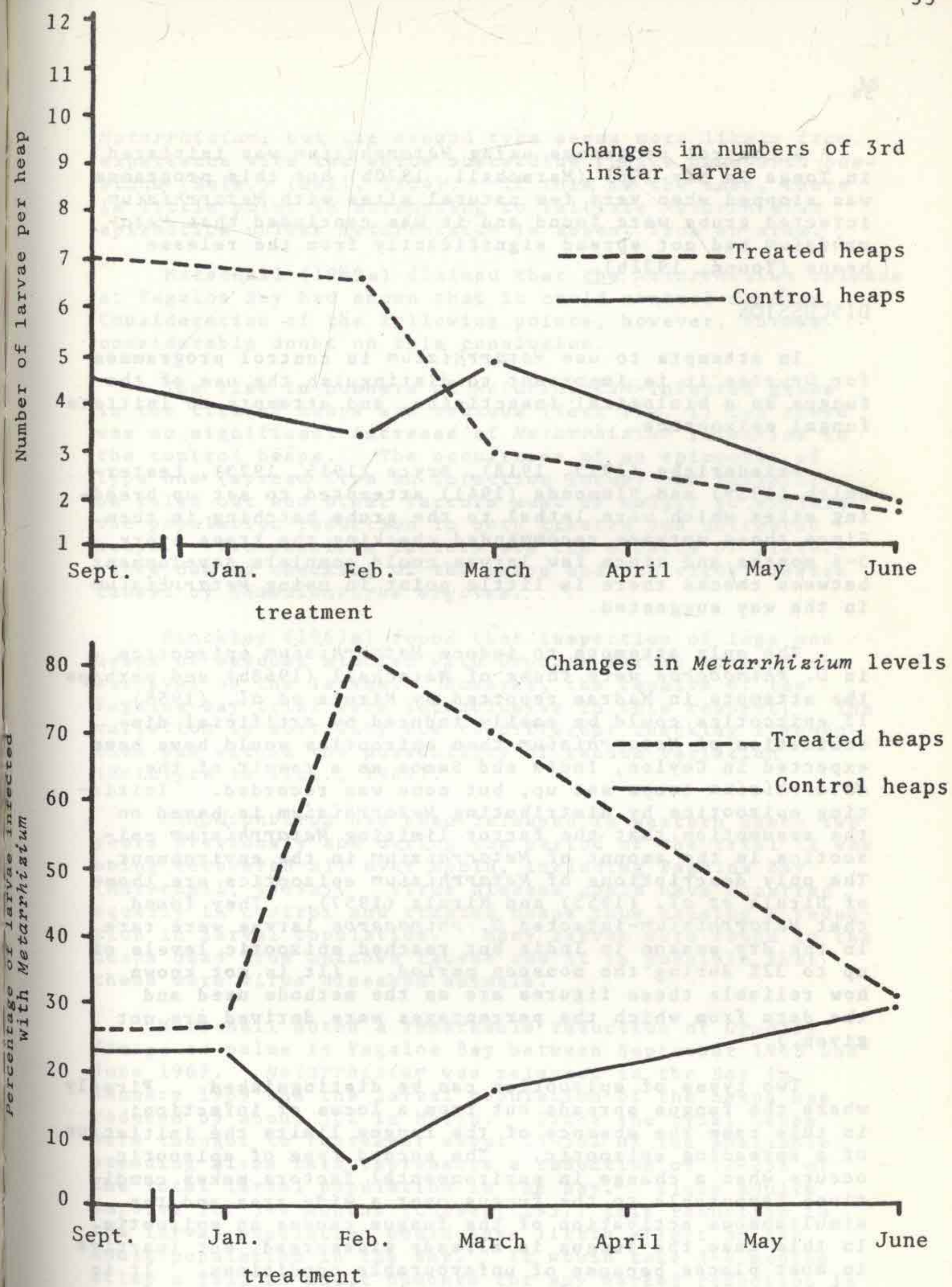
3. Does an artificially induced epizootic eventually reduce the total population of *Oryctes* in the area?

Heaps of coconut logs were erected in Fagaloa Bay, a coconut growing area which is relatively isolated from the rest of Upolu. It was estimated that the heaps represented 25-50% of all breeding sites in the area. Fifty-three heaps were sprayed with *Metarrhizium* spores and 63 were left as untreated controls, which also served to detect any spread of *Metarrhizium* from the treated heaps. The effect of disturbing the heaps when they were inspected was assessed by grouping them into three lots and inspecting them once, twice and three times respectively.

Metarrhizium levels were diagnosed by inspecting the heaps for dead larvae covered by the characteristic green spores and obviously sick larvae showing extensive brown spots on the skin, a symptom of *Metarrhizium* infection. (Brown spots on the skin are not a reliable symptom of *Metarrhizium* infection as many larvae with such spots are completely healthy (Nirula *et al.*, 1955; Zelazny, pers. comm., 1971). Marschall's data for *Metarrhizium* mortality may thus be somewhat inflated. However, grubs may also die from *Metarrhizium* without showing the brown spots.)

A pre-treatment check of all heaps was made five months before treatment to determine the natural level of *Metarrhizium* infection in the larval population. It was found that 20% of the larvae in the heaps were infected with *Metarrhizium*.

A summary of the results of the trial was given by Marschall (1969a). Unfortunately there was great variation in the number of larvae in the heaps (many heaps contained few or no larvae) and this made it difficult to draw conclusions on all aspects of the trial. The changes in *Metarrhizium* levels and larval population are illustrated in Text fig. 1. Similar trends appear when total larval population or third instar larvae only are considered. Larval populations in both treated and untreated heaps fell markedly. During the period of the trial a conspicuous reduction in *Oryctes* damage to palms in Fagaloa Bay occurred and it was concluded that the *Metarrhizium* treatment had effectively suppressed the beetle population in that area (Marschall, 1969a).



Text fig. 1. Changes in *Metarrhizium* infection and population of *Oryctes* larvae per heap.

(data from Marschall 1969a)

A control programme using *Metarrhizium* was initiated in Tonga in May 1969 (Marschall, 1970b) but this programme was stopped when very few natural sites with *Metarrhizium* infected grubs were found and it was concluded that *Metarrhizium* had not spread significantly from the release heaps (Young, 1971b).

DISCUSSION

In attempts to use *Metarrhizium* in control programmes for *Oryctes* it is important to distinguish the use of the fungus as a biological insecticide, and attempts to initiate fungal epizootics.

Friederichs (1913, 1918), Bryce (1915, 1923), Lester-Smith (1939) and Simmonds (1941) attempted to set up breeding sites which were lethal to the grubs hatching in them. Since these workers recommended checking the traps every 3-6 months and since few larvae could complete development between checks there is little point in using *Metarrhizium* in the way suggested.

The only attempts to induce *Metarrhizium* epizootics in *O. rhinoceros* were those of Marschall (1968b) and perhaps the attempts in Madras reported by Nirula *et al.* (1955). If epizootics could be easily induced by artificial dissemination of *Metarrhizium* then epizootics would have been expected in Ceylon, India and Samoa as a result of the *Metarrhizium* traps set up, but none was recorded. Initiating epizootics by distributing *Metarrhizium* is based on the assumption that the factor limiting *Metarrhizium* epizootics is the amount of *Metarrhizium* in the environment. The only descriptions of *Metarrhizium* epizootics are those of Nirula *et al.* (1955) and Nirula (1957). They found that *Metarrhizium*-infected *O. rhinoceros* larvae were rare in the dry season in India but reached epizootic levels of up to 32% during the monsoon period. (It is not known how reliable these figures are as the methods used and the data from which the percentages were derived are not given.)

Two types of epizootics can be distinguished. Firstly where the fungus spreads out from a locus of infection; in this case the absence of the fungus limits the initiation of a spreading epizootic. The second type of epizootic occurs when a change in environmental factors makes conditions favourable to the fungus over a wide area and the simultaneous activation of the fungus causes an epizootic. In this case the fungus is already widespread, but inactive in most places because of unfavourable conditions. It is not known which type of epizootic is characteristic of

Metarrhizium, but the second type seems more likely from experience with the white muscardine fungus *Beauveria bassiana* (Bals.) (Hall, 1964). If this is the case, there is little point in attempting to initiate *Metarrhizium* epizootics unless *Metarrhizium* is absent from an area.

Marschall (1969a) claimed that the *Metarrhizium* release at Fagaloa Bay had shown that it could control *Oryctes*. Consideration of the following points, however, throws considerable doubt on this conclusion.

The rise in numbers of *Metarrhizium*-infected grubs in the treated heaps was obvious (Text fig. 1) but there was no significant increase of *Metarrhizium* infection in the control heaps. The occurrence of an epizootic of type one (spread from an infection locus) can therefore be ruled out and other factors must be sought to explain the population reduction in both treated and untreated heaps. Two possible factors are the effects of disturbance due to checking of the heaps and the virus disease caused by *Rhabdionvirus oryctes*.

Hinckley (1967a) found that inspection of logs and heaps of sawdust stocked with *Oryctes* larvae lowered the survival of the larvae. However, the results of the Fagaloa Bay trial were inconclusive in this respect. The variation in mortality due to different checking frequencies was within the possibility of random variation (McIntyre in litt., 1969).

Rhabdionvirus had been released in Western Samoa two years previously and during the period of the trial it was being recovered all over Upolu, including Fagaloa Bay (Marschall, 1969a). Virus disease could have occurred equally in control and treated heaps thus causing a reduction in larval population. Many larvae were found in the heaps dead from unknown causes and it is possible that these were virus diseased animals.

Marschall noted a remarkable reduction of *Oryctes* damage to palms in Fagaloa Bay between September 1968 and June 1969. *Metarrhizium* was released in the Bay in January 1969 and the larval population of the heaps was reduced by about 50% in March. Since the trial heaps were thought to represent about 25-50% of the available breeding sites this represents a reduction of 12-25% of the total larval population in the Bay. Since adults survive for 3-4 months (Cumber, 1957) this reduction in the larval population would have little effect on the adult population in the Bay. It would take 3-4 months after a fall in adult numbers for any marked reduction in palm damage to become apparent, as all the leaves cut in an attack by a beetle will not have unfolded before 4-5 months (E.C. Young, pers. comm., 1971). A marked reduction in damage could be detected about 6 months after an extensive collapse of the adult population or about 8 months after a collapse of the grub population. Before this time the damaged leaves from previous attacks will still be unfolding. Thus the reduction of the larval population in the trial heaps from January - June 1969 could not have caused the marked reduction of palm damage visible in June 1969. The small numbers of beetles found infected with *Metarrhizium* suggest that the fungus did not cause any significant adult mortality.

Two factors could have been responsible for the reduction of damage noted by Marschall: a *Rhabdionvirus* epizootic in the *O. rhinoceros* population in 1968, or the disruptive effects of the pre-treatment check on the larval populations in September 1968. During the period of the trial there was a conspicuous reduction in *O. rhinoceros* damage to palms all over Upolu and this reduction in the *O. rhinoceros* population was ascribed to the effects of *Rhabdionvirus* (Marschall, 1969b, 1970a). If *Rhabdionvirus* was responsible for the population reduction in the rest of Upolu then it could have been equally responsible for the population reduction in Fagaloa Bay.

There are many conflicting reports on the longevity of *Metarrhizium* spores. Walstad *et al.* (1970) showed that high temperatures reduce life: at 21°C most spores were inviable after two months. Temperatures in coconut logs in Samoa range from 24 to 35°C and in sawdust heaps the average temperature is 28°C (Hinckley, 1967a). *Metarrhizium* levels in the treated heaps at Fagaloa Bay had returned to normal after 6 months suggesting that the added spores were dead by this time. The key factor in the survival of *Metarrhizium* spores is the humidity. At high humidities the spores will germinate. However, it is likely that *Metarrhizium* can grow saprophytically and this may be the way it survives in the absence of a suitable host.

In the Fagaloa Bay trial the heaps were disturbed frequently and *Metarrhizium* spores would have been disturbed throughout the heap. It is doubtful if *Metarrhizium* applied to the top of compact compost heaps or the outside of logs would have any effect on grubs living within the heaps and logs. Since most small-scale *Metarrhizium* release trials are checked frequently to follow the incidence of *Metarrhizium* this disturbance factor could explain why this fungus often gives good control in trials but

fails in field control programmes where it is only applied to the surface of the breeding material.

It is concluded that *Metarrhizium* has little use in traps because its use requires such careful supervision. It is very difficult to use as a biological insecticide because *Oryctes* grubs are so well concealed. There have been no successful attempts to induce *Metarrhizium* epizootics in *Oryctes* and previous extensive experience with this fungus and other related fungi suggests that further attempts would be equally fruitless.

Beauveria bassiana

This fungus was discovered on *O. rhinoceros* in India by Venkatraman (1956a). It is similar to *Metarrhizium* in action. Apparently it also attacks *O. nasicornis* in Europe. The strains of *B. bassiana* tested by Steinhaus and Huger were possibly not virulent for *O. rhinoceros*. As with *Metarrhizium* it would be very difficult to utilise *B. bassiana* in the control of *Oryctes*.

Cordyceps sp. (n. sp.?)

A fungus of this genus has been found by Venkatraman (1958) at Fenerive in Madagascar and by Bedford (1969b) on the Isle Sainte Marie, Madagascar. Lepointe (1960) recorded an '*Isaria*' fungus from these two places and this was probably the same *Cordyceps*. Venkatraman recorded "heavy mortality of *Oryctes* larvae in a water-logged area". Bedford found about 50% of the *Oryctes* larvae in one small area had been killed by *Cordyceps*. Lepointe observed diseased larvae on three occasions and once found infected pupae. Venkatraman tried to culture the fungus and sent specimens to E.B. Mains of the University of Michigan who considered it to be a new species (Venkatraman, 1958; Anon., undated). There is no further record of these enquiries.

Marschall (pers. comm., 1971) failed to infect *O. rhinoceros* larvae with *Cordyceps* sent from Madagascar by Bedford and it is possible that the fungi were non-viable on arrival. However, species of *Cordyceps* are usually very difficult to culture in the laboratory.

Hurpin (1966) has a photograph of a *Strataegus aloeus* L. larva infected by a *Cordyceps* fungus. No information on the fungus is given.

BACTERIA

Venkatraman (1958), Surany (1960) and Manjunath *et al.* (1969) found various bacteria in *O. rhinoceros* in

India. However, none of the bacteria seems to be truly pathogenic to *Oryctes*, most are probably saprophytic.

RICKETTSIAE

No rickettsial disease of *Oryctes* is known at present.

VIRUSES

Rhabdionvirus oryctes

The only known virus disease of *Oryctes* is "Malaya disease" caused by *R. oryctes* which was described from *O. rhinoceros* larvae by Huger (1966b). Both Huger (1966a,b, 1969a) and Marschall (1970a) claimed that the virus caused heavy mortality of larvae in the field in Malaya and Western Samoa, respectively. However, their mortality figures were derived from larvae which had been collected in bulk containers and it is very likely that healthy larvae were infected by virus and *Metarrhizium* diseased larvae during collection. Huger (1966a) reported 60-80% virus mortality but only 1-3% *Metarrhizium* mortality in Malaya in 1963. Marschall (1970a) found 70% virus and 23% *Metarrhizium* mortality in Western Samoa in 1969. Huger did not present the data from which his percentage mortalities were derived and these may only be estimates.

These high disease levels were taken to indicate that the virus could cause epizootics in larval populations. Because all larvae developed the disease at the same time Huger considered that the disease must have been present in a latent state, but these observations are more easily explained by assuming cross contamination of virus during collection of the larvae. There is as yet no good evidence for *Rhabdionvirus* epizootics in larval populations or for latent infections of *Rhabdionvirus*.

In Malaya Barlow and Chew Poh Soon (1970) held 88 field-collected larvae individually in tins until they had died or pupated. Ten larvae died with virus symptoms, one with *Metarrhizium* and 28 died from "concussion". (No confirmatory tests were carried out on the virus grubs and these figures are thus somewhat unreliable as virus symptoms are not consistent.) In 1970 Barlow made further surveys and found that about 10% of sites in the field contained virus-infected larvae (pers. comm., 1971). In Western Samoa in 1969-1970 Maddison and Zelazny (1970) collected 647 larvae individually from natural sites, taking stringent precautions to avoid cross contamination. When held in the laboratory nine larvae died from virus (confirmed by feeding tests) and nine from *Metarrhizium*.

Zelazny (1971a) has subsequently found that about 8% of *O. rhinoceros* breeding sites in Western Samoa contained virus-infected larvae. Bedford (1971b) and Marschall (1971) visited Malaya in July 1970 to survey *Rhabdionvirus* on *O. rhinoceros*. They found that virus was widespread, but infected larvae were very rare in the field. *O. rhinoceros* caused great damage in some areas of Malaya and control measures against it were necessary.

The above evidence shows that *O. rhinoceros* situation in Malaya is similar to that in Western Samoa. Zelazny (1971a) estimated that *Rhabdionvirus* caused 8-15% mortality of *O. rhinoceros* larvae in Western Samoa.

The evidence accumulated by Zelazny (1971a) suggests that the major effect of *Rhabdionvirus* is on the adult population causing a reduction in fecundity and length of life. In this light the rapid spread of *Rhabdionvirus* and its controlling effect in Western Samoa seem easier to explain.

The effects of *Rhabdionvirus* release on *O. rhinoceros* populations should be determined in current release programmes being conducted by the UN/SPC Project in Tonga, Fiji and American Samoa.

It is likely that *Rhabdionvirus* has always been present in Malaya, but there is no evidence that it ever controlled *O. rhinoceros* at economic levels. *O. rhinoceros* has always been a major pest and sanitation is widely practised to control it. At best the virus disease may play a substantial role in an integrated control programme for *O. rhinoceros*. No attempt has yet been made to increase the effects of the virus in the field. Barlow (pers. comm., 1971) is currently investigating the use of the virus as an insecticide. Current research by the UN/SPC Project should provide information on the ecology and dynamics of *Rhabdionvirus* and show how mortality from virus could be increased, though this would seem difficult because of the high percentage of infected beetles prevailing in an apparently stable situation.

DISEASE ORGANISMS FROM OTHER INSECTS

It is doubtful if any disease of a distantly related insect could spread naturally through an *Oryctes* population in an epizootic. However, some of these disease organisms could be used as 'biological insecticide' to treat *Oryctes* breeding sites such as sawdust or compost heaps. The use of chemical insecticides in such sites is often dangerous to domestic animals, stock, and humans. A non-specific chemical also destroys beneficial organisms.

Pathogens	Usual Host	Tester	Result
Bacillus popilliae Dutky	*Popillia japonica* New.	Steinhaus (1951)	-
B. lentimorbus Dutky	" "	"	-
B. thuringiensis Becl.	Various lepidoptera	"	?
Beauveria bassiana (Bals.)	Numerous hosts	"	?
Aspergillus sp.	*Alabama argillacea* (Hbn.)	"	-
Bacillus lentimorbus var. *australis* Beard	*Heteronychus sanctaehelenae* Blanc.	Cumber (1956)	-
B. euloomarahae Beard	"	"	-
Moratovirus lamellicornium (K. and H.)	*Melolontha* sp.	Huger *et al.* Darmstadt	-
Pseudomoratovirus tipulae (TIV) Xeros	*Lymantria dispar* L.	"	-
Rickettsiella spp.	*Melolontha* sp.	"	-
B. popilliae	Commercial preparation	"	-
B. lentimorbus	*H. sanctaehelenae*	"	-
B. euloomarahae	"	"	-
Beauveria tenella (Del.)	Lamellicornia	"	+
Sericesthis iridescent virus (SIV)	*Sericesthis pruinosa* (Dal.)	Krieg (1968)	-
Sarcina lutea Schr.	(Isolated from *O. rhinoceros* by Lal in India)	"	-
Pseudomonas aeruginosa (Schroeter) Migula		"	-
Serratia marcescens Bizio		"	-
B. thuringiensis type IIIb strain HDI		Zelazny (1971b)	-
B. thuringiensis	R + M, L-69	"	-
B. popilliae	"Doom"	"	-
B. popilliae	"Japonex"	"	-

+ = Recovered; - = Not recovered; ? = Not evaluated

TABLE 1

SUMMARY OF PREDATORS, PARASITES AND PATHOGENS INTRODUCED INTO PACIFIC COUNTRIES

Species	Country of origin	Country of release	Year	Approx. no. released	Habits and Habitat in country of origin	Result
		PREDATORS				
Elateridae						
Lanelater fuscipes	Ceylon	W. Samoa (Upolu)	1955	47	In rotting coconut logs	+
	W. Samoa	Tonga	1966	26	In and under coconut logs	?
	W. Samoa	Tokelaus	1971	36	In and under coconut logs	?
	W. Samoa (Upolu)	W. Samoa (Savai'i)	1971	38	In and under coconut logs	?
Alaus speciosus	Ceylon	W. Samoa	1955	45	In rotting coconut logs	+
Pyrophorus pellucens	Trinidad	New Guinea	1954	4290	Larvae found in crowns of palms, in soil and coconut logs. Ecology not well known.	-
+ two other *Pyrophorus* sp.		Fiji	1953-54	2700		
Alaus montraveli	New Caledonia	Wallis	1965-66	83	In rotting forest logs	?
A. farinosus	New Caledonia	Wallis	1965-66	16	In rotting forest logs	?
Histeridae						
Pachylister chinensis	W. Samoa	Palaus	1952	100	Found under split log traps and in compost	+
	Fiji	New Guinea	1952	1000?	Originally introduced from Java to control flies breeding in cow-dung	+
	W. Samoa	A. Samoa	1954	?		+

Species	Country of origin	Country of release	Year	Approx. no. released	Habits and Habitat in country of origin	Result
Leionata spp.	Trinidad	New Guinea	1952	?	Found in decaying banana stems	-
	Trinidad	Fiji	1953-54	16000		-
	Trinidad	Palaus	1952	?		
Placodes ebeninus	Kenya	Palaus	1952	25	In decaying bases of sisal plants	-
Carabidae						
Carabus sp.	Europe	W. Samoa	1917	?	Large ground carabid	-
Catascopus fascialis	Malaya	W. Samoa	1939	122	Under the bark of rotting rubber logs	-
Mecodema spinifer	New Zealand	Fiji	1954	60	Large ground carabid	-
Pheropsophus hilaris sobrinus	India	Fiji	1962	179	In manure pits and compost	-
	India	Tonga	1962	40		
	India	Wallis	1962	98		
	India	Fiji	1971	330		
P. lissoderus	India	Fiji	1971	113	In manure pits and compost	?
P. occipitalis	India	Fiji	1971	185		?
P. stenoderus	India	Fiji	1971	20		?
Oxylobus punctatosulcatus	India	Tonga	1962	38	In manure pits and compost	-
Scarites dubiosus & *Scarites* sp.	India	Fiji	1962	113	In manure pits and compost	-
	India	Tonga	1962	60		-
	India	A. Samoa	1962	37		-
		W. Samoa	1962	32		-
Scarites madagascariensis	Madagascar	Fiji	1957	263	Found in rubbish heaps	-
	Madagascar	Wallis	1957-59	227	Feeding on scarabaeid larvae	-
Neochryopus savagei	Nigeria	Fiji	1960-63	2228	In axil debris in the tops of oil palms	+
	Nigeria	New Guinea	1960-63	4104		+
	Nigeria	A. Samoa	1960-63	1328		-
	Nigeria	W. Samoa	1960-63	793		-
Ochryopus gigas	Nigeria	Fiji	1960	12		-
Reduviidae						
Platymeris laevicollis	Zanzibar	Palaus	1961 to 1969	1000 + adults, nymphs and eggs	In the crowns of coconut palms. Predator of adult beetles.	-
	Zanzibar	W. Samoa				
	Zanzibar	A. Samoa				-
	Zanzibar	New Britain				-
	Zanzibar	Tonga				-
	Zanzibar	Fiji				-
	Zanzibar	Wallis				-
	Zanzibar	Tokelaus				-
Vertebrates						
Talpa europaea	Europe	W. Samoa	1912	?		-
Erinaceus europaeus	Europe	W. Samoa	1912	?		-
Lygosoma nigra	Tonga	Tonga		?		?
PARASITES						
Scoliidae						
Scolia oryctophaga	Madagascar and Mauritius	W. Samoa	1939	202	Parasite of *O. simiar* and *O. ranavola*. In Mauritius it parasitises *O. tarandus*.	-

Species	Country of origin	Country of release	Year	Approx. no. released	Habits and Habitat in country of origin	Result
	Mauritius	New Britain	1952	80		-
	Mauritius	New Britain	1953	1000		-
	Mauritius	Fiji	1954	750		-
	Madagascar	Fiji	1956	14		-
Scolia ruficornis	Zanzibar	W. Samoa	1945	465	Parasite of *O. boas* in compost heaps	+
	Zanzibar	Palaus	1948-51	301		+
	Zanzibar	New Britain	1952	301		+
	Palaus	Fiji	1958	230		+
	W. Samoa	Fiji	1965	150		+
	Palaus	Wallis	1959	130		+
Scolia procer	Malaya	Palaus	1963	1	Primarily a parasite of *Chalcosoma atlas* in palm logs. Secondarily a parasite of *O. rhinoceros*.	-
	Malaya	New Britain	1963	?		-
Scolia quadripustulata	India	Tonga	1962	6	One specimen found parasitising 2nd instar *O. rhinoceros* in a manure heap.	-
	India	Fiji	1962	8		
Elis romandi	Madagascar	W. Samoa	1939	1	Host unknown	-
Campsomeris azurea	India	Fiji	1962	15	Host unknown, found near manure heaps	-
Acarina						
Hypoaspis sp.	Ivory Coast	Tokelaus	1968	Large no.	Predator of the eggs of *O. monoceros* in Africa	?
Nematoda						
Rhabditis sp.	Madagascar	Fiji	1957	Large no.	Parasite of *Oryctes*	+
	Madagascar	A. Samoa	1957	" "		
Rhabditis sp. nr. *maupausi*	Ceylon	W. Samoa	1957	" "	Parasite of *O. rhinoceros* in manure heaps	?
	Ceylon	A. Samoa	1957	" "		?
	Ceylon	Wallis	1957	" "		?
		PATHOGENS				
Fungi						
Metarrhizium anisopliae	Java	W. Samoa	1939		Used against *O. rhinoceros* in traps	+?
	Argentine	Wallis	1952			
	W. Samoa	Tokelaus	1967		Disease of *O. rhinoceros*	?
	W. Samoa	Tonga	1969			+?
Viruses						
Rhabdionvirus oryctes	Malaya	W. Samoa	1967		Disease of *O. rhinoceros* in Malaya	+
	Malaya	Tokelaus	1967			+
	W. Samoa	Fiji	1970		Disease established on *O. rhinoceros* in W. Samoa	+
	W. Samoa	Tonga	1970			+
	W. Samoa	Palaus	1970			+
	W. Samoa	Wallis	1970			+
	W. Samoa	A. Samoa	1972			+
Bacteria						
Bacillus popilliae	U.S.A.	Palaus	1951		Disease of the Japanese beetle in the U.S.A.	-
		A. Samoa	1957			-

+ = Recovered; - = Not recovered; ? = Not evaluated

Ten varieties of *Bacillus thuringiensis* were tested by Kurian (1969) in India, but the results of these tests were inconclusive as there was 60% mortality in the control larvae. Certain varieties caused 100% mortality of *O. rhinoceros* larvae after 21 days.

SUGGESTIONS FOR FUTURE WORK

No control agent has yet been found which promises to control *Oryctes* populations unaided. It has never been conclusively demonstrated that any *Oryctes* population in any country is controlled below an economic level by a natural enemy. In view of these discouraging facts the best policy is to introduce all promising control agents. Acting together, a complex of minor controls may make a useful contribution to an integrated control programme for *Oryctes*.

Biological control agents which merit further study, with a view to introducing them into the Pacific area are listed below. Before introducing an agent into the Pacific, the following points should be considered.

1. The ease of obtaining large numbers of the agent for release or the ease of rearing large numbers in the laboratory.
2. Ecological similarity between the habitat of the agent in its country of origin and the habitats in the Pacific area.
3. The ability of the agent to find its *Oryctes* host.
4. The specificity of the control agent for *Oryctes*.
5. The potential rate of increase of the agent.
6. The potential of the agent for reducing the *Oryctes* population.
7. Potential harmful side effects of the agent.

COLEOPTERA

Carabids

No promising species of carabid for *Oryctes* control is known. Most species previously introduced did not live in habitats ecologically similar to those of *O. rhinoceros* in the Pacific.

Elaterids

Although they are relatively uncommon some large elaterid larvae are adapted to preying on beetle larvae and other insects living in and under rotten logs. This fact makes them the best *Oryctes* predators available and they should be introduced into all Pacific countries where *O. rhinoceros* occurs. Two elaterids, *Alaus speciosus* and *Lanelater fuscipes*, were introduced into Western Samoa from Ceylon in 1955. Although less than 50 specimens of each insect were introduced they became established and have spread slowly from their release sites. Thus although elaterids are difficult to collect and rear in the insectary they can become established from small releases of larvae and adults.

L. fuscipes and *A. speciosus* could be introduced into other Pacific countries from Western Samoa. *Lanelater* seems to breed rapidly in sawdust heaps and these could be set up as release sites for larvae. *Alaus* is common in softwood logs such as kapok and also seems to prefer higher altitudes in Western Samoa. *Alaus* larvae would probably be best released into softwood logs or well-rotted coconut logs. Termites are a common alternative prey for *Alaus* larvae.

The Malayan *Lanelater aequalis* Cand. and *Alaus lacteus* F., could be introduced into the Pacific area to diversify the elaterid fauna. The Madagascar elaterids could also be considered as these may be adapted to prey on *Oryctes*. *Alaus depressicollis* from the Palau Islands may be better adapted to survive on the lower coral islands of the Pacific. Elaterid larvae could be collected by "beetle gangs" in the course of *Oryctes* control work. The larvae seem to survive well in captivity and travel easily. A few adults, the ideal stage for introduction, might be caught by light or attractant trapping.

Histerids

Pachylister chinensis and *Plaesius javanus* could be introduced into Pacific countries that do not yet have them. They are probably very minor predators of *Oryctes* but could be useful against a variety of noxious insect larvae.

HEMIPTERA

Reduviids

No suitable reduviid is known at present. After the experience with *Platymeris* it seems that this group will not establish easily in the Pacific.

HYMENOPTERA

Scoliids

Two scoliids, *Scolia ruficeps* from Malaya and *Scolia cyanipennis* from India, have been recorded as possible primary parasites of *O. rhinoceros* larvae. The possibility of further study of the latter (*S. ruficeps* is rare) and possible introductions could be investigated.

Introductions of adult *S. procer* from Malaya could be considered, even though it is primarily a parasite of *Chalcosoma*. This wasp has never been released in the Pacific in any numbers. Large numbers of adults seem to be available in Malaya. This parasite should also be tested against *Scapanes*, as *Scapanes* appears to be closely related to *Chalcosoma*.

Scolia ruficornis should be introduced into countries where *O. rhinoceros* breeding in compost and rubbish is a problem (e.g. Tonga).

DIPTERA

No suitable dipterous parasite or predator is known at present.

ACARINA

In spite of the confusion over the identity of the *Hypoaspis* mites on *Oryctes* and of their role as egg predators it seems profitable to introduce mites from a variety of countries in case one or more varieties or species prove to be more predatory on *Oryctes* eggs than the *Hypoaspis* already in the Pacific. The *Caloglyphus* mites from Malaya or Africa could also be introduced. There would seem to be little possible harm arising from these introductions. Mites have the advantage that they can be carried into the *Oryctes* breeding site on the adult beetle. *Hypoaspis* at least seems specific to *Oryctes*.

PATHOGENS

In view of the dubious results obtained by Surany in the only major search for pathogens of *Oryctes*, and of the later discovery of a very useful virus disease in Malaya, it seems that there is still potential for further discoveries in the field.

PROTOZOA

No promising protozoan is known at present.

NEMATODA

The rhabditids studied by Poinar may warrant some further study of a low priority. Present evidence suggests that they are not sufficiently pathogenic to be of much use.

FUNGI

Because of the difficulty of applying *Metarrhizium* to *Oryctes* breeding sites it has limited use as a biological insecticide. Its low rate of dispersal makes it very difficult to initiate epizootics. Nevertheless because *Metarrhizium* can cause substantial mortality of *Oryctes* under favourable conditions it should be introduced into countries in which it is not found.

If possible the *Cordyceps* sp. found on *Oryctes* in Madagascar should be tested against *O. rhinoceros* in the laboratory and in the field.

BACTERIA AND RICKETTSIA

No bacterial pathogens of *Oryctes* are known. It is unlikely that none exists and this seems a promising field for future research.

In view of the possibility of mammalian pathogenicity of rickettsia, great caution should be exercised in their study and use.

VIRUSES

Present studies of *Rhabdionvirus oryctes* should determine its natural role in the population regulation of *Oryctes* and the effects of manipulating the amount of virus in the environment. The virus has already been introduced into most countries where it does not occur.

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PROCEEDINGS OF THE THIRD INTERNATIONAL SYMPOSIUM ON BIOLOGICAL CONTROL OF WEEDS

September 1973

Edited by

A. J. WAPSHERE

MISCELLANEOUS PUBLICATION NO. 8
COMMONWEALTH INSTITUTE OF BIOLOGICAL CONTROL

COMMONWEALTH AGRICULTURAL BUREAUX
FARNHAM ROYAL, SLOUGH SL2 3BN, ENGLAND
JUNE 1974