Rat-control procedures on the Pacific islands, with special reference to the efficiency of biological control agents. I : Appraisal of the monitor lizard, Vuranus indicus (Daudin), as a rat-control agent on Ifaluk, Western Caroline Islands')

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Rat-control procedures on the Pacific islands, with special reference to the efficiency of biological control agents. I

Appraisal of the monitor lizard, *Varanus indicus* (Daudin), as a rat-control agent on Ifaluk, Western Caroline Islands[1])

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Abstract

Two kinds of rats, i.e., roof rats, ***Rattus** rattus* (Linnaeus) and Polynesian rats, ***Rattus** exulans* (Peale) have become widespread among the islands of the Central and South Pacific. Coconuts are being subjected to extremely heavy rat damage. Not only is there ensueing economic loss, but rat-gnawed coconuts are intensively utilized as larval habitats by mosquitoes including vectors of Bancroftian filariasis and dengue. Effective integrated rat control procedures are therefore of pressing importance to the Pacific islands in general. Such procedures would call for the joint use, against an adequate background of ecological knowledge, of chemical and biological control measures. The latter might well involve the use of predators, and in this connexion it has been reported that *Varanus indicus* (Daudin), a large grey-green monitor lizard which has been introduced into certain Micronesian islands, is of local importance as a rat-control agent,

To appraise whether this lizard merits consideration for introduction elsewhere in Micronesia and Polynesia for the purpose of decreasing rat damage to coconuts, the present study was thus undertaken on the atoll of Ifaluk (lat. 07° 15' N, long. 144" 27′ E), Western Caroline Islands. While it was established that *V. indicus* certainly makes some contribution to rat control, it is concluded that the data reported herein do not favour further consideration of an experimental introduction of this

1) Contributions from the Zoological Laboratory, Faculty of Agriculture, Kyushu University, No. 395. This study was undertaken while the the author was serving as a consultant to the World Health Organization (Division of Environmental Health), 23 October-30 November, 1965. Presented at the Eleventh Pacific Science Congress of the Pacific Science Association, Tokyo, 1966.

predator in the South Pacific area. It is submitted that a better candidate for a field trial against coconut-gnawing rats in the South Pacific would be the Japanese weasel, *Mustela sibiricu itatsi* Temminck & Schlegel. This animal is thus discussed in some detail with reference to its environmental requirements and the practicability of establishing it under tropical conditions.

Introduction

By gnawing holes in growing coconuts on Pacific islands, roof rats and Polynesian rats not only cause serious economic loss but also create huge numbers of larval habitats for container-utilizing mosquitoes, e.g., *Aedes polynesiensis* Marks, the major vector of Bancroftian filariasis in Eastern Polynesia, and other dangerous members of the *scutellaris* complex of *Aedes* (*Stegomyia*). In this context, Laird (1963) drew attention to the relationship between monitor lizards and rats on certain Micronesian islands. The purpose of my visit to Ifaluk[1] as a WHO consultant was to report my views on whether monitor lizard in fact merits serious consideration for introduction elsewhere in the tropical Pacific in the interests not only of rat control but also of decreasing rat damage to coconuts with particular respect to the consequent transformation of the latter into mosquito larval habitats. Although the abbreviated article appeared in the Bulletin of WHO (Uchida, 1966), the full text is presented herein.

The excellent monograph entitled "Pacific Island Rat Ecology" and edited by Storer (1962) was based on field studies by a team of investigators who worked on Ponape and adjacent islands of the Eastern Carolines" in 1955-1958. Shortly before during 1953 Bates and Abbott (1958, 1959) had participated in human ecological research on the atoll of Ifaluk, Western Carolines (Fig. 1). The works cited above provided an invaluable background for the present study, the first helping me to grasp the problems caused by rats in this area and the account presented by Bates and Abbott serving as an introduction to Ifaluk.

Ifaluk Atoll (lat. 07° 15′ N, long. 144" 27′ E) consists of four islets, i.e., Falarik, Falalap, Ella and Elangalap, the last two of which are uninhabited, surrounding a central lagoon with a diameter of only 1.6

1) Sometimes spelt "Ifalik."

2) The Carolines were under German administration prior to World War I, then a Japanese Mandated Territory; since World War II they have formed part of the United Nations Trust Territory of the Pacific Islands, administered by the United States of America.

km. The total area of the atoll is as little as 1.3 km", the highest point being merely 4.5 m above sea level. At the time of my visit the population numbered 316, these people being distributed among four villages - Falarik and Rauau on the islet of Falarik, and Iyour and Ifang on Falalap (Figs. 2 and 3).

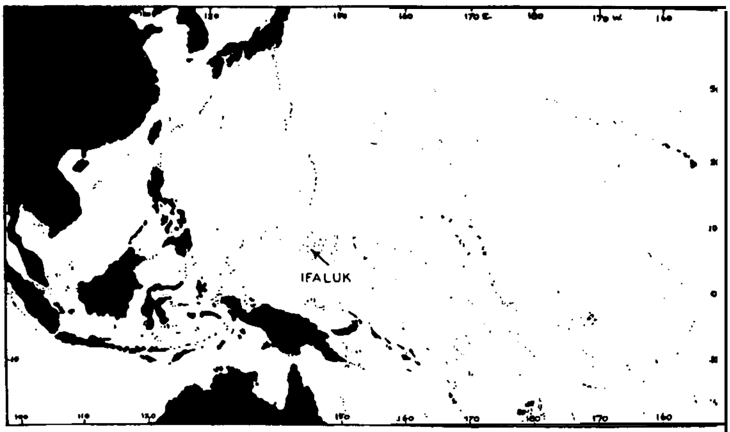

Fig. 1. Location of Ifaluk Atoll, Western Caroline Islands (From Bates & Abbott, 1959).

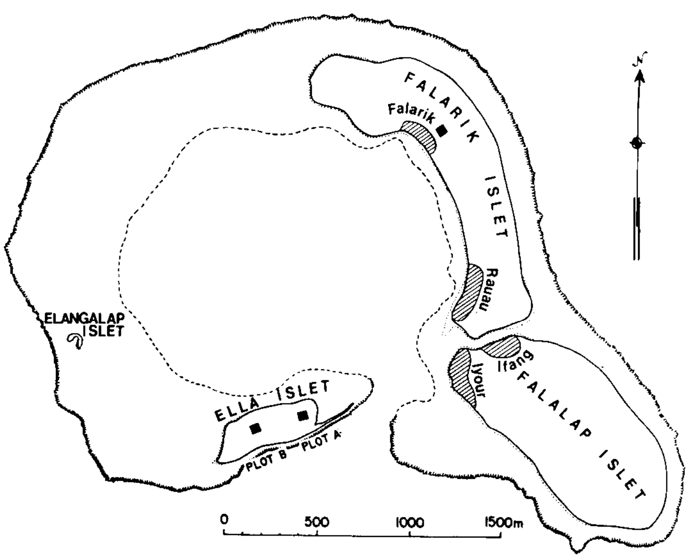

Fig. 2. Outline map of Ifaluk Atoll, showing locations of villages (indicated by oblique lines) and trapping areas (indicated by black squares) (Modified from the map by Arnow, 1955).

In 1953, Bates and Abbott found that monitor lizards were abundant on the islets of Falarik and Falalap, but were rare on Ella (Bates & Abbott, 1958, p. 197). On the other hand, although rats were present on Falarik and Falalap, their numbers on Ella "were really fantastic" (Bates & Abbott, 1958, p. 115). They (p. 197) were informed by the older islanders that rats had been "much more numerous and destructive of coconuts and thatched roofs" prior to the introduction of monitors. Because of this and the prevailing density of the rat population on Ella, they were ready to believe that the abundance of this lizards on the two main islets might be the explanation of the relative scarcity of rats there.

Fig. 3. Untended coconut grove. Rauau Village, Falarik Islet, Ifaluk Atoll, 23 November 1965.

History of the introduction of monitors

The history of the introduction of monitors into Micronesia is not adequately documented, although available evidence suggests their first having been established in Saipan, Rota and Yap, and later in Angaur (Palau Group) and other islands. The introduction into Saipan must have been carried out before 1919, for regulations controlling the capture of monitors there were promulgated in July of that year by the Administration of Saipan District, South Sea Islands Government Office of Japan (Esaki, 1940), A Civil Administrative Department had been established only a year earlier, and there are in fact grounds for believing that ***V. indicus*** may have been first brought into Micronesia under German rule prior to World War I and not during the period of the ensueing Japanese Mandate as has been rather widely assumed. It is indisputable, however, that introductions of monitors into certain of the Micronesian islands, for the express purpose of controlling rats, took place during the Japanese administration.

According to the Ifalukians, two monitors were initially introduced into Falalap Islet, Ifaluk Atoll from Woleai Atoll about 1939 by the Japanese. Although soon after they had bred and spread into Falarik Islet, they were still rare and not firmly established on Ella Islet in 1953 (Bates & Abbott, 1958). Since about 1955, however, they have become established on Ella; having spread from Falalap by swimming and bred there subsequently.

Relationship between *V. indicus* and rat population density

1. *Methods*

It was initially planned to estimate the actual rat population density on Ella (where it was believed that the monitor had failed to become established) and that on Falarik or Falalap where the predators are abundant, and to make direct comparisons between the two population densities simultaneously. Such a comparison, however, could not after all be made, because, as already stated, there proved to be no islet of Ifaluk where monitors were rare or absent. Therefore the only way to proceed was to compare indirectly Bates and Abbott's general observations on the fantastic prevalence of rats in 1953 on Ella, and the views of some islanders who guided them in 1953 and who assisted me during the present project, with the present incidence of rats on Ella according to my own observations.

For estimating rat population numbers the removal method by snap traps in grids of 10x10 at 10-metre intervals and the method of mark-and-release followed by poisoning were used at the same time. However, the population numbers were not obtained by the former method because before the rats became active at night there was an excessive amount of trap disturbance by other animals such as small lizards (skinks -***Emoia cyanurum, Dasia smaragdinum*** and an unknown species - and the gecko ***Gehyra oceanica),*** hermit crabs[1] ***(Coenobita rugosus*** and C. ***hilgendorfi (= C. clypeatus)),*** land crabs" ***(Cardisoma hirtipes, C. carnifex*** and ***Gecarcoidea lalandli***) and giant. coconut crabs ***(Birgus latro).*** Therefore

1) Identified by Prof. S. Miyake of Kyushu University.

the removal method by snap traps will not be discussed further, the population numbers given below being values calculated from the application of Bailey's formula (1952) by the method of mark-and-release. Since cage traps were in grids of 5x 5 at 10-metre intervals the experimental site covered an area of 0.16 hectare (40 m x 40 m). Fresh coconut meat was used routinely for bait in all trapping, as it was readily available and easy to use. Rats were marked individually by cutting toes to the base with scissors, and were released at the sites of capture.

Since it was necessary to use a rodenticide highly toxic only to rats and non-toxic to monitors, it was decided to use "norbormide".[1] So

Fig. 4. Plant cover of Falarik Village area where rat population was estimated using the technique of mark-and-release followed by poisoning. Note coconut palm banded with leaves of screw pines instead of aluminium strip (indicated by an arrow). Falarik Islet, Ifaluk Atoll, 3 November 1965.

1) 5-[α-hydroxy-α-phenyl-α- (2-pyridylmethyl)] -7- (phenyl- 2-pyridylmethylene)-5- norbornene-2.3-dicarboximide.

far as was known, however, norbormide had not been tested to any extent on reptiles. After I myself confirmed its harmlessness to monitors even when the dosages were increased to about 600 mg and 900 mg in two cases on Guam[1] and Ifaluk, I used this rodenticide for the purpose of rat population estimate. Dumplings made of mixed fresh coconut meat and taro were used as the base of poison bait.

2. *Rat population density on Falarik Islet*

The monitors were relatively abundant in the bush, but scarce around houses on Falarik Islet because of predation pressure by dogs. Mark-and-release operations were carried out in the bush[2] near Falarik Village in the northern part of the islet. The area in question is situated at the middle portion of the islet and consists of coconuts, the relatively large tree, ***Eugenia javanica,*** breadfruit trees ***(Artocarpus altilis)***, screw pines ***(Pandanus),*** Indian mallows, papayas, taros and ferns (Figs. 2 and 4). From November 5 to 9 the total set of 125 trap/nights took 46 rats, including 17 recaptures (three among roof rats, 14 among Polyne-

Table 1. Rat population data obtained by the method of mark-and-release followed by poisoning in an area of 0.16 hectare on Ifaluk.

Population data*	Falarik		Plot A, Ella
	Roof rat	Polynesian rat	Roof rat
R	13	12	25
C	6	2	18
r	2	1	6
$\check{N}\pm$ std dev.	30 ± 11	38 ± 6	68 ± 19
D ± std dev.	8 ± 3	9 ± 3	19 ± 5

* R: Number of rats marked and released. C: Number of dead rats picked up. r: Number of marked rats in C. $\check{N}$: Raw population size. Bailey's formula : $\check{N}=\frac{(C+1)R}{r+1}$, with a standard deviation of $\frac{R^2(C+1)(C-r)}{(r+1)^2(r+2)}$. D : Corrected population size, $D=\check{N}A/A'$, where A is the census area, surrounded by the outermost trap-lines, and A' is the corrected area according to Dice's formula, $A' \doteq A+\frac{1}{2}\sqrt{S}\times L$; L=total perimeter of census area and S= area of rat home range, assumed to be a circle of diameter 60 m for roof rats and 24 m for Polynesian rats.

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1) A monitor kept in captivity by Fish & Wildlife Division, Department of Agriculture, Government of Guam, was used for this test.

2) The word "bush" is used herein for what the Ifalukians term "niwel." Bates and Abbott (1958, pp. 41-42) used "boondock" in this context, i.e., that of a "wild tangle of miscellaneous vegetation . . . not exactly wild... (and) not exactly cultivated either."

sian rats), with a corrected trapping success of 47.7 % (a raw trapping success of 36.8 %) in spite of some trap disturbance. Polynesian rats seem to be prone to recapture. Of these, 13 roof rats and 12 Polynesian rats were marked and released. After the poisoning I was able to find two previously marked individuals out of six dead roof rats recovered, while of two Polynesian rats recovered one had been marked. It should be mentioned that finding the bodies of rats was a difficult task, as the quadrat was thickly covered with vegetation. Therefore the raw population density was estimated at 30 $\pm$ 11 for roof rats and 18 $\pm$ 6 for Polynesian rats per 0.16 hectare respectively (Table 1).

3. *Rat population density on Ella Islet*

As stated earlier, monitors became established here too about 10 years ago, and are now at least as abundant as on Falarik. Population estimates were initiated in the coconut grove, which includes a few screw pines and breadfruit trees, near the easternmost end of the islet (Fig. 2-Plot A). From November 11 to 15 the total set of 125 trap/nights took 31 roof rats alone, including two recaptures, with a corrected trapping success of 33.7 % (a raw trapping success of 24.8 %) in spite of some trap disturbance. Some of the captured rats were attacked and killed by monitors. Eventually 25 roof rats were marked and released. Subsequently six previously marked rats were found out of 18 dead examples picked up after poisoning work. Therefore the raw population density was estimated at 68 $\pm$ 19 (Table 1). Next, only the mark-and-release operation was carried out in the bush consisting of *Morinda citrifolia, Allophylus timorensis, Premna corymbosa, Pipturus argenteus,* Indian mallows, screw pines, breadfruit trees, a few coconut trees, *Scaevola frutescens* and ferns. The quadrat was situated at the central part of the islet (Fig. 2-Plot B). From November 17 to 19 the total set of 75 trap/nights took 16 roof rats alone, including one recapture, with a corrected trapping success of 30.5 % (a raw trapping success of 21.3 %), and finally 13 rats were marked and released. On this plot, poisoning work was not carried out. However, judging from the relative ratio of population density obtained from a comparison of the three days' capture records on Plots A and B, the density near the centre of Ella (Plot B) proves to be considerably high.

4. *Correction to values of rat population density*

The raw population densities given above will be too high because of the small size of the trapping area compared to the home range of the rats, i.e., 60-75 m for roof rats and 24440 m for Polynesian rats (Jackson & Strecker, 1962). The population densities corrected by Dice's formula (1938) are also given in Table 1. On Falarik the corrected value was estimated at 8 ± 3 for roof rats and 9 ± 3 for Polynesian rats, and on Ella (Plot A) at 19 ± 5 for roof rats, per 0.16 hectare in each case. This corresponds to about 100 per hectare on each islet. This is very high, in view of the abundance of monitors at the time and their gradual increase during the past 26 years on Falarik and 10 years on Ella.

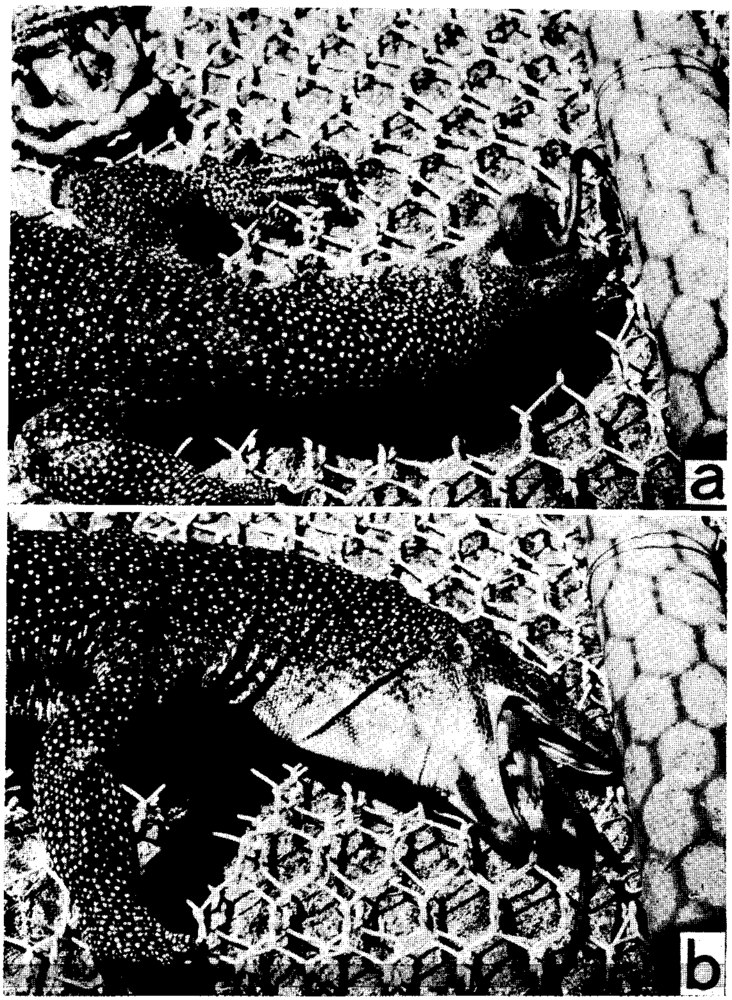

Fig. 5a and b. Monitor swallowing a roof rat, and turning the head from side to side while doing so. Note dead and only partly eaten coconut crab in upper left corner of upper picture (a). Rauau Village, Falarik Islet, Ifaluk Atoll, 14 November 1965.

Monitor's behaviour against rats in captivity

I kept one male monitor 134 cm in total length and 1.7 kg in weight (No. 7 in Table 2) in captivity in a cage of 110 x 80 x 60 cm in size and observed its behaviour against live rats thrown into the cage. It was captured on November 3 and killed on November 20. During this interval frequent observations on its feeding behaviour were made, this behaviour being found strikingly snake-like. Just as described by Bates and Abbott, the monitor caught rats by creeping up on them stealthily and then making a final dash and lunge. However, these attempts often failed, although the monitor was ultimately able to catch a rat for every two or three attempts. It would swallow a rat head first, turning its head from side to side without chewing (Fig. 5a and b). The act of swallowing took about five to seven minutes to complete. Having eaten a rat, the monitor rarely made a determined attack on the other available rats for three to five days. Nevertheless, small lizards were vigorously attacked, one or two of them in fact being eaten during this period. It is of interest to note that although the captive monitor always completely swallowed each rat eaten, I was often able to pick up dead rats torn up by monitors following poisoning operations. Most of these remains consisted of the skin and limbs only, the head usually being missing.

Analysis of monitors' stomach contents

Seven monitors were dissected for stomach analysis to determine to what extent these lizards eat rats and the nature of their other food. The data are shown in Table 2. In only one of these examples was the body of a Polynesian rat (♂, ca 40 g) found. The bulk of the contents consisted of small lizards of other species, land crabs and hermit crabs ; and even one monitor egg was found.[1] Land crabs eaten by the predators measured 23 mm and 46 mm in carapace breadth, being thus of quite modest size. The captive monitor did not eat a large land crab (about 80 mm in carapace breadth) thrown into the cage although killing the crab after attempt lasting for several hours. In the case of a coconut crab (about 70 mm in carapace breadth) it

1) According to the data furnished by the Fish &Wildlife Division, Department of Agriculture, Government of Guam, the stomach contents of each of three monitors proved to consist of (i) the muscular feet of two African snails; (ii) insects, including grasshoppers and beetles; and (iii) crab chelae, carapace part and the foot of an African snail.

Table 2. Stomach contents of monitors from Ifaluk.

Monitors						Stomach contents	
No.	Sex	Total length (cm)	Body weight (g)	Locality	Date collected	Species (and number) of animal remains	Weight (g)
1	♀	83	283	Falarik	Nov. 7, 1965	***Rattus exulans*** (1 ♂)	ca 40
2	♂	130	1130	Ella	Nov. 8, 1965	***Cardisoma hirtipes* (1** ; carapace width 23 mm), ***Dasia smaragdinum*** (feet only), ***Coenobita*** sp. (one shell and fragmeents)	**5.3**
3	3’	106	670	Ella	**Nov. 8,** 1965	***Cardisoma hirtipes*** (fragments only)	2.4
4	♂	83	283	Ella	**Nov. 8,** 1965	***Emoia cyanurum* (1)** and fragments	6.2
5	♀	90	400	Falarik	Nov. 12, 1965	Egg of ***Varanus indicus***	***15.2***
6	♂	87	350	Falarik	Nov. 14, 1965	Empty	***0***
7*	♂	134	1700	Falarik	Nov. 3, 1955	***Cardisoma hirtipes* (1** ; carapace width 46mm) and fragments, ***Gehyra oceanica* (1)**	47.8

* The monitor was kept in captivity. In the case of this animal, ingested material was not derived from its stomach, but from material vomited up when it was collected.

ate only the soft part of the abdomen after a prolonged attack (Fig. 5a). It thus seems that *V. indicus* preys upon relatively small crabs rather than upon large ones. The captive example also attacked a smaller monitor (No. 6 in Table 2) thrown into the cage and bit it to death. According to the islanders, they often see large monitors swallow small ones. Although the number examined was insufficient for a really detailed stomach analysis, the data certainly suggest that, although the monitors undoubtedly prey on rats under natural conditions, the rate of such predation is relatively low as reported with regard to them on Guam by Dryden (1965).

Other observations

1. Relationship between monitor and other animal populations

As shown in the stomach-contents analysis data, ***V. indicus*** preys upon other lizards, land crabs, hermit crabs and rats. Besides these animals, according to the islanders, their predatory activity extends to partly grown coconut crabs, wild birds, chickens and their eggs. The islanders claim that land crabs and coconut crabs were more abundant on Ella Islet than elsewhere on Ifaluk until 1955. Since then, though, following the establishment of monitors, the numbers of these crabs have decreased considerably. At the present, indeed, their density on Ella has become appreciably lower than on Falarik and Falalap, judging from the comparison of trapping records for these islets. It is definitely indicated by Bates and Abbott that the reverse was the case in 1953, and it seems likely that the decrease in numbers of crabs is due to predation by the monitors.

V. indicus is an excellent tree climber. The islanders assert that the monitor takes wild birds and their eggs by a sudden lunge and snap, not only on the ground, but even in trees. I am personally inclined to doubt that attacks on birds are at all frequent. Furthermore, chickens which the islanders allow to run loose suffer losses from the monitors which take chicken eggs too. In general, small lizards of other species and crabs, especially land crabs and hermit crabs, are densely distributed on Ifaluk and serve as food for the monitors. The latter seem to prefer these animals to rats, finding it easier to catch them. Because of this, and the diversity of its feeding behaviour, ***V. indicus*** exerts stronger predation pressure on populations of land crabs and coconut crabs than of rats.

This monitor also eats coconut beetles and, like chickens, frequently dies from feeding on the poisonous toad *Bufo marinus* introduced into Kayangel, Palaus in order to exterminate ***V. indicus***. Gressitt felt that coconut palms were more important than chickens to the local people, and pointed out that the toads pollute the scanty water supply by dying in the wells or in crevices among the rocks lining the wells (Gressitt, 1952-quoted from Wiens, 1962 ; Gressitt, 1954).

2. ***Rat damage to coconuts***

On Ifaluk, rat damage to coconuts would be estimated at about 10 to 20 % of_ total production. The islanders proved not to care greatly about this, because the production of coconuts is more than adequate for present purposes. The human population was 316, but it is estimated that the coconuts are enough to support about 500 people. Although the people would prefer to be rid of the rats, and some of them are well aware that rats can be kept from the crowns of coconut palms by proper rat-guards, only a few of the tree trunks were banded- and then only with the leaves of screw pines instead of aluminium strips (Fig. 4). It was possible to find many rat-gnawed coconuts here and there all over Ifaluk (Fig. 6).

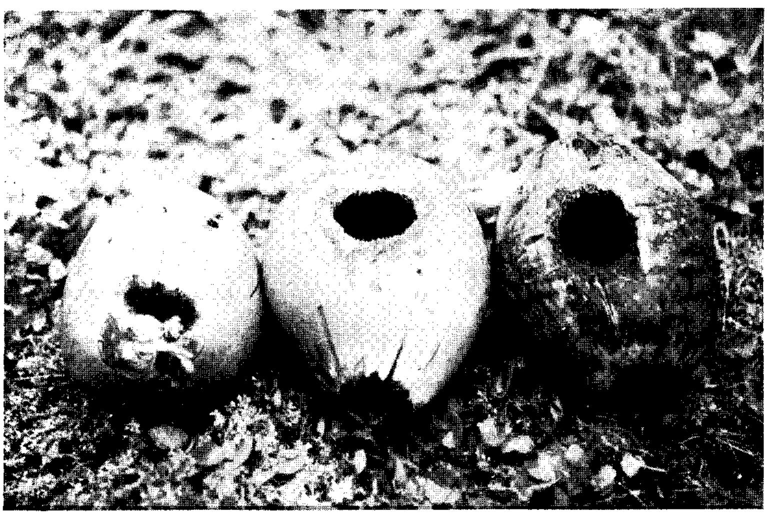

Fig. 6. Coconuts gnawed into by rats. Ifaluk Atoll, 6 November 1965.

According to the islanders, rat damage to coconuts on Ella seemed to decrease somewhat after the invasion of monitors. I learned on Fais Island, though, that considerable damage (more than on Ifaluk) was done to coconuts by rats despite the abundance of monitors. The islanders of Fais complained of the damage. It was stated by Ifalukians that on some atolls free from monitors (e.g., Lamotrek, Elato and Eauripik in the Woleai Group), a great deal of damage has been done to coconuts by rats since former times. This is easily understood in view of my very high estimates of rat population density even on Ifaluk where ***V. indicus*** is abunbant.

3. ***Attitude of the Ifalukians towards monitors***

While acknowledging the contribution made by monitors to rat control, the Ifalukians gave more weight to monitor damage to other useful animals than to benefit from them. Although fish forms the basic animal food of these islanders, they eat quantities of land crabs and coconut crabs too, and the fine and delicate flavour of these crustaceans is highly esteemed. The islanders resort to them too when they cannot fish on account of bad weather or for other reasons. Of course, chickens and their eggs are of greater importance than crabs as food for these people. ***V. indicus*** attacking poultry too, the islanders are thus prejudiced against them and have in fact deliberately built up their dog population to help reduce the number of monitors. At the present there are more than 30 dogs on Falarik and more than 20 on Falalap. Dogs were eaten by the Ifalukians in former times, and it seems that some have been present on the atoll for very many years, although Bates and Abbott stated that in 1953 only five existed there. It is therefore rare to find monitors around houses on either islet they occur principally in bushed areas. The islanders told me that on this account the incidence of ***V. indicus*** seems to have decreased somewhat on both islets by comparison with former times. Nevertheless, it was still easy to find numerous monitors there. The fact that monitors have swum to Ella from Falalap seems to be at least partially due to predation pressure by dogs. At the present time the incidence of ***V. indicus*** is higher on Ella than anywhere else on Ifaluk, and individuals may even be seen prowling near the edges of the reef flat at low tide. It is certain that the islanders are rather pleased with the lowering of this lizard's population by means of dogs, and in this connexion it should be noted that there is already a record (Wiens, 1962) of Micronesians wishing to exterminate monitors by introducing poisonous toads from the Palaus.

Other candidates for the biological control of rats

On Ifaluk the monitors are the only predator on rats. Therefore other candidate biological control agents for the purpose should be discussed. In this connexion, attention is called to the weasel, ***Mustela sibirica*** Pallas, because the usefulness of weasels as predators upon rats has been positively proved both experimentally and in practical apprication in Japan. Several years ago I kept a male Korean weasel, ***M. sibirica coreana*** (Domaniewski) in captivity in a cage measuring 80 x

80×150 cm, and observed its behaviour against live rats. On various occasions several rats were thrown into the cage at the same time. The weasel always annihilated the rats at once, even if the interval between two tests has been only a short one (Uchida, unpublished). Inukai (1949) and Hiraiwa et al. (1959) reported on successful instances of rat control consequent upon the introduction of weasels into certain small islands of Hokkaido and Kyushu, Japan.

Before introducing weasels into the tropics, however, the two following prerequisites must be carefully considered. The first question is whether the Japanese weasel, *M. sibirica itatsi* is able to adapt itself to the natural features of the tropics. By stopping over in the Kyukyus on my way home from the Carolines, I was able to learn a good deal about the effectiveness of Japanese weasels for the biological control of rats, and on the feasibility of this procedure under tropical conditions. The southernmost island where a significant degree of rat control has already been achieved by the introduction of Japanese weasels, is Zamami-shima Island, Kerama Islands, Okinawa Group of the middle Ryukyus (lat. 26” 14’ N, long. 127” 18’ E). For a number of years rats have been responsible for considerable damage to sugar-cane production all over the Ryukyus, and the introduction of a natural enemy against them has been strongly demanded. Since my visit to the Ryukyus in December 1965, *M. sibirica itatsi* has been introduced into some islands of the Ryukyus, e.g., Minami-daito-jima Island and Ishigaki-jima Island etc. It is considered that these introductions may result in an appreciable lowering of the rat populations. I thus wish to emphasize the great importance of this field trial in the Ryukyus as a preliminary test to further experimental introductions elsewhere in the tropics ; for perhaps the Japanese weasel may ultimately be felt to merit consideration as a candidate biological control agent for trial in isolated oceanic islands of the Pacific.

Even if the Japanese weasels prove capable of adapting themselves to tropical areas, a second question remains: this relates to possible harm being done to populations of animals other than rats by the weasels, and it raises issues that must be very carefully considered. There is no doubt that to some extent at least *M. sibirica itatsi* may make attacks on chickens, land crabs, coconut crabs and wild birds, all of which are useful to islanders as food. Again, they may feed on small lizards which are useful in the reduction of insects bothersome to man or to his efforts in agriculture. It seems quite certain, however, that this weasel is Par more effective against rats than are monitors, and it may well prove capable of controlling rats to the extent that scarcely any harm will be found to coconuts. Attention must therefore be directed to the difference in predatory efficiency between the two animals, It is submitted that the weasels may well prove conspicuously effective upon rats on small tropical atolls or other islands having relatively simple natural environments such as Ifaluk or the Tokelau Islands, South Pacific. The weighing up of the public health and economic advantages to be gained against possible adverse effects of predator introductions (e.g., attacks upon useful animals) is of course a matter that would require the most careful prior consideration by the authorities concerned and the islanders themselves. The decision would probably be influenced by the degree of development of the islands in question, and particularly by the local importance of the copra industry and filariasis incidence.

The introduction of a biological control agent must be carefully considered in all aspects. Where it concerns vector control in a developing area it poses problems of considerable complexity ; and being intimately bound up with the living problems of the local people it cannot be measured on any arbitrary basis. The relationship between the predator and other animal populations or human health and safety is, of course, a most important problem.

In this context more widely-known natural enemies of rats, the small Indian mongoose, *Herpestes auropunctatus* (Hodgson) and the Indian grey mongoose, *H. edwardsi* (Geoffroy) may present a human health hazard, as the former does in Puerto Rico where it has become an important reservoir and vector of rabies (Pimental, 1955). Furthermore, reservations have been expressed on the effectiveness of the mongoose as a practical biological agent for controlling rats. In Jamaica (Espeut, 1882), Hawaii (Baldwin et al., 1952) and Okinawa (Kishida, 1927a), the introduction of mongoose at first had good effects upon the general level of rat control but in the first-named island, California and Puerto Rico this animal seems to have been more injurious than beneficial to human life in the long run. Therefore it is not felt that the Indian mongoose deserves consideration for future introduction elsewhere in the tropics. However, even though European and North American weasels are among the wildlife reservoirs of rabies mentioned as of present importance by the WHO Expert Committee on Rabies during its Fifth Session (WHO, 1966), it should be noted that the disease is not present either in Japan or in the oceanic islands of the Pacific. Therefore, this hazard would not apply in so far as experimental introductions in the latter area are concerned.

Discussion and conclusions

As stated above, in judging the influence of monitors upon rats there was no choice but to make indirect comparisons between rat situations prior to and after the establishment of monitors in about 1955 on Ella. Bates (Bates and Abbott, 1958) spoke of the rats on this islet in 1953 as follows; "... I happened to go back, a few minutes later, to the place where we had opened the coconuts, to find it teeming with tremendous, fearless rats, ..." and "... the numbers on Ella were really fantastic." At the time when I went to Ella, however, I could not find such a phenomenon although I tested in the same way. This fact shows that the rat population density on Ella had decreased considerably over the preceding 12 years. Also, an islander who guided the American scientists in 1953 and who now guided me confirmed this fact without hesitation. As already mentioned, however, rats are densely distributed even now over Ella. It is very evident from this fact that the effectiveness of monitors upon rat control falls short of what it was expected to be.

The data presented herein indicate that there is no need for further consideration of experimental introductions of monitors for the biological control of rats elsewhere in the tropics. This follows from the fact that the rat population has been at a very high density on Ifaluk despite the presence of abundant monitors for certainly 12 and probably about 26 years.

The Japanese weasel, *Mustela sibirica itatsi,* is recommended herein as a better candidate biological control agent meriting serious attention for further tropical field trials against rats. The greatest care must, however, be taken for the proper conservation of endemic animals when considering the introduction of a predator such as a weasel which will be a terminal animal in a certain food chain. In a personal communication (1966) Dr. Marshall laird pointed out the possibility of destruction that might be brought about by weasels among endemic birds, and that would certainly lead to strenuous complaints by bird-lovers and conservationists. According to him, in the case of the South Pacific atolls inhabited by man, most such birds are sea birds which nest in trees, some, like the fairy terns simply depositing their eggs on flattened branches quite close to the ground. The question of whether the Japanese weasel climbs trees readily is thus very relevant in evaluating the merits and demerits of possible introductions. In this connexion, the weasels spend much time on the ground, but swim readily and well, They climb trees too, if necessary, but rarely do so in the field. It should be mentioned that Kishida (1927b) found in quantitative analyses of weasels' stomach contents (107 specimens) from the northern part of Honshu, Japan, during the winter, over 40 % occurrence of murine mammals, 22.6 % frogs and 2.8 % wild birds such as sparrow and thrush ; while Inukai (1935) found in speimens (241 weasels) from Hokkaido during the winter 50.6 % murine mammals and 7.1 % wild birds. These data clearly indicate that under winter conditions murine mammals form the bulk of the food of the Japanese weasel, wild birds being much less commonly eaten. To my knowledge, though, there is no information available on stomach contents analyses for *M. sibirica itatsi* during the summer months. Subject to further information to the contrary, the possibility of these weasels adversely influencing the populations of certain endemic birds must therefore be admitted.

It is concluded that further consideration of the possibility of experimental introductions of monitors, *Varanus indicus* (Daudin), into the South Pacific is unwarranted. It is submitted that a better biological control agent for use against rats is the Japanese weasel, *Mustela sibirica itatsi*, Temminck & Schlegel, but that further introductions of the Japanese weasel into appropriate tropical islands or atolls should not be initiated until clear evidence of the beneficial nature of the Ryukyus trial is forthcoming. Accordingly, I propose to pay close and careful attention to the future development of the rat control programme in the latter islands.

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Résumé

Deux espèces de rats, le rat des toits, *Rattus rattus* (L.) et le rat polynésien, *Rattus exulans* (Peale) se sont multipliés dans les iles du

Pacifique central et du Pacifique Sud. Ces rongeurs ont une action dévastatrice sur les noix de coco. Il en résulte non seulement une perte économique mais des risques sanitaires, car les noix de coco rongkes sont très largement utilisées comme gîtes larvaires par les moustiques, notamment par les vecteurs de la filariose bancroftienne et de la dengue. 11 est donc urgent d'appliquer des mesures coordonnées de dkratisation dans l'ensemble des îles du Pacifique. Une telle campagne, fond& sur de bonnes connaissances kcologiques, devrait associer les moyens chimiques aux procédés de lutte biologique. L'utilisation de prédateurs naturels doit retenir l'attention et l'on a signalé, par exemple, que le varan des Indes (*Varanus indicus* (Daudin)), gros lézard gris-vert qui a été introduit depuis quelques annkes dans certaines iles micronésiennes, joue un rôle assez important dans la destruction des rats.

C'est pour déterminer s'il serait intkressant d'introduire ce lézard dans d'autres iles de Micronésie et de Polynésie pour protéger les noix de coco contre les rats que l'étude dont il est rendu compte ici a été entreprise sur l'atoll d'Ifaluk (lat. 07° 15' N, long. 144" 27' E), dans les Carolines occidentales. Tout en reconnaissant que *V. indicus* contribue à détruire une certaine quantité de rats, l'auteur considère, sur la base des observations réunies, qu'une introduction expérimentale de ce prédateur dans les iles du Pacifique Sud n'est pas indiquée. Tout d'abord, bien que les varans soient toujours très nombreux depuis qu'on les a amenés sur l'atoll, la densité de la population de rats se maintient à environ 100 par hectare ; en second lieu, des expériences portant sur le comportement des varans en présence de rats captifs ont montré que leur agressivité est faible à l'égard de ces rongeurs ; en troisième lieu, l'analyse du contenu stomacal de *V. indicus* a révélé que le taux de prédation à l'égard des rats est relativement peu élevé dans la nature ; enfin, les habitants des îles ont eux-mêmes de fortes préventions contre ces lézards qui se nourrissent non seulcment de rats, mais aussi d'animaux utiles (notamment de poulets et de crabes). Il semble que la belette japonaise *Musteta sibirica itatsi* Temminck & Schlegel serait plus indiquée pour un essai pratique de lutte contre les rats mangeurs de noix de coco. L'auteur donne des détails sur cet animal et les conditions de milieu qu'il exige et il examine les chances de succès d'une tentative d'acclimatation en région tropicale.

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