2.5 ppm and an LC_{50} value for larvae of 0.00053 ppm. The ratios between the feeding activity of the guppies and the LC_{50} for the larvae were: OMS-1211, 261; OMS-1210, 182; fenthion, 83; fenitrothion, 46; ronnel, 45; Dursban, 38; dichlorvos, 13; diazinon, 2; lindane, 0.38; dieldrin, 0.085.

From these investigations it is concluded that Abate is the most suitable larvicide for controlling the larvae of *C. p. fatigans* in bodies of water that also contain guppies. The insecticides OMS-1210 and OMS-1211, as well as fenthion and fenitrothion, were also found to be very effective in controlling mosquito larvae without adversely affecting the guppies in most bodies of water.

* * *

The authors wish to acknowledge the valuable suggestions made by Professor Manabu Sasa, Institute of Medical Sciences, University of Tokyo, Japan, and by Professor Chamlong Harinasuta, Faculty of Tropical Medicine, University of Medical Sciences, Bangkok, Thailand. The authors also wish to thank Mr Sangdow Umyin and Miss Parichart Kanlayanamitr for their assistance. Supplies of insecticides OMS-1210 and OMS-1211 were kindly donated by WHO.

Observations on the Efficiency of the Japanese Weasel, *Mustela sibirica itatsi* Temminck & Schlegel, as a Rat-Control Agent in the Ryukyus*

by TERU AKI UCHIDA, *Zoological Laboratory, Faculty of Agriculture, Kyushu University, Fukuoka, Japan*

Laird [a, b, c] drew attention to the special public health hazards caused by rats on certain Pacific islands, where the gnawing of young growing coconuts by rats leads, not just to serious economic loss, but also to the consequent transformation of the nuts into larval habitats for mosquitos, including vectors of Bancroftian filariasis and dengue.

In a previous paper [d] it was shown that the monitor lizard, *Varanus indicus*, which had been introduced into some Micronesian islands, was not an effective rat-control agent. At the same time it was suggested that the Japanese weasel, *Mustela sibirica itatsi*, might be better, as the usefulness of weasels as predators on rats had been established both experimentally and by practical trials on certain islands off Hokkaido and Kyushu, Japan. [e, f] Although weasels feed upon birds to some extent, Inukai's data,[g] which give a quantitative analysis of weasels' stomach contents, clearly indicate that murine animals form the bulk of their food under winter conditions and that wild birds are much less commonly eaten.

At the time of my earlier visit to the Ryukyus, in December 1965, a rat population census was made and soon after this large numbers of weasels were introduced into several widely separated islands. I visited these islands again from 1 February to 10 March 1967 and from 25 December 1967 to 9 January 1968 to assess the effects the weasels were having on the rat population, and this paper presents the results and conclusions of this study.

The first aim of using predators such as weasels is, of course, to reduce quickly the extent of rat damage. If the predators can be permanently established, however, they may bring about a long-term suppression of the rat population, a new ecological

* These studies were carried out with financial support from the World Health Organization.

[a] Laird, M. (1963) *Rats, coconuts, mosquitoes and filariasis*, In: Gressitt, J. L., ed., *Pacific basin biogeography*, Honolulu, Bishop Museum Press, pp. 535–542.

[b] Laird, M. (1966) *Integrated control and* Aedes polynesiensis *: an outline of the Tokelau Islands Project, and its results.* (Unpublished documents WHO/EBL/66.69, WHO/FIL/66.63, WHO/Vector Control/66.204).

[c] Laird, M. (1966) *Biological control of rodents.* In: *Seminar on rodents and rodent ectoparasites.* (Unpublished document WHO/Vector Control/66.217).

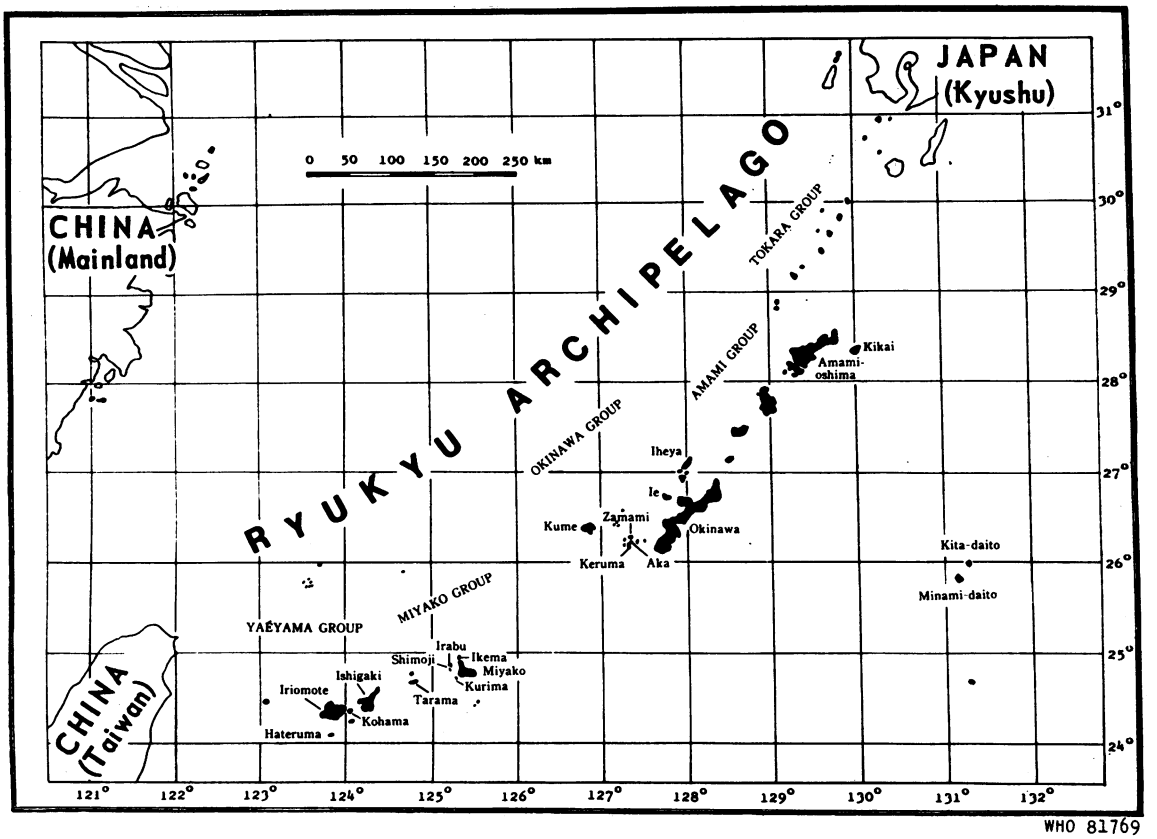
[d] Uchida, T. A. (1966) *Bull. Wld Hlth Org.*, **35**, 976–980.

[e] Inukai, T. (1949) *Trans. Sapporo nat. Hist. Soc.*, **18**, 56–59.

[f] Hiraiwa, Y. K., Uchida, T. A. & Hamajima, F. (1959) *Sci. Bull. Fac. Agric. Kyushu Univ.*, **17**, 335–349.

[g] Inukai, T. (1935) *Jap. J. appl. Zool.*, **7**, 49–52.

LOCATION OF THE ISLANDS SURVEYED



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equilibrium being established at a markedly lower level of rat density. Excellent monographs by Wiens [h] and Storer [i] helped me to understand the problems of establishing predators on the atolls and small islands in the Pacific Ocean.

History of the introduction of weasels

The location of the islands of the Ryukyu archipelago is shown in the accompanying figure. Kikai-jima, in the Amami group in the middle Ryukyus, was the first island on which an encouraging level of rat control was achieved by the introduction of Japanese weasels in 1942. After that weasels were introduced into some other islands of the Amami group but, although some reports of these trials have been published,[j, k] few details are available.

Later, under USCAR,[l] weasels were introduced into the islands of Zamami-shima, Aka-jima and Keruma-jima in 1957 and 1958. After further reports of heavy rat damage to agricultural products from many parts of the Ryukyus, large numbers of weasels (a total of 6843) were introduced into 14 islands from December 1965 onwards. The accompanying table summarizes the details of weasel introduction and shows which of the islands were later visited.

[h] Wiens, H. J. (1962) *Atoll environment and ecology*, New Haven & London, Yale University Press.

[i] Storer, T. I., ed. (1962) *Pacific island rat ecology*, Honolulu, Bishop Museum Press.

[j] Yotsumoto, T. (1959) *Jap. Wildl. Bull.*, **17**, 156–158.

[k] Iha, K. (1966) *J. Okinawa Agric.*, **5**, 45–53.

[l] Since the end of the Second World War in 1945 the southern part of the Ryukyu archipelago has been administered by the United States Civil Administration, Ryukyus (USCAR). The northern part continues to be administered by Japan.

WEASEL INTRODUCTION INTO THE RYUKYUS IN RECENT YEARS

Group	Island	Area of island (ha)	Weasels introduced: Total no.	Sex: M	Sex: F	No. per 100 ha	Period of introduction	Rodenticide used in addition	Result
Okinawa	Zamami [a]	594	ca 40	63	20	7	Mar 1957 and 1958	None	No damage; weasels have become established
	Aka [a]	307	? 83			?		Little	Considerable damage; weasels failed to become established
	Keruma [a]	ca 100	?			?		Little	Considerable damage; weasels failed to become established
	Kita-daito	1 820	178	146	32	10	Dec 1965–Feb 1967	Much	Little damage to crops
	Minami-daito [a]	2 591	481	416	65	19	Jan 1966–Feb 1967	Much	Little damage to crops
	Ie [a]	2 020	360	296	64	18	Apr–Dec 1966	Much	Little effect yet; should be effective later
	Iheya	2 252	472	427	45	21	Oct 1967–Jan 1968	Little	Not yet clear because of the short time since introduction
	Kume	7 065	537	472	65	8	Oct 1967–Jan 1968 [b]	Much	Little effect yet; numbers of weasels still too small
Miyako	Irabu-Shimoji [a]	3 888	732	613	119	19	Dec 1966–Jan 1968	Little	Little damage
	Tarama	1 866	472	396	76	25	Jan 1967–Jan 1968	Little	Little damage
	Miyako [a]	14 791	531	443	88	4	Feb – Mar 1967 [b]	Little	Little effect; too few weasels and too little rodenticide used
	Kurima	262	70	47	23	27	Nov 1966–Mar 1967	Little	The effect is expected soon
	Ikema	262	62	55	7	24	Oct 1967–Jan 1968	Little	Not yet clear because of the short time since the introduction
Yaéyama	Ishigaki [a]	25 834	2 074	1 842	232	8	Dec 1965–Jan 1968 [b]	Much	Little damage in spite of insufficient numbers of weasels
	Iriomote [a]	32 574	319	288	31	1	Jan 1966–Jan 1968	Much	Heavy damage because of scarcity of weasels
	Kohama	1 033	207	180	27	20	Nov 1966–Jan 1968	Much	Little damage
	Hateruma	1 496	348	299	49	23	Nov 1966–Jan 1968	Much	Little damage
Total [c]		97 754	6 843	5 920	923				

[a] Islands visited. [b] Weasel introduction will be continued until 1971. [c] Excluding the figures for Zamami, Aka and Keruma.

Methods

In the first survey, in February–March 1967, I visited the following islands, where weasels had been introduced, in order to estimate the rat populations: Zamami-shima, Aka-jima, Keruma-jima, Minami-daito-jima, Ie-jima, Irabu-Shimoji-jima, Miyako-jima and Ishigaki-jima. In the case of Ishigaki it was also possible to make direct comparisons with the rat population in December 1965, before the weasels were introduced. About 9 months later I revisited Ishigaki and Irabu-Shimoji to investigate further changes.

The removal method was employed to estimate rat populations, with snap-traps placed 10 m apart and arranged in grids of 10×5 or 10×10, thus covering an area of 0.5 ha or 1.0 ha. Fresh sweet-potato was used as a trap bait and, to avoid trap-shyness, pre-baiting was carried out the day before setting the traps.

Rat population density

Ishigaki-jima. This island has an area of 25 834 ha and is one of the largest islands on which weasels have been introduced; it has mountains which rise to 525 m above sea-level. Sugar-cane is cultivated, mainly on the alluvial plains and table lands, and pineapples are grown on the mountain slopes.

In December 1965 a rat population census was carried out in a heavily damaged sugar-cane field in the dry zone of the island. A total of 300 trap/nights captured 29 roof rats in 3 days, 20 on the first day, 6 on the second and 3 on the third day. From this result the population density was estimated as about 30 per hectare.

Between December 1965 and January 1967 about 1600 weasels were introduced into the island, and in February 1967 further population estimates were made. Only small quantities of rodenticide had been used on the island since the introduction of the weasels and on this occasion the use of 300 trap/nights caught 34 rats in 3 days, 20 on the first day, 9 on the second, and 5 on the third day, giving an estimated population density of 38 per hectare. Other studies using the mark-release method, although unfortunately spoilt by local interference, also showed that the rat population was still high.

Another census was made, in February 1967, in a sugar-cane field in a humid zone, which appeared to have a low rat population. Warfarin rodenticide had been used occasionally in this area during the previous year. A total of 300 trap/nights captured 5 roof rats per hectare, 4 on the first day, and 1 on the third day. At the same time the mark-release method was used in another field in the humid zone and these results confirmed that the rat population density was low in this area, being little more than 5 or 6 per hectare. In this field I found some evidence of weasel activity. The considerable difference in the rat population densities between the dry and the humid zones confirms that the weasels are inclined to gather in the humid zone (i.e., forests and river basins) in search of food.

By the time of my visit in December 1967 the number of weasels introduced into the island had increased to 2074 (1842 males, 232 females), giving a density of about 8 weasels per hectare at introduction. Large quantities of anticoagulant rodenticides had also been used since April 1967. During the period 27–29 December 1967, a total of 300 trap/nights in the dry-zone sugar-cane field captured only 1 roof rat and 2 Ryukyu grey musk-shrews, *Suncus murinus riukiuanus*, the former being trapped on the first day and the latter on the second day. The rat population density had thus dropped markedly since February 1967.

Other studies showed, however, that rats were still abundant on paddy fields and waste land where no rodenticides had been used. Few rat remains were found in the samples of weasel faeces collected on the island. These data indicate that the reduction in the rat population that had occurred was probably due to the use of rodenticides and that the weasel population was not yet large enough to give effective rat control.

Minami-daito-jima. This island is a raised atoll with an area of 2591 ha and has many ponds and bogs. Sugar-cane is cultivated all over the island, except in the forest areas.

The use of rodenticides (warfarin and sodium fluoroacetate) had been the only rat-control measure before the introduction of weasels and sugar-cane products had suffered very heavy rat damage (about 20%–30%).

Between January 1966 and February 1967 a total of 481 weasels (416 males, 65 females) was introduced and the only rodenticide used after this was warfarin. The weasel density at the time of my visit in February 1967 was about 19 per 100 ha, similar to the density found to be ideal in earlier studies in Sagi-shima of Kyushu.[f]

In February 1967 I found little evidence of rat damage and in studies carried out in 2 sugar-cane fields, a total of 200 trap/nights captured only 2 rats. No rat remains were found in weasel faeces.

This indicated that the integrated control measures (weasels+rodenticide) had proved effective in the period of just over 1 year since their introduction.

Zamami-shima. This island was the southernmost island on which a significant degree of rat control had already been achieved by weasel introduction. The island is small and mountainous, having an area of 594 ha and the highest point being 140 m above sea-level. It is distinguished from the other islands because its main industry is fishing. In addition to some narrow flat fields, terraced fields on mountain slopes are cultivated with sweet potatoes, wheat and potatoes. There are also a few sugar-cane fields.

Agricultural produce had been subjected to heavy rat damage prior to weasel introduction in spite of the use of rodenticide (sodium fluoroacetate). About 40 weasels were introduced in March 1957 and 1958 and they had become established since that time. During my visit in March 1967, the use of 50 trap/nights in each of 2 sweet-potato fields led to the capture of only 1 rat. However, no rat remains were found in samples of weasel faeces collected on the island. It should be noted that no rodenticide had been used on the island since the weasels were introduced.

Irabu-Shimoji-jima. This territory consists of 2 flat islands, separated by a narrow watercourse which weasels can cross at low tide by wading or swimming. The islands have a high water-table, 1.5 m–2.0 m below the surface, but the spring-water is not suitable for the weasels to drink as it is brackish. Sugar-cane is cultivated on both islands. A total of 119 weasels (104 males, 15 females) was introduced into the islands in December 1966. When I visited the islands in February 1967 local farmers reported that the numbers of rats had been decreasing gradually for a month and that they had found several dead rats.

By the time of my second visit in January 1968 the total number of weasels introduced had risen to 732 (613 males, 119 females), the density reaching about 19 weasels per 100 ha. Since the weasels were first introduced the number of roof rats had markedly decreased despite the fact that only small quantities of anticoagulant rodenticide had been used. Rat remains were found in 8 of the 11 samples of weasel faeces examined.

Ie-jima. This island is very dry and has a poor natural fauna. Sugar-cane is cultivated all over the island. A total of 360 weasels was introduced from April to December 1966 but when I visited the island in February 1967 a high rat population still persisted in spite of the relatively high weasel population density (about 18 per 100 ha).

On Miyako-jima the weasels had only recently been introduced and the population density was still too low to have an effect on the rat population. On both Aka-jima and Keruma-jima weasels had failed to become established for reasons which are not understood.

Relationship between weasel and other animal populations

Faeces analysis has shown that *M. sibirica itatsi* preys upon rats, shrews, birds, toads, frogs, fish, crabs, scolopendrids and insects. According to the local inhabitants, they also feed on snakes, lizards and chickens. Zamami is a good example of the faunal changes that occur after weasel introduction, because it is now 10 years since they were first introduced.

Prior to weasel introduction, snakes (*Natrix pryeri, Opheodrys semicarinatus, Dinodon semicarinatus, Calliophis boettgeri* and *Trimeresurus okinavensis*) and frogs (*Microhyla ornata, Rana limnocharis* and *Rhacophorus japonicus*) were abundant in Zamami.[m] The inhabitants confirmed that these animals had decreased gradually since weasel introduction and there is no doubt that this, as well as the reduction in numbers of rats, was due to predation by weasels. Newts (*Triturus pyrrhogaster ensicauda*) are still abundant, however, and no newt remains were found in weasel faeces. Frog and snake populations have therefore decreased as much as rat populations. I also found many clusters of half-eaten crabs (2 kinds of sesarmid crabs, *Helice tridens latimera* and *Chasmagnathus convexus* and species of marine crab, *Scylla serrata*)[n] in stream beds near to an outfall where weasels had been seen; but crabs are still abundant on the island.

On Minami-daito large amounts of toad and frog remains were found in the samples of weasel faeces examined. However, the bones found were all small, indicating that the prey were young toads or frogs. Scales of the fish *Tilapia mossambica* were found in only 1 sample. On Ishigaki I found some remains of half-eaten frogs (*Rana catesbiana* and *Rhacophorus*

[m] Takara, T. (1962) *Sci. Bull. Div. Agric. Home Econ. Engng. Univ. Ryukyus*, 9, 1–202.

[n] Identified by Dr S. Miyake of Kyushu University.

viridis) and crabs (*Sesarma dehaani* and *Cardisoma carnifex*). As it is not long since weasels were introduced to both these islands no great change in the fauna was evident.

On Ishigaki I learned of only one example of damage to chickens by weasels, about 90 being killed in an open hen-house. Slight damage was also occasionally inflicted on unpenned chickens on those islands where weasels were introduced. The remains of wild birds were evident in weasel faeces in 2 samples from Ishigaki, 4 from Irabu-Shimoji, 2 from Zamami and 1 from Minami-daito out of a total of 32 samples. On Ishigaki wild birds, such as Indian water hens (*Gallinula chloropus indica*), were occasionally attacked by weasels. However, on none of the islands had the population of wild birds decreased because of weasels.

Discussion and conclusions

The increase in the rat population in the Ryukyus in recent years has been due to a number of different factors, and the introduction of predators was recommended because there were few indigenous carnivorous mammals.[h, o, p, q, r]

The object of using weasels as predators was to prevent rat damage as quickly as possible. The interval before they became effective, however, varied according to the number introduced, the topographical features and whether or not rodenticides were used at the same time. A further aim of weasel introduction was to suppress the rat population permanently by establishing an ecological equilibrium between predator and prey as has occurred on Sagi-shima and Zamami-shima. The establishment of the weasels, however, often depends on the abundance of wild animals useful to weasels as a source of food and the extermination of weasel predators, such as wild dogs. The smaller the island the sooner it is possible to assess the results; on large islands such as Ishigaki and Miyako the situation must be watched with patience.

It is clear from these investigations that eventual success in rat control on crop-cultivated islands or coconut-planted islands will not be achieved by the use of rodenticides alone, whether the islands are large or small. Biological control of rats was effective by itself on small islands such as Sagi-shima (about 100 ha) and Zamami-shima (594 ha) and was also effective on larger islands (Minami-daito, 2600 ha; and Irabu-Shimoji, 3900 ha) in combination with rodenticides, if weasel populations of about 19 per hectare were established. Weasels have proved capable of adapting themselves to the subtropical climate of Zamami, which lies not far north of the Tropic of Cancer, as long as conditions are not too dry.

The possibility of secondary poisoning in weasels, due to warfarin, should be mentioned. So far as I know, warfarin has not been tested to any extent on weasels, but there is no record of weasels having died as a result of secondary poisoning by this rodenticide on any of the islands on which weasels were introduced. However, cats often die because of direct poisoning. I carried out one experiment with 1 male Korean weasel, *M. sibirica coreana*, and this animal eventually died after eating 25 rats poisoned with warfarin in 24 days. The particular rodenticide used in this experiment contained 0.2% warfarin and this relatively high concentration might account for the rather rapid toxic effect.[s] Although weasels may eat 1 rat per day, it is unlikely that they would continue doing so for such a length of time under natural conditions.

The introduction of any biological control agent must, however, be carefully considered in all aspects. The greatest care must be taken for the proper conservation of endemic animals (especially sea birds) when considering the introduction of a predator such as a weasel which will be a terminal animal in a certain food chain.[d, t] In fact, Wodzicki[u] is of the opinion that liberation of exotic predatory animals into the Pacific islands should not be permitted except on an experimental basis and under strict supervision. Predators should certainly not be introduced into islands which are wild-life sanctuaries or are otherwise of special importance by reason of their fauna.

[o] Marshall, J. T., Jr (1957) *Atoll Res. Bull.*, **56**, 1–11.

[p] Johnson, D. H. (1962) *Rodents and other micronesian mammals collected.* In: Storer, T. I., ed., *Pacific island rat ecology*, Honolulu, Bishop Museum Press, pp. 21–38.

[q] Uchida, T. A. (1963) *Rep. Committee Foreign Sci. Res., Kyushu Univ.*, **1**, 117–138.

[r] Kirkpatrick, R. D. (1966) *J. Mammal.*, **47**, 701–704.

[s] Price–Evans, D. A. & Sheppard, P. M. (1966) *Some preliminary data on the genetics of resistance to anticoagulants in the Norway rat.* In: *Seminar on rodents and rodent ectoparasites* (Unpublished document WHO/Vectrol Control/66.217).

[t] Laird, M. (1968) *Recent advances of biological control in medical entomology.* In: *International Symposium on New Perspectives on the Control of Injurious Insects*, Rome (In press).

[u] Wodzicki, K. (1968) *An ecological survey of rats and other vertebrates of the Tokelau Islands*, Wellington, New Zealand, Government Printer.

Further consideration of the experimental introduction of the Japanese weasel, *Mustela sibirica itatsi* Temminck & Schlegel, into tropical Pacific islands would seem justified, as it appears that suppression of rat populations, on small, isolated islands, is possible by an integrated rat control procedure consisting of the joint use of weasels and anticoagulant rodenticides such as warfarin.

* * *

I wish to express my thanks to Professor Marshall Laird of Memorial University of Newfoundland, Canada (formerly with the World Health Organization) and to the World Health Organization for their help in this project, and to Professor Sadayoshi Miyake, Professor Keizo Yasumatsu and Dr Koji Yano of Kyushu University, the late Professor Yoshi Kuni Hiraiwa of Fukuoka Jogakuin College, Professor Sadao Ikehara and Professor Tetsuo Takara of the University of the Ryukyus, and Professor William B. Jackson of the Bowling Green State University, Ohio, USA, for their advice and encouragement. I should also like to thank the staff of the Department of Agriculture and Forestry, Government of the Ryukyus, the local authorities concerned and Mr Kiyohiko Inafuku, Head of Ishigaki-jima Sugar Manufacture Inc., for their hospitality and assistance; and Dr Keiji Baba of my laboratory, who assisted me. Finally, I should like to thank the Sumitomo Chemical Company, Osaka, Japan, for supplying rodenticides.

Age-corrected Proportional Mortality Indicator (PMI) as a Comprehensive Health Indicator

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In 1957, Swaroop & Uemura [a] reported their Proportional Mortality Indicator (PMI) as a valuable comprehensive indicator for the assessment of levels of health. A WHO Study Group on the Measurement of Levels of Health [b] used the indicator as one of the comprehensive health indicators because of its usefulness in comparisons between health levels in different areas, and on account of the simple procedure for calculation and the ease of collecting the basic data. The PMI is calculated simply as the proportion of deaths in persons aged 50 years and over to total number of deaths in a population; the age-distribution in the population is therefore not taken into consideration.

The present authors have reported the use of the PMI in comparisons of health levels within a country and have shown that its validity is dependent on the size of population.[c, d] The limited usefulness of the PMI is, to a considerable degree, related to the age-distribution of the population.

Thus, the present authors tested an age-corrected PMI with a correction also to a standard age-distribution in the observed population, similar to the calculation for corrected death-rate. Using data from Shizuoka Prefecture, Japan (Fig. 1, inset), the effectiveness of the new indicator was examined and assessed.

Materials and methods

The data used in the study were annual health statistics, including demographic conditions, for each region covered by a health centre in Shizuoka Prefecture in 1955, 1960 and 1965. Population data for 1965 in Shizuoka Prefecture were used for the standard population in this study.

[a] Swaroop, S. & Uemura, K. (1957) *Bull. Wld Hlth Org.*, **17**, 439–481.

[b] WHO Study Group on the Measurement of Levels of Health (1957) *Wld Hlth Org. techn. Rep. Ser.*, **137**.

[c] Katsunuma, H. & Koizumi, A. (1962) *Minzoku Eisei*, **28**, No. 1, pp. 101–105.

[d] Katsunuma, H. et al. (1964) *Jap. J. publ. Hlth*, **11**, No. 2, pp. 61–67.