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Introduction

The Rhinoceros beetle, *Oryctes rhinoceros* (L.), is one of the most serious pests of coconut palms in many of the coconut growing countries in the world. The adults attack the young folded leaves in the heart of the palm and infested trees may receive a serious set back and may even die. Though the coconut palm is its favoured host, the beetle also attacks other palms and has also been reported feeding on agave, banana, *Colocasia*, pineapple, screw pine, sugarcane, tree-fern, etc. In India this pest has caused great concern to coconut growers since very early times. Attempts have been made to control it by chemical and mechanical methods without satisfactory results. The possibility of biological control has received scant attention. On behalf of the South Pacific Commission Dr. T.V. Venkatraman conducted a survey for natural enemies of *Oryctes* in India from 1954 to 1956 and his records are mentioned elsewhere in this paper. The present authors made an extensive survey from January 1961 to December 1962, and again from September 1963 to December 1964 in the States of Andhra Pradesh, Assam, Gujarat, Kerala, Madras, Maharashtra, Orissa and West Bengal where damage to coconuts by *Oryctes* has long been serious. The results of this survey, which was financed by the South Pacific Commission, are embodied in this paper. A résumé of previous work on the natural enemies of *O. rhinoceros* in India and other countries is also given.

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Résumé of previous work on natural enemies of *O. rhinoceros* in India and other countries

1. Parasites

Scolia procer Ill. has been reported to parasitise a large percentage of the larvae of *O. rhinoceros* in the Federated Malay States (Richards, 1919). In 1961 one of the present authors (V.P. Rao) also observed it parasitising the larvae at Layang Layang in Johore State during the course of his observations in oil palm estates. Gressitt (1953) reported the introduction of *S. procer* from Malaya into Palau and that it was not recovered until December 1952. Corbett (1936) suspected that larvae of *O. rhinoceros* in a coconut stump in Malaya were parasitised by *Scolia ruficeps* Sm. However, later investigations failed to confirm this (Simmonds, 1940). Wood (1964) referred only to *S. procer* as a native parasite of *O. rhinoceros*, which is a serious pest of oil palms in Malaya.

Thompson (1958) catalogued as parasites of *O. rhinoceros* the Scoliid wasps *Campsomeris luctuosa* Sm. (in the Dutch East Indies), *Scolia azurea* Chr. (in the Dutch East Indies and Taiwan), *S. oryctophaga* Coq. (in Mauritius and Java), *S. procer* (in the Dutch East Indies) and *S. ruficeps* (in Malaya).

Since *S. oryctophaga* from Madagascar and Mauritius was able to breed on *O. rhinoceros* grubs in Java it was shipped from the former two islands to Samoa (Simmonds, 1940) but failed to become established, possibly because of the absence of a definite cool season which controls the development of the pupae (Simmonds, 1949). *S. oryctophaga* was also introduced into Fiji from Madagascar (Coconut Pests & Diseases Board, Fiji, 1956-1957).

Scolia ruficornis F., a parasite of the grubs of *Oryctes monoceros* Ol. and *O. boas* F. in Zanzibar, was introduced into Western Samoa against *O. rhinoceros* in 1945. By 1949 it was established (Simmonds, 1949) and by 1956 it was found to be widely distributed and to have increased greatly in numbers (Coconut Pests & Diseases Board, *loc. cit.*). *S. ruficornis* from Zanzibar and *S. patricialis* Burm. var. *plebeja* Grib. from Malaya, where the latter is known to parasitise *O. rhinoceros* larvae, were introduced into the Palau Islands (Bryan, 1949). Hoyt and Catley (1967) mentioned the establishment of *S. ruficornis* in the Palaus and also in North Island (Seychelles) and New Britain in addition to Samoa, Fiji and Diego Garcia. Orian (1959) had earlier reported the successful establish-

ment in Diego Garcia of *S. ruficornis* introduced from Zanzibar but with little effect on the population of *O. rhinoceros*. This parasite has been introduced into Malaya from East Africa and is being established in various parts of the country (Wood, 1964).

Pillai (1923) mentioned that a larva of *O. rhinoceros* was parasitised by a Dipteron in Kerala. Venkatraman *et al* (1954) reared a Sarcophagid, *Sarcophaga fuscicauda* Bottcher, from adults of *O. rhinoceros* collected at Trichur (Kerala).

Venkatraman (1955) found *Campsomeris indica* Sauss. in a coconut estate in Kurunegala (Ceylon) where heavy *Oryctes* breeding was noticed. The three female wasps collected were provided with different larval stages of *Oryctes* but they laid no eggs. Later he (1958) reported the presence of *Scolia* sp. (*rubiginosa* ?) in the larval tunnel of *Oryctes* in a dead coconut log at Mangaldai (Assam) and remarked that it appeared to be a promising parasite. *S. rubiginosa* F. is considered as a synonym of *S. azurea*. Dammerman (1929) had earlier recorded *S. azurea* as a parasite of *Xylotrupes gideon* F. in Malaya but doubted its capacity to parasitise *O. rhinoceros*.

Menon & Pandalai (1958) have stated that so far no Scoliid parasites have been found to attack *O. rhinoceros* in the important coconut-growing areas in India.

2. Predators

Neochryopus savagei Hope is predaceous on the adults of *O. boas*, *O. monoceros* and *O. agamemnon* Burm. attacking oil palms in Dahomey in West Africa (Alibert, 1938). Lepesme (1947) referred to this Carabid preying on the Scarabaeids attacking palms in tropical Africa. Hoyt (1963) considered *N. savagei* as the most important bio-control agent in Nigeria and reported its introduction into and liberation in Fiji, Samoa, Tonga and the Territory of Papua and New Guinea for the control of *O. rhinoceros*. Another Carabid, *Ochryopus gigas* Schiodte, was also sent to Fiji from Nigeria in 1960; it was obtained only in small numbers (14 adults) and was found to attack all larval stages and also the adults of *Oryctes* (Coconut Pests and Diseases Board, Fiji, 1959-1965).

Catascopus fascialis Wied. was found to attack young *Oryctes* larvae in Malaya and a consignment of this Carabid was successfully shipped to Samoa in February 1939 (Lever, 1939). Venkatraman (1958) reported adults and larvae of *Catascopus whithilli* Hope preying on *Oryctes* grubs in

Kuthupuramba near Tellicherry (Kerala) and that they occurred in association with the grubs in Kamrup (Assam).

Gressitt (1953) mentioned the introduction into the Palaus of the Histerid *Pachylister chinensis* (Quens.) from Western Samoa in 1952 where it was established for the control of *Musca domestica* L., and found feeding on young *Oryctes* larvae. Another Histerid, *Placodes ebeninus* Lewis was also introduced into the Palaus from Tanganyika for the possible control of *O. rhinoceros*.

Hololepta marginepunctata Mars. (*Leionata colombiana* Mars.), *H.* (*L.*) *quadridentata* (F.) and probably a third Histerid species of the same genus, which were reported to prey on the larvae of the banana weevil borer (*Cosmopolites sordidus* (Germ.)), and the Elaterid *Pyrophorus pellucens* Eschscholtz were sent by the CIBC West Indian Station, Trinidad to Fiji; these and another Histerid, *Plaesius javanus* Erichs. introduced into Fiji from Java against *C. sordidus*, were observed to feed very well on young *Oryctes* larvae in the laboratory (but this, of course, means very little since in the laboratory many of these predaceous larvae are very polyphagous); all these predators were released near the Tamavua river, where *Oryctes* infestation was reported to be heaviest and some of the Histerids also near Nausori; *P. chinensis* already occurs in Fiji, having been introduced from Malaya (O'Connor, 1953). Small numbers of the predaceous Carabid *Mecodema spinifer* Broun obtained from New Zealand were also liberated in Fiji (O'Connor, 1955).

The Elaterids *Lanelater* (= *Agrypnus*) *fuscipes* (F.) and *Alaus speciosus* Linn. were also introduced into Western Samoa from Ceylon, where they were reported to be common in rotten coconut logs and stumps and in compost pits containing large numbers of rhinoceros beetle and other insect larvae (Cumber, 1957). Both these species have become established (Hoyt & Catley, 1967). In Mauritius Vinson (1963) noticed *L.*(=*A.*) *fuscipes* in association with *O. rhinoceros* in a coconut grove.

The Carabid *Scarites madagascariensis* Dej. was regarded as an efficient predator of Dynastid larvae in Madagascar and, therefore, was introduced into Fiji against *O. rhinoceros* in 1957. 131 adults were released, but since large numbers of toads were later found at the liberation sites it was doubtful whether any Carabid has survived (Coconut Pests & Diseases Board, Fiji, 1957-1959).

The Reduviid *Platymerus rhadamanthus* Gerst. was obser-

ved by Vanderplank (1958) to kill adults of *O. boas* and *O. monoceros* in Zanzibar and it was suggested that it might also be of value against other species of *Oryctes* elsewhere. It has since been introduced into Fiji, New Britain, New Guinea, the Palau Islands, Samoa, Tonga and Wallis Island. Despite the liberations of many thousands of individuals in all stages of development there has been no indication of establishment in any of the South Pacific territories. In Western Samoa research conducted by the U.N./S.P.C. project indicated that perhaps the only obvious factor limiting its establishment is predation of eggs and nymphs by the ant *Pheidole megacephala* (F.), which nests in the litter accumulated in the axils of coconut fronds (Hoyt & Catley, 1967). *P. rhadamanthus* has also been brought into Malaya from Africa but as it is feared that it may attack climbers in the coconut trees liberations have not to date been made (Wood, 1964). This predator was also imported into India and found to feed on adults of *O. rhinoceros* in the laboratory (Kurian & Pillai, 1964). Since it could not be successfully bred in the laboratory field liberations were not made.

Rao & Manjunath (1964) recorded the Carabid beetle *Pheropsophus sobrinus* (Dej.) var. *desbordesi* Maindr. feeding on the young larvae of *O. rhinoceros* in manure pits at Gauhati (Assam). Several shipments of the beetle were sent to Fiji and Mauritius where in the laboratory they voraciously fed on the second instar larvae of *Oryctes*.

Venkatraman (1958) and Hoyt (1963) reported the occurrence of mites on *Oryctes* in Asia and Africa. Surany (1960) is of the opinion that considerable mortality is caused by mites feeding on eggs and freshly hatched grubs though they do not seem to cause much damage to the older larvae or to the adults.

3. Diseases

Friedrichs (1913) reported an entomogenous fungus, *Metarrhizium anisopliae* (Metsch.) Sorokin, to be the most important natural enemy of *O. rhinoceros* in Samoa. After conducting several experiments to assess the pathogenicity of this fungus, he (1920) concluded that under laboratory conditions it was possible to infect many different species with the disease owing to certain unnatural conditions which tended to predispose the host to attack, but that in their natural surroundings the same hosts proved to be more or less immune to the disease unless a particularly virulent form of it was produced.

Cultures of *M. anisopliae* were introduced into Ceylon from the Philippines, Malay States, Hawaii and Samoa. No growth was obtained from the last two cultures, but pure cultures were established from the Philippine and Malay stocks. In field experiments using breeding traps the fungus attacked only the larvae that had been kept in captivity until their vitality was impaired, and it was obvious that the disease could only occur when conditions favoured the fungus and not its host. Its use against rhinoceros beetle was, therefore, not recommended (Bryce, 1915 and 1923). Corbett & Pagden (1941) expressed the same view on the use of this fungus against *Oryctes* in Malaya. However, *M. anisopliae* is receiving a final evaluation to determine its significance as a controlling factor of *O. rhinoceros* under field conditions in Western Samoa (Hoyt & Catley, 1967).

A culture of *M. anisopliae* was introduced into India from Ceylon in 1937. A number of laboratory and field trials with this fungus have been conducted (Administrative Report of the Madras Agricultural Department, 1938-1940; Cherian & Ananthanarayan, 1939; Nirula, 1958; Nirula *et al*, 1955, and Radha *et al*, 1956), but the results obtained were very erratic.

In 1954 two bacilli, *Bacillus lentimorbus* Dutky var. *australis* Beard and *B. euloomarahae* Beard, isolated from the larvae of *Sericesthis pruinosa* (Dalm.) and *Heteronychus sanctae-helenae* Blanch., respectively, were obtained from the U.S.A. for trial against *Oryctes* in Western Samoa. Injections of spores of either species into the coelomic cavity of the third instar larvae of *O. rhinoceros* resulted in some mortality but no rapid multiplication of bacilli was noticed (Cumber, 1957).

Huger (1966) detected a virus disease in the larvae of *O. rhinoceros* in Malaya. It was easily transmitted to third instar larvae by contaminated food as well as by intrahaemocoelic inoculation. Death ensued in about 6 to 30 days. The virus has been placed in a new genus *Rhabdionvirus* and named *R. oryctes* Huger; the disease caused by it is called "Malaya disease". Field trials with this virus are being contemplated in Western Samoa.

4. Nematode parasites

A nematode, *Rhabditis* sp. nr. *maupasi*, which infests and kills larvae and adults of *O. rhinoceros* in Ceylon, was introduced into Fiji in 1957. It was reared in the laboratory and found also to infect other Lamellicorn larvae. Colonies of it were despatched to Samoa (Coconut

Pests & Diseases Board, Fiji, 1955-1957). In 1957-58 another nematode, closely resembling that from Ceylon, was imported from Madagascar. An improved breeding technique using killed host larvae was employed for both the nematodes, and breeding and distribution were continued (Coconut Pests & Diseases Board, Fiji, 1957-1959).

Exploratory work in India

A. Search for parasites

1. Search for parasites of *Oryctes* grubs

a) Examination of manure heaps and trunks of dead coconut trees

Since Scoliids are parasites of *Oryctes* larvae elsewhere, intensive search for them was carried out in a number of areas in the States of Andhra Pradesh, Assam, Gujarat, Kerala, Madras, Maharashtra, Mysore, Orissa and West Bengal where coconuts are grown over large areas. Manure pits and heaps, dead coconut trunks, municipal rubbish heaps and similar sites where heavy breeding of rhinoceros beetles was noticed, were frequently examined for adult Scoliids. *Campsomeris* sp., *C. azurea* Chr., *C. azurea* Chr. sub-sp. *rubiginosa* F., *Scolia quadripustulata* F. and *S. fichteli* Betr., were found actively hovering over and occasionally entering into manure heaps in several areas in Assam. Large collections of different stages of *Oryctes* grubs were made from such areas and thoroughly examined for parasitism, especially for Scoliid eggs and larvae. Examination of several thousand grubs provided only a single hymenopterous larva preying on a late second instar grub in a manure heap at Amingaon (Assam). It was reared to the adult stage and identified as *Scolia quadripustulata* F. var. *barmanica* Magr. (Plate I, figs. 1 & 2). Subsequently, small numbers of this species were seen hovering over manure heaps at Amingaon, North Gauhati, Hajo and Ganesthala (Assam). Large numbers of *Oryctes* grubs collected from these areas were kept in moist sawdust in laboratory cages for emergence of parasites, but none emerged.

Collections of different species of Scoliids found hovering over manure heaps were made for laboratory study. Attention was also paid to citrus orchards where adult Scoliids were found hovering over the blossoms and feeding on the nectar and pollen grains. *C. azurea*, *C. azurea* sub.-sp. *rubiginosa*, *C. aureicollis* Lep. and *Scolia erythrosoma* Barm. were collected on citrus and banana

flowers at Burnihat and Kahikuchi (Assam). At Jorhat, Mangaldai and Tangla (Assam) also Scoliids were often seen resting on citrus flowers. *C. azurea* adults were sometimes observed (and captured) burrowing into the earth at the base of bamboo trees. However, these Scoliids were scarce and adults of both the sexes were not found in sufficiently large numbers at a time. In limited laboratory experiments they did not breed on *Oryctes* grubs.

No Scoliids or other parasites were noticed around dead coconut trunks.

b) Setting-up of "Fiji-type" cages

With a view to attracting Scoliids which might be parasitic on rhinoceros beetle larvae, specially designed cages similar to those used in Fiji for breeding *S. rufi-cornis* were set up at Coimbatore (Madras), Ernakulam (Kerala), Hajo (Assam) and Puri and Sakhigopal (Orissa). However, no Scoliids appeared over the cages nor were any *Oryctes* larvae kept in the cages parasitised.

c) Testing field-collected Scoliids on *Oryctes* grubs

The testing technique adopted by Mr. H.W. Simmonds and suggested by Dr. A.D. Hinckley was employed in an attempt to determine the hosts of different species of Scoliids collected in Assam.

Two grubs, some honey-agar and a wad of wet cotton were placed in a gallon tin two-thirds full of compost. After releasing a female wasp in it the tin was covered with brown paper and left over-night and the grubs were then carefully examined for eggs. In no case was there any sign of paralysis or oviposition.

d) Attempts to breed *S. quadripustulata* var. *barmanica*

Attempts were made in the laboratory to breed *S. quadripustulata* var. *barmanica* since this was the only species actually reared, although only once, from a late second instar grub of *Oryctes*.

A cage 3' x 2' x 3' with a wooden base, glass front and wire gauze on all the other sides was used. A cloth-sleeve was provided on each side of the cage. The bottom was covered with a 4"-layer of moist sawdust on which about 50 *Oryctes* grubs of different stages were placed. Field-collected parasite adults were then

released into the cage. The females were observed to approach the grubs and even to settle on them but parasitisation never occurred.

Female wasps were also released in a large field-cage containing rotting coconut logs, cow-dung and moist sawdust infested with rhinoceros beetle grubs. Though the wasps readily entered the dung egg-laying was not observed.

Similar experiments were conducted with other Scoliids but with no fruitful result.

2. Search for parasites of *Oryctes* adults

a) Collection and examination of *Oryctes* adults

Adult *Oryctes* beetles were collected in different areas to determine whether any were parasitised. Professional climbers who were trained to remove the beetles carefully and also to look for parasites and predaceous insects were engaged to collect beetles from the crowns of coconut palms. Younger trees with easily accessible crowns were examined directly by the authors. Thousands of infested palms were examined and several hundred beetles collected. Collections were also made from manure heaps and pits and from rotting coconut logs.

Light traps using Petromax lamps were set up regularly at night in coconut groves to see whether beetles would be attracted to them. This did not yield encouraging results. However, it was sometimes observed that a few beetles were attracted to bright street lights.

It was reported by earlier workers that a moist mixture of castor cake and a little manure kept in pots in the crowns of coconut palms attracted the beetles. This method was tried without success.

Living rhinoceros beetles collected from different areas were kept separately in moist sawdust in cylindrical glass jars to rear parasites, if any. They were examined and the sawdust changed once in three days. The beetles thus kept survived for 30 to 60 days. No parasite was obtained from them.

b) Testing Sarcophagids reared from *Oryctes* adults

Two species of Sarcophagids, *Sarcophaga orientaloides* S.W. and *S. annandalei* S.W., were reared from adult rhinoceros beetles collected from the crowns of coconut palms at Bairapatna and Mandya (Mysore State), Gauhati (Assam)

and Mahadanapuram (Madras State). The beetles were dead when collected and the fly maggots were seen feeding on them In view of an earlier record of a Sarcophagid, *S. fuscicauda*, on *Oryctes* adults (Venkatraman *et al*, 1954), these flies were studied further. Mated female flies were provided with living beetles in cages containing manure and also with beetles on coconut fronds in separate cages. No oviposition was noticed. Females which completed their gestation period were dissected and the active maggots obtained were inoculated on living beetles. The maggots failed to develop further. However, these Sarcophagids bred very well on dead beetles and other putrified matter. It was, therefore, concluded that these flies were in fact only saprophytic.

c) Field cages to attract parasites and predators of *Oryctes* adults

In coconut fields out-door cages with large numbers of rhinoceros beetles kept in moist sawdust were erected. Each cage was covered with a chicken-mesh which would allow natural enemies of the beetles, such as Sarcophagids, to enter but prevent the beetles from escaping. The cages were examined periodically for parasites and predators, but with negative results.

B. Search for predators

1. Search for predators of *Oryctes* larvae

Large numbers of *Oryctes* larvae were noticed in manure heaps and pits in Bangalore, Hiriyur, Kengeri and Tiptur (Mysore State); Puri and Sakhigopal (Orissa); Burnihat, Khanapara, Kahikuchi, Mangaldai, Ramdia and on the northern banks of the Brahmaputra river (Assam); Ambalapuzha, Elanthodu, Ernakulam, Kottayam, Kulachal, Thannirmukkam and Thottapally (Kerala) and Kanyakumari, Mahadanapuram and Nagercoil (Madras State). These heaps and pits were thoroughly dug over to expose any actual or potential predators. A large number of predatory beetles and their larvae were, in fact, found feeding on *Oryctes* grubs. These predators are listed in Table I. A thorough search was also made of standing coconut stumps, felled, rotting logs, compost heaps and pits in Assam and Kerala for the predator *C. whithilli* recorded by Venkatraman (1958). However, this predator was not seen.

TABLE I

List of predators found feeding on *Oryctes* grubs and pupae in fields

Predator	Locality	Habitat	Stage attacked
	CARABIDAE (COLEOPTERA)		
1. *Abacetus reflexus* Chaud.	Hiriyur (Mysore)	Manure heap	1st instar grubs
2. *Clivina memnonia* Dej.	Bangalore (Mysore), Gauhati (Assam)	" "	" " "
3. *Itamus* sp. (not in British Museum) (Plate III, fig. 3)	Gauhati	" "	1st and 2nd instar grubs
4. *Omphra atrata* (Klug) (Plate III, fig. 1)	Bangalore	" "	" " "
5. *Oxylobus alveolatus* Chaud. (Plate II, fig. 3)	"	" "	" " "
6. *O. lateralis* (Dej.)	Bangalore, Gauhati	" "	" " "
7. *O. punctatosulcatus* Chaud. (Plate II, fig. 4)	Bangalore	" "	All instars
8. *Pheropsophus lissoderus* Chaud.	Bhubaneswar, Puri, Sakhigopal (Orissa), Gauhati, Jorhat (Assam), Mandya (Mysore)	Manure heap and moist dung	1st and 2nd instar grubs and pupae
9. *P. occipitalis* Macl.	Bhubaneswar, Gauhati, Mandya, Puri	" "	" " "
10. *P. sobrinus* (Dej.) var. *desbordesi* Maindr.	Bangalore, Bhubaneswar, Chandannagar (West Bengal), Gauhati, Jorhat, Mandya, Puri, Sakhigopal	Manure heap, moist dung and dead coconut logs	" " "

Predator	Locality	Habitat	Stage attacked
11. *P. stenoderus* Chaud.	Bhubaneswar, Gauhati, Jorhat, Mandya, Puri	Manure heap and moist dung	1st and 2nd instar grubs and pupae
12. *Pseudozaenia orientalis* (Klug)	Gauhati	Manure heap	1st and 2nd instar grubs
13. *Scarites dubiosus* Andr. (Plate II, fig. 2)	"	" "	All instars
14. *S. inconspicuus* Chaud.	Puri, Sakhigopal	" "	1st and 2nd instar grubs
15. *S. indus* Oliv.	Bangalore, Ernakulam (Kerala), Puri	In *Oryctes* larval tunnel in a dead and fallen coconut trunk	" " "
16. *S. parvus* Wied.	Bangalore, Gauhati	Manure heap	1st instar grubs
17. *S. praedator* Chaud.	Gauhati	" "	All instars
18. *Scarites* sp. (not in British Museum)	"	" "	1st instar grubs
19. *S.* sp. nr. *dentatus* Andr.	"	" "	All instars
20. *S.* sp. nr. *orthomus* Chaud. (Plate II, fig. 1)	"	" "	" "
21. *S. sulcatus* Oliv.	"	" "	" "
22. *Siagona atrata* Dej. (Plate III, fig. 2)	"	Manure heap and crowns of coconut palms	1st and 2nd instar grubs

Predator	Locality	Habitat	Stage attacked
	HISTERIDAE (COLEOPTERA)		
23. *Hister* (*Pachylister*) *ceylanus* Mars.	Jorhat	Manure heap	1st and 2nd instar grubs
24. *H.* (*P.*) *lutarius* Er.	Bangalore, Gauhati	" "	" " "
25. *H.* (*Santalus*) *parallelus* Redt.	Gauhati	" "	1st instar grubs
26. *Hister* sp. (Plate III, fig. 4)	Bangalore, Gauhati	" "	" " "
27. *Hister* (s. str.) sp.	Bangalore	" "	" " "
	REDUVIIDAE (HEMIPTERA)		
28. *Sirthenca* sp.	Mandya	" "	" " "

All the predaceous beetles listed are effective burrowers and were generally found 1 to 2 feet deep in manure heaps and pits. The higher the incidence of Carabids observed in the field, the lower was the population of *Oryctes* larvae. Moreover, dead remains of eaten grubs were noticed, possibly a result of Carabid activity.

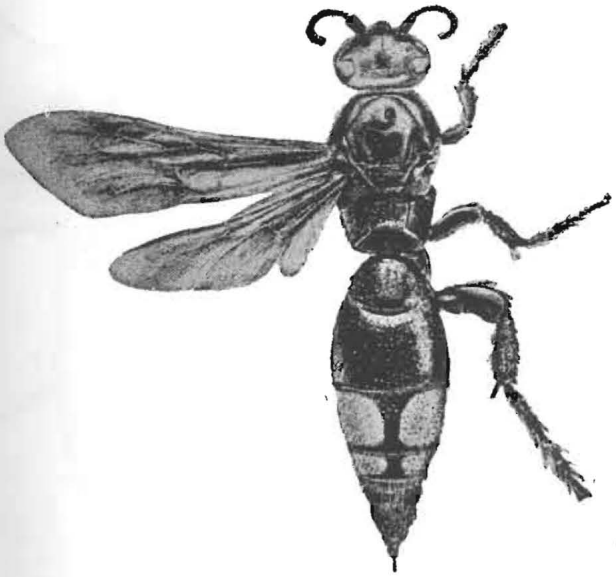
Most of these predators were found to be greatly attracted by light and the easiest way to collect the adult was to use light traps on a night preceded by rainfall. During May and June 1962 several hundred Scaritid and other beetles were collected at South Gauhati (Assam) at street lights on the southern banks of the Brahmaputra river.

Pheropsophus beetles were also noticed in straw and debris in neglected plantations in Assam, Orissa and Mysore States. Sometimes they were also found in dead coconut logs. These beetles were available throughout the year.

All the beetles except *Pheropsophus* attack grubs usually on the 1st and 2nd thoracic segments which remain slightly depressed when the grubs lie in a characteristic 'C' form. At times the Scaritid beetles have been seen to merely injure a grub by biting and then discard it, possibly due to their being already fully fed. Such injury is sufficient to induce bacterial infection which subsequently kills the grubs and is in itself an indirect method of control. The particular stage of the grub preferred by different predators under laboratory conditions is indicated in Table I. Under laboratory conditions *O. punctatosulcatus*, *S.* sp. nr. *orthomus*, *S. dubiosus*, *Pheropsophus* spp., *S. atrata*, *S. indus*, *Hister* sp. and *O. atrata* were found to be the most efficient predators in the given order in terms of the number of grubs consumed.

Attempts were made to breed *P. sobrinus* (Plate IV, fig. 1) in the laboratory. The beetles laid eggs readily when kept in moist sawdust in large cylindrical glass jars and fed regularly with *Oryctes* grubs. The eggs (Plate IV, fig. 2), 1.26 mm. long and 0.53 mm. broad, are sub-cylindrical and creamy-white with their surface finely shagreened and one end slightly broader. They gradually turn brownish as they become old. Incubation period ranged from 8 to 10 days at 78°F. The active, freshly emerged larvae (Plate IV, fig. 3) were found to accept very young housefly maggots as food. The full-grown larvae were found to attack and feed on early first instar grubs of *Oryctes* (Plate IV, fig. 4).

PLATE I



Scolia quadripustulata var. *barmanica*

Fig. 1. A female × 2.

Fig. 2. A male × 2½.

PLATE II

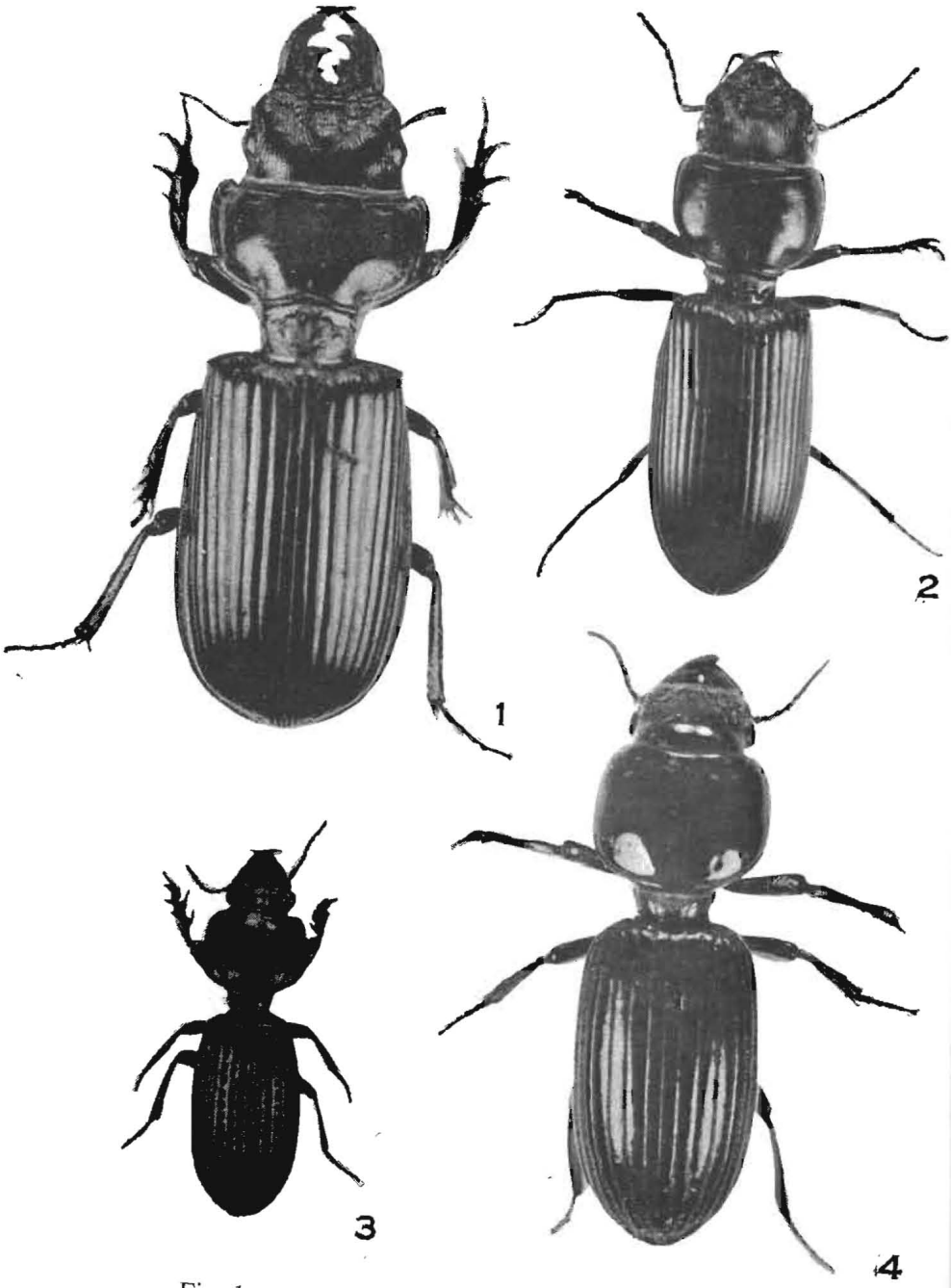


Fig. 1. *Scarites* sp. nr. *orthomus* × 2½.
Fig. 2. *S. dubiosus* ,,
Fig. 3. *Oxylobus alveolatus* ,,
Fig. 4. *O. punctatosulcatus* ,,

PLATE III

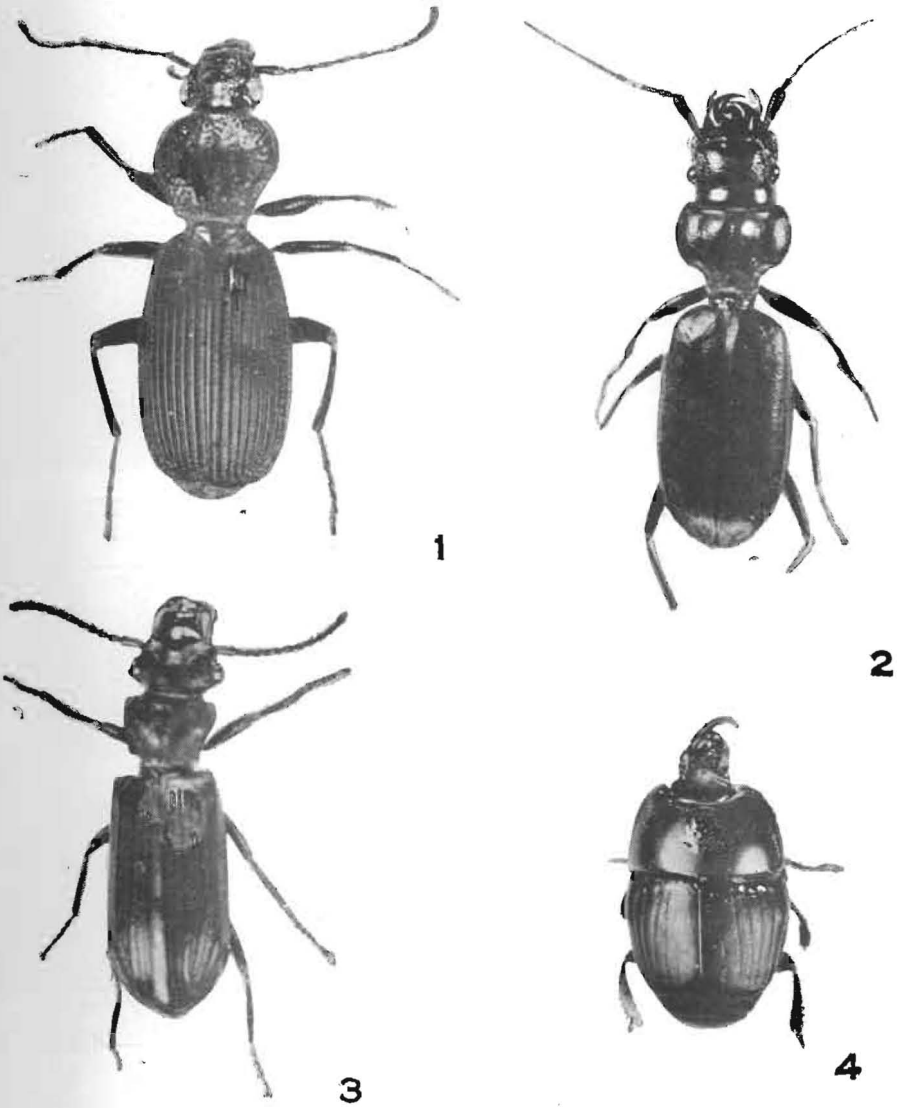
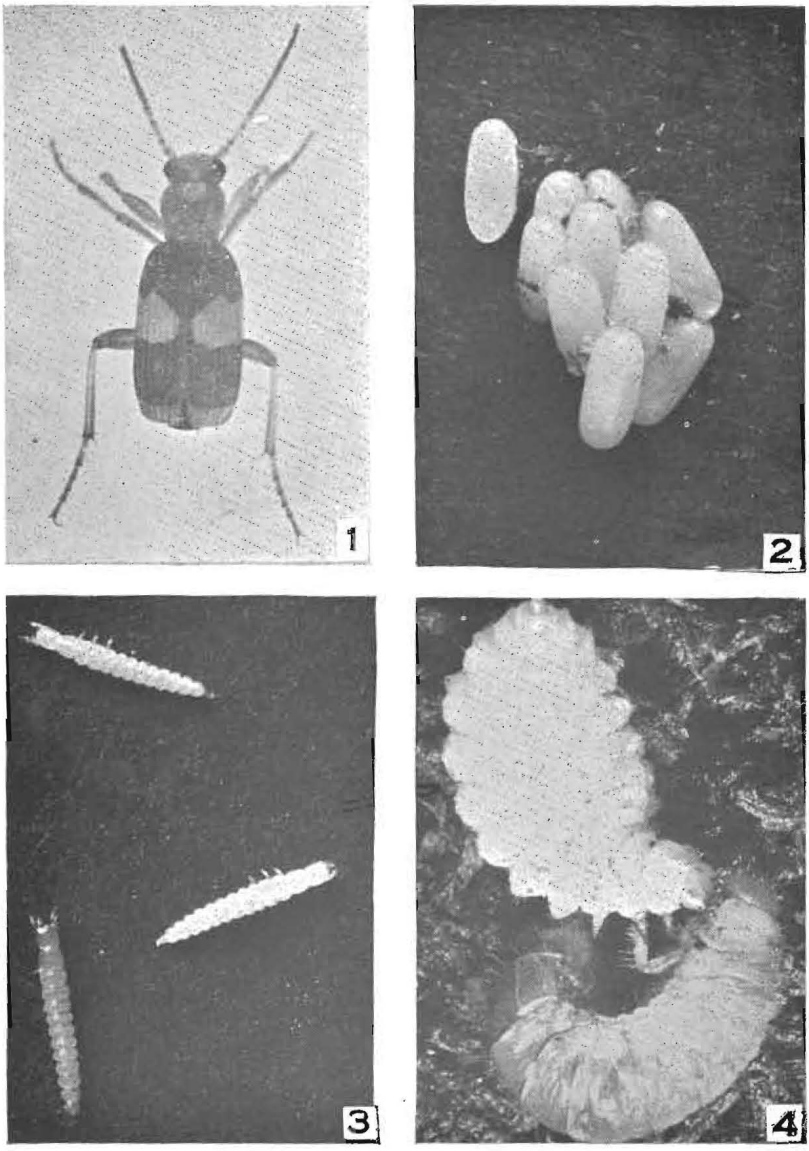


Fig. 1. *Omphra atrata* × $2\frac{1}{2}$.
Fig. 2. *Siagona atrata* ,,
Fig. 3. *Itamus* sp. ,,
Fig. 4. *Hister* sp. ,,

PLATE IV



Pheropsophus sobrinus var. *desbordesi*

Fig. 1. Adult × 2½.

Fig. 2. Eggs × 14.

Fig. 3. Freshly emerged larvae × 4.

Fig. 4. Full-grown *Pheropsophus* larva feeding on a 1st instar *O. rhinoceros* grub × 4.

When kept under similar conditions *Hister* beetles and *O. atrata* also laid eggs in the laboratory; the other predaceous beetles mentioned earlier may also do so.

2. Search for predators of *Oryctes* adults

Thousands of young and old coconut palms were thoroughly examined for predators in many localities in the States of Andhra Pradesh, Assam, Kerala, Mysore and Orissa. Special attention was paid to those which showed symptoms of rhinoceros beetle attack, such as debris or fibrous material accumulated in the leaf axils. In most of the crowns examined adult rhinoceros beetles and a few red palm weevils were obtained. There was, however, no sign of predators.

C. Diseases of *O. rhinoceros*

A large number of diseased grubs of *Oryctes* were collected in the areas surveyed. Most of them turned limp, losing bristles, producing a foul smell, and finally becoming a liquid mass. Some turned black, starting from small spots on the abdominal segments and then gradually over the entire body. Specimens of diseased grubs were sent to Prof. E.A. Steinhaus at Berkeley (U.S.A.), who reported that the specimens from Ernakulam (Kerala), Hajo (Assam), Hiriyur (Mysore State) and Sakhigopal (Orissa) harboured large gram-negative rods which belonged primarily to the Enterobacteriaceae. *Bacillus cereus* Fr. & Fr., and other *Coccus*-like forms were also reported to be abundant.

The green muscardine fungus *M. anisopliae* was found to be responsible for the death of the grubs, pupae and adults of *O. rhinoceros* collected from all the places surveyed, but mortality was very low. However, during August and September 1964, 40-50% of the adult beetles collected in Kamrup (Assam) were found to be killed by this fungus.

D. Nematodes associated with *O. rhinoceros*

More than 90% of the *Oryctes* adults collected from the crowns of coconut palms and manure heaps in different areas were found to be severely infested with *Rhabditis* sp. The nematodes were commonly found in clusters on the legs at the joint between the coxa and the trochanter. They were also found in the inter-segmental membrane of the abdomen and under the elytra at the wing bases. Another species of *Rhabditis* was found in association with the grubs of *Oryctes* collected in the manure heaps at

Ambajipet (Andhra Pradesh). Dr. H.E. Welch, Belleville (Ont., Canada) who identified these nematodes has commented that they are probably secondary invaders and saprophytic rather than parasitic.

Dissection of the living *Oryctes* grubs collected from manure heaps at Bangalore revealed the presence of different stages of a nematode inside the rectum of the second instar grubs. The infected grubs showed no external symptoms of nematode infestation but looked quite healthy and normal. This nematode is conspicuous by its long and pointed tail. Specimens sent for identification have not yet been named.

A large number of adult *O. rhinoceros* was dissected but no nematode infestation was observed in the bursa copulatrix or the collateral glands of the females or in the aedeagus and associated glands in the males.

E. Mites associated with *O. rhinoceros*

Most of the grubs, pupae and adults of *O. rhinoceros* were found to be infested with the following five species of mites: *Coleolaelaps rhinocerotis* Oudemans, "*Anoplocelaeno*" *aplygyna* Berlese, "*A.*" *politricha* Berlese, *Zygoseius imitans* Berlese and *Coleopterophagus procerus* Berlese. Dr. Donald E. Johnston, Institute of Acarology, Wooster, Ohio, U.S.A., who identified the mites has commented that the relationship of "*Anoplocelaeno*" spp. and *Zygoseius* with rhinoceros beetle is undoubtedly one of phoresy and *C. procerus* may be parasitic.

Shipments of predators and Scoliids to other countries

Several consignments of the predators *S. dubiosus*, *O. punctatosulcatus*, *P. sobrinus* var. *desbordesi* and a few other species of Scaritids were sent for trial release against *Oryctes* in the South Pacific area. Although its status as an *Oryctes* parasite is doubtful *C. azurea* was also sent at the specific request of the South Pacific Commission authorities. In addition a small number of *S. quadripustulata* var. *barmanica* were supplied for trial.

All the four species of *Pheropsophus* and several species of Scaritids were shipped to Mauritius. It has been learnt that *Pheropsophus* spp., besides attacking *Oryctes*, feed on the grubs of *Clemora smithi* Arrow and *Cosmopolites sordidus* Germ. Recoveries of the beetles were made from the field in 1961 four months after their liberation (Dr. F.J. Simmonds and Mr. Orian, Entomologist, Reduit, Pers. Comm.).

Discussion and Conclusions

During the present survey for natural enemies of *O. rhinoceros* in India, although several species of Scoliids were found hovering over or burrowing into the manure heaps infested with rhinoceros beetle grubs only *S. quadripustulata* var. *barmanica* was once reared from a second instar grub at Amingaon (Assam). However, large collections of grubs from the same and other areas where adults of *S. quadripustulata* var. *barmanica* were found did not yield any more of this species or of any other Scoliids. Attempts to breed the Scoliids on different larval stages in the laboratory were not successful. It appears, therefore, that *S. quadripustulata* var. *barmanica* is not a true parasite of *O. rhinoceros* and that the solitary instance was probably an accidental attack. In view of the absence of Scoliid parasites it may be worthwhile introducing from other countries parasites such as *S. ruficornis* and *S. oryctophaga* for trial against *O. rhinoceros* in India.

The present investigations have resulted in the discovery of a number of predators. But these predators were found to feed on a number of other organisms breeding in manure heaps, and they did not show any preference for *Oryctes* grubs. This reduces their efficiency in controlling *Oryctes*. However, in some parts of Assam where some of these predators were common the population of *Oryctes* grubs was comparatively low. It might be useful if detailed studies on the feeding habits of these predators are made, and their value against *Oryctes* is assessed. It is significant that some of the predators found in one area were not found in others where *Oryctes* attack was prevalent. In view of this, it may be worthwhile transferring some of the predators (when their value is known) from one area to the other. The predator fauna was richer and the population of the predators higher in Assam than in other States.

It is also desirable to try *Platymeris* in India. There appears to be some confusion regarding the specific identification of *Platymeris*. A consignment of about 100 eggs, stated to be those of *P. rhadamanthus* of Zanzibar origin, was obtained by the Indian Station, CIBC, from Malaya and the authors have built up a culture of this predator in the laboratory at Bangalore. The adult bugs reared were sent to the British Museum for correct identification and were identified as *P. laevicollis* Dist. Dr. M.S.K. Ghauri, who identified the specimens stated "if, as a result of further research, *Platymeris laevicollis* is not synonymised with *Platymerus rhadamanthus*,

then the specimens from the culture emanating from Zanzibar will remain *P. laevicollis*". Field liberation of *P. laevicollis* in the Androth island in the Laccadive Islands group has been made in May 1968 by the CIBC Indian Station in collaboration with the Central Coconut Research Station, Kayangulam (Kerala). Additional material for liberation was also obtained from the CIBC Pakistan Station, Malaya and Western Samoa.

The performance of *M. anisopliae* has not been consistent. It appears to attack only already injured *Oryctes* and, therefore, its efficacy in controlling this pest is limited. The virus, *R. oryctes*, discovered by Huger (1966) in Malaya appears to be promising and the possibility of using it is being explored in the Pacific areas. If these experiments give positive results, the introduction of this virus into India for trial against *O. rhinoceros* may be considered.

A survey of the literature on biological control work on *O. rhinoceros* carried out to date shows that although several attempts have been made over a number of years, little control has actually been achieved except for partial success with *S. ruficornis* in some areas. This is because greater stress appears to have been laid so far on shipments of insects suspected to be predators or parasites than on detailed investigation of the biology and ecology of these insects. The study of these two aspects should receive priority in any future programme of work on the biological control of *Oryctes*.

Summary

In a country-wide survey carried out in India for natural enemies of *Oryctes rhinoceros* (L.), 28 species of predators were recorded. These include the Carabids *Abacetus reflexus* Chaud., *Clivina memnonia* Dej., *Itamus* sp., *Omphra atrata* (Klug), *Oxylobus alveolatus* Chaud., *O. lateralis* (Dej.), *O. punctatosulcatus* Chaud., *Pheropsophus lissoderus* Chaud., *P. occipitalis* Macl., *P. sobrinus* (Dej.) var. *desbordesi* Maindr., *P. stenoderus* Chaud., *Pseudozaenia orientalis* (Klug), *Scarites dubiosus* Andr., *S. inconspicuus* Chaud., *S. indus* Oliv., *S. parvus* Wied., *S. praedator* Chaud., *Scarites* sp., *S.* sp. nr. *dentatus* Andr., *S.* sp. nr. *orthomus* Chaud., *S. sulcatus* Oliv. and *Siagona atrata* Dej.; the Histerids *Hister* (*Pachylister*) *ceylanus* Mars., *H.* (*P.*) *lutarius* Er., *H.* (*Santalus*) *parallelus* Redt., *Hister* sp. and *Hister* (s. str.) sp. and the Reduviid *Sirthenca* sp. Wherever some of these predators were common the population of *Oryctes* grubs was comparatively low and dead remains

of the eaten grubs were seen in breeding sites. Field observations show that these predators are playing a very useful role by feeding on the rhinoceros beetle grubs, particularly in the Assam region where the majority of them were found.

No promising parasite was obtained during this survey. However a Scoliid, *Scolia quadripustulata* F. var. *barmanica* Magr., was once reared from a second instar grub of *Oryctes* collected from a manure heap at Amingaon (Assam): its specificity to this host is doubtful. Though several Scoliids were found hovering over and occasionally burrowing into the manure heaps infested with rhinoceros beetle grubs there was no evidence of their parasitism on this host.

A large number of diseased grubs of *Oryctes* were collected in the areas surveyed. These harboured large gram-negative rods belonging primarily to the Enterobacteriaceae. *Bacillus cereus* Fr. & Fr., and other *Coccus*-like forms were also abundant. The fungus *Metarrhizium anisopliae* (Metsch.) Sorokin was common. During August and September 1964 it caused 40-50% mortality of adult beetles in Kamrup (Assam).

More than 90% of the adult *Oryctes* collected from different areas were severely infested with a nematode, *Rhabditis* sp. The infestation was external and it seems that these nematodes are unable to kill the beetles and are only saprophytic. Another *Rhabditis* sp., slightly different from the above, was recorded on *Oryctes* grubs collected from a manure pit at Ambajipeta (Andhra Pradesh). In the rectum of living second instar grubs collected from the manure heaps at Bangalore (Mysore State) another species of nematode was found. Their effect on the host is not known.

Infestation by mites was very common on all stages. Five species of mites were found but they do not seem to cause any damage to the host even in high infestations.

Several consignments of the predators *S. dubiosus*, *O. punctatosulcatus*, *P. sobrinus* var. *desbordesi* and a few other *Scarites* spp. were shipped for trial in the South Pacific area. The Scoliids *Campsomeris azurea* Chr. and *S. quadripustulata* var. *barmanica* were also sent in small numbers. All four species of *Pheropsophus* and several species of Scaritid beetles were also sent to Mauritius for trial, where *Pheropsophus* has been recovered.

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