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A Large-scale Experiment in the Control of Aquatic Snails by the Use of Molluscicides on a Sugar Estate in the Northern Region of Tanganyika *

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The author describes a large-scale experiment in which the molluscicide Bayer 73 (Bayluscide) was used in an attempt to eliminate Biomphalaria pfeifferi, *the snail host of* Schistosoma mansoni, *from an irrigation system in Tanganyika. Applied at a concentration of 1 p.p.m., the molluscicide gave a very high kill of snails and much of the treated area remained completely free of vector snails for seven months after treatment. However, there were a few survivors in small pockets associated with a drainage area that became flooded during heavy rains coincident with the application of molluscicide. From these survivors a dramatic resurgence of snails occurred in some of the treated canals. This resurgence may be analogous to similar phenomena observed in some insecticide work. The suggestion is made that removal of parasites and predators, in particular trematode parasites, by a molluscicide might increase the snail's capacity for repopulation. Studies of the seasonal fluctuations of snail population density in an adjacent, but separate, irrigation system suggest that molluscicide applications would be more effective if timed to coincide with the end of the rainy seasons.*

Since July 1960 studies have been undertaken to investigate the biology and control by molluscicides of *Biomphalaria pfeifferi*, the snail host of *Schistosoma mansoni*, in a bilharziasis-endemic area in the Northern Region of Tanganyika. The area under investigation (Fig. 1) is a sugar plantation where about 2800 ha (7000 acres) of sugar cane are furrow-irrigated by water which is gravity-fed from a river. The irrigation system, comprising eight reservoirs used as night storage dams and some 300-500 km (200-300 miles) of canals, provides excellent snail habitats. In the older part of the estate 1200 ha (3000 acres) of sugar cane are irrigated by about 1100 litres/second (40 cusecs) of water taken continuously from the river at the " old " intake, and in the newer part of the estate 1600 ha (4000 acres) by about 1700 litres/second (60 cusecs) from the " new " intake. In effect there are two irrigation systems, the Old Area and the New Area, which are not contiguous at any point. In each system there are four reservoirs and a number of primary, secondary and tertiary canals. The primary canals carry water from the river to the night storage dams; the secondary canals carry water from the dams to the tertiary canals, which supply water to the fields of sugar cane. The fields dry out every day and therefore do not support aquatic snail populations.

A preliminary snail survey was carried out to examine the distribution of snails, species present, population densities and the infection rates of *Biomphalaria pfeifferi*. Later, more detailed work was aimed at developing an efficient sampling technique for estimating the density of snail populations. A mud-sampling technique, which is essentially a quadrat method, was evaluated and found to give reliable estimations (Crossland, 1962; Yeo, 1962). This work on sampling of snail populations, together with some field screening trials of new molluscicides, had indicated that snail populations which were not wholly eliminated were capable of re-establishing themselves within a very short time. These results indicated that a very high degree of

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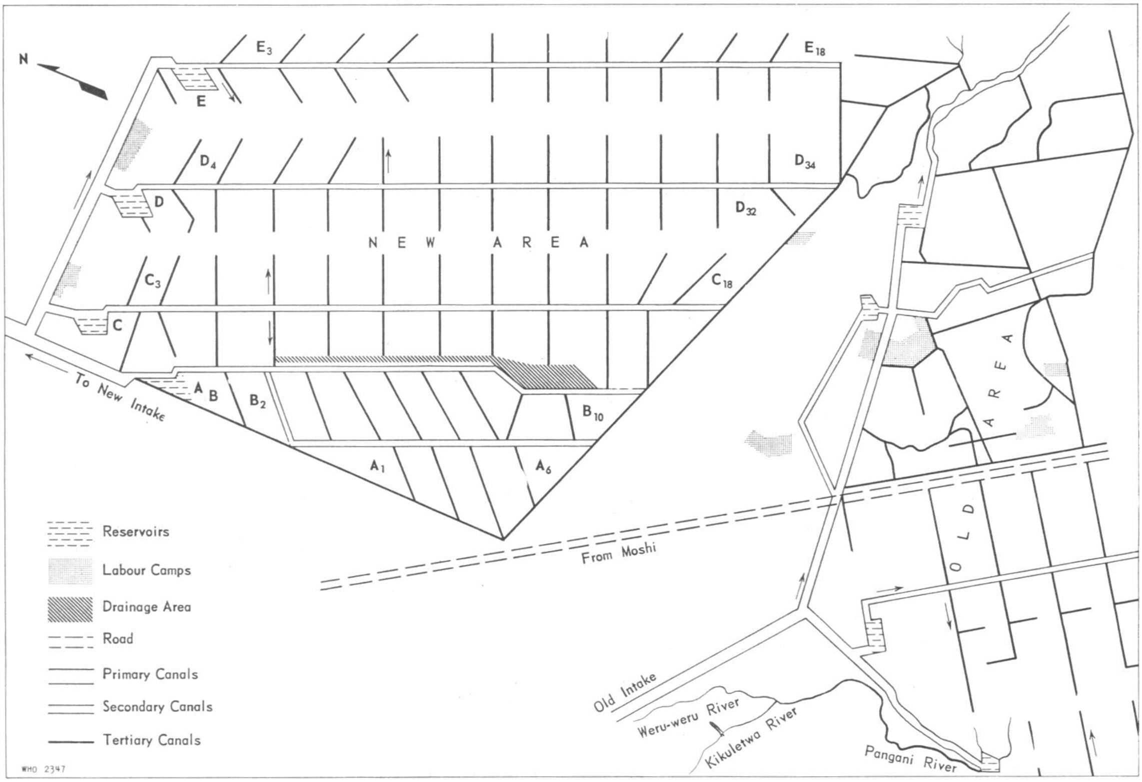
FIG. 1
SKETCH MAP OF EXPERIMENTAL AREA



efficiency, if not complete elimination of snails, would be necessary to achieve a long-lasting reduction in snail density.

APPLICATION OF MOLLUSCICIDE

In November 1961 the New Area was treated with a 70% dispersible-powder formulation of Bayer 73 (Bayluscide), the ethanolamine salt of 5,2′-dichloro-4′-nitro-salicylicanilide, at a dose of 1 p.p.m. The aim was to achieve a minimum concentration × time product of 8 p.p.m.-hours in all reservoirs and irrigation canals.

The water was shut off at the intake from the river, and the reservoirs and canals were drained in preparation for treatment. Application of molluscicide was carried out in stages to cover the whole of the New Area during a period of six days (4-9 November 1961). In the first stage the reservoirs C and E were filled with treated water containing 1 p.p.m. of Bayer 73. The capacity of each of these reservoirs was 42.5×10^6 litres (1.5×10^6 cubic feet), and each required 24 hours to fill at a rate of 500 litres/second (17.5 cusecs). This treated water was then held for 24 hours in the reservoirs before being channelled to all downstream secondary and tertiary canals. To prolong the effect of the molluscicide, and to ensure that all canals were full during treatment, small earthen, temporary weirs were constructed to cause ponding of the treated water. In the second stage the reservoirs AB and D were similarly filled with treated water. The capacity of reservoir AB was 96.2×10^6 litres (3.4×10^6 cubic feet) and that of reservoir D was 48.1×10^6 litres (1.7×10^6 cubic feet); 36 hours were required to fill reservoir AB with treated water and 24 hours to fill reservoir D. In all 229.2×10^6 litres (8.1×10^6 cubic feet) of water were treated with Bayer 73 at a concentration of 1 p.p.m.

The amount of Bayer 73 applied was monitored by on-the-spot analyses of water samples taken about 100 m downstream of the molluscicide dispensers. The results of these analyses are reported in Table 1, and show that the actual dose approximated to the calculated dose of 1 p.p.m.

In addition to these field determinations about 300 water samples were taken from various places during treatment of the New Area and were removed to the laboratory for later analysis. These were stored for up to two weeks before being analysed, and the results obtained were very much lower than those obtained from water samples which were analysed immediately. Considerable loss of Bayer 73 took place during storage of the water samples; much of this loss was probably due to the high silt content.

TABLE 1

ANALYSES OF TREATED WATER CARRIED OUT IN THE FIELD ABOUT 100 METRES DOWNSTREAM OF MOLLUSCICIDE APPLICATORS

Date and time	Concentration of Bayer 73 (p.p.m.)
4 November 1961	
07.15	0.9
09.00	0.9
09.30	0.75
11.00	0.75
14.00	0.75
17.00	1.1
8 November 1961	
06.45	1
07.30	1
07.45	1
08.00	0.75
08.15	1
09.30	1
14.00	0.75
16.00	1

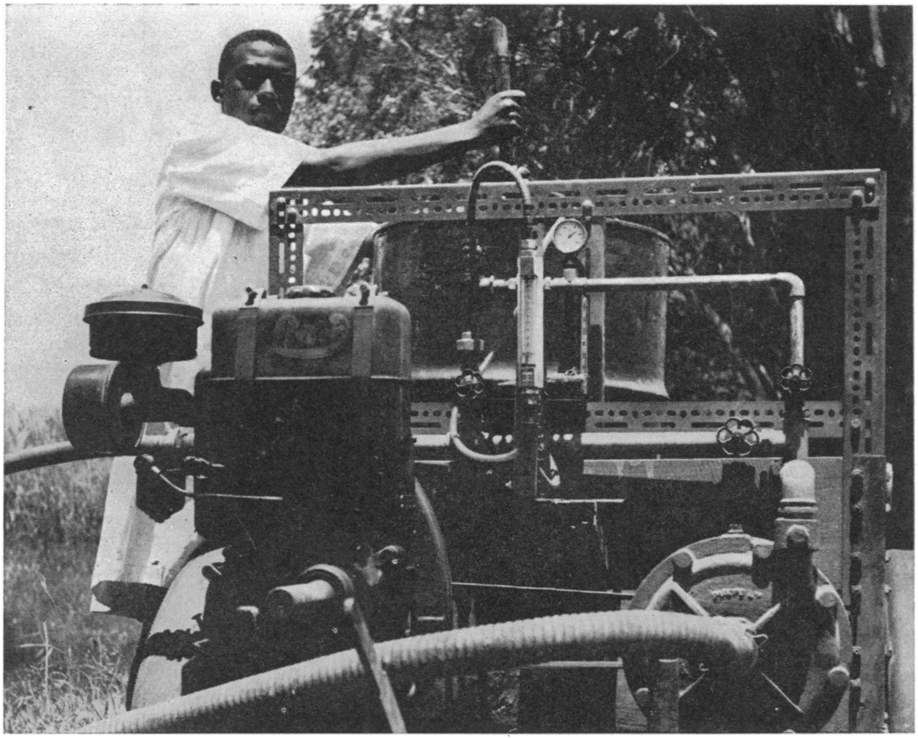
DISPENSING EQUIPMENT

The first stage of the molluscicide application was carried out using a constant-flow, drip-feed dispenser devised by Foster & Poulton (1960). The device is basically a constant-head apparatus incorporating a mechanical stirrer for agitation of the molluscicide suspension. This dispenser was efficient for treating canals with a carrying-capacity of up to 700 litres/second (25 cusecs); when larger canals were treated, however, blocking of tubes and orifices was troublesome. A motorized dispenser (Fig. 2) was then used, incorporating a circulation pump which passes water through a Venturi meter at a pressure of 20-40 p.s.i. (1.4-2.7 atm). A needle situated in the throat of the Venturi meter is connected to the supply of molluscicide *via* a flowmeter to give a direct reading of the discharge rate. At first this dispenser was satisfactory but with continued use blocking of the flowmeter was experienced. This problem was overcome by by-passing the flowmeter and checking the discharge rate by timing the rate of flow from a calibrated drum containing 200 litres (44 Imperial gallons) of a 10% concentrate of Bayer 73.

SAMPLING METHODS AND SEASONAL CHANGES IN THE ABUNDANCE OF SNAILS

The Old Area of the estate was not treated and served as a control area. Mud-sampling was carried out in a regular pattern in such a way that the samples were taken from similar and representative places in both the treated and control areas. Starting in March 1961, 30 samples were taken weekly from each of the four reservoirs in both areas and a further 120 samples from the irrigation canals, making a total of 240 samples weekly from each area. The results, for the vector snail *B. pfeifferi*, are shown in Fig. 3, where they are expressed as the mean number of snails per 100 m^2 of bottom mud and plotted on a logarithmic scale. In the control area the seasonal variation in density is shown together with the total monthly rainfall for the period March 1961 to October 1962. There appears to be a correlation between variation in density and amount and duration of rainfall. Coinciding with the beginning of the rains the density of *B. pfeifferi* falls to rise again during the dry months of the year; from October 1961 to January 1962 the rains were particularly heavy and prolonged, and these rains coincided with a very considerable reduction in snail density. This effect probably occurs because water for irrigation is not required during times of prolonged, heavy rain; extensive drying out of the reservoirs and canals takes place; many snails die and there is little breeding. Other factors causing

FIG. 2
MOTORIZED MOLLUSCICIDE DISPENSER



high death-rates and low birth-rates may be the presence of much silt in the water and relatively low water temperatures when water for irrigation is taken from the river during part of the rainy seasons. In the dry months this water is warm and clear.

Also shown in Fig. 3 is the mean density of *B. pfeifferi* in the treated area (i.e., the New Area) for the same period. The mean density before molluscicide was applied was comparable with that in the control area, and the rains in March, April and May 1961 affected the snail population in a similar manner.

Some 720 mud samples were taken from the New Area during the week before treatment and a further 1200 samples during the week after treatment. Both live snails and dead snails were counted during these weeks; a summary of the counts is given in Table 2, where the post-treatment results from 1200 samples have been multiplied by a factor of 720 ÷ 1200 to facilitate comparison with the pre-treatment results. Altogether 1069 live snails and 3331 dead snails were collected in the pre-treatment sampling. No live snails were collected in the post-treatment sampling but 5954 dead snails were collected.

Yeo (1962) has shown that there is no difference in the form of the distribution for different species of snails collected at Arusha Chini, so that for the purpose of statistical analysis no serious error is involved if all the snails are regarded as being drawn from the same population. Using Yeo's method of analysis the 95% fiducial limits of the pre-treatment count of total live snails are 920 and 1225. From Yeo's data there is 1 chance in 40 (i.e., $P = 0.025$) that the true figure for the live snails in the post-treatment sampling should be 3 or greater. 1200 samples were taken in the post-treatment sampling and the errors in the pre-treatment sampling are pro-

FIG. 3. SEASONAL FLUCTUATIONS IN *BIOMPHALARIA PFEIFFERI* POPULATIONS AT ARUSHA CHINI, CORRELATED WITH RAINFALL

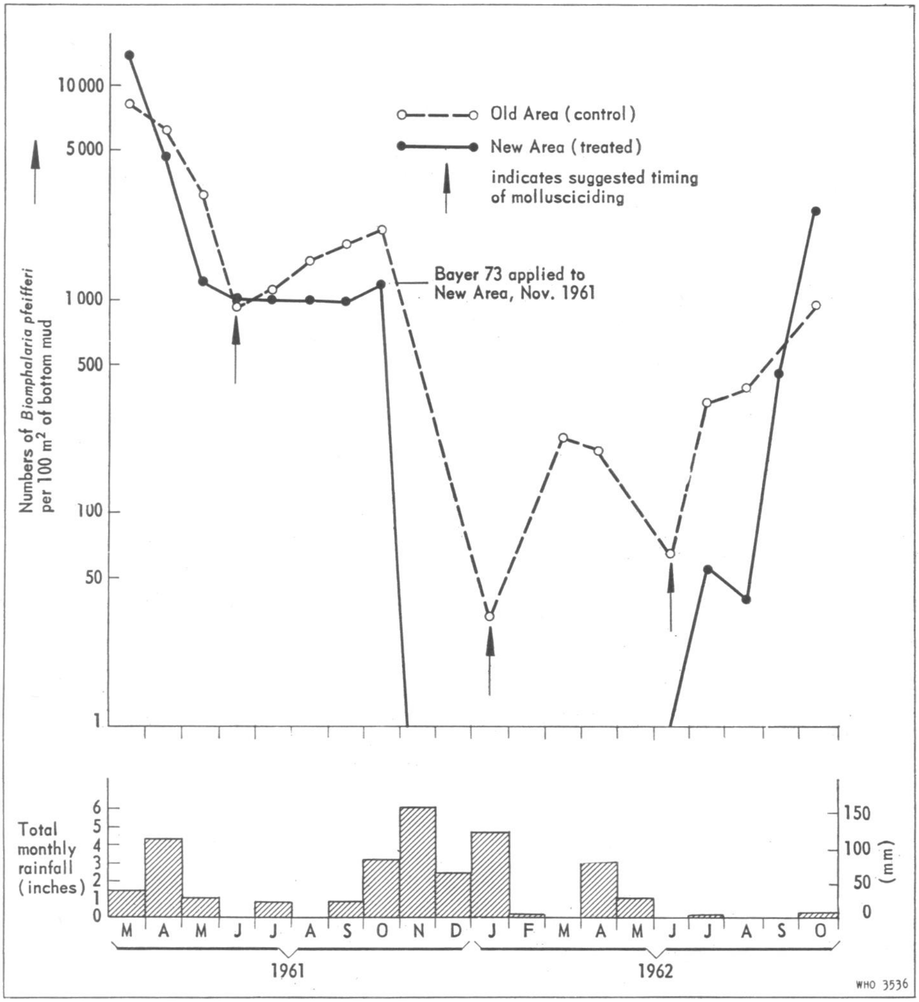


TABLE 2. SPECIES OF SNAILS COLLECTED FROM 720 MUD SAMPLES DURING THE WEEK IMMEDIATELY BEFORE AND THE WEEK IMMEDIATELY AFTER MOLLUSCICIDE TREATMENT

Condition	*B. pfeifferi*	*B. tropicus*	*M. t. tuberculata*	*L. natalensis*	Other species	Total
			Week before treatment			
Live	192	113	684	74	6	1 069
Dead	230	247	2 686	150	18	3 331
Total	422	360	3 370	224	24	4 400
			Week after treatment			
Live	0	0	0	0	0	0
Dead	455	494	4 558	394	53	5 954
Total	455	494	4 558	394	53	5 954

TABLE 3

WEEKLY HAND COLLECTIONS OF *B. PFEIFFERI* FROM THREE SECONDARY CANALS [a] FOLLOWING MOLLUSCICIDE TREATMENT ON 5 NOVEMBER 1961, RESULTS BEING EXPRESSED AS NUMBERS OF SNAILS COLLECTED PER MAN-HOUR SEARCH

Date	Canal B_2-B_{10}	Canal C_3-C_{18}	Canal A_1-A_6	Total number of plots in which snails were found [b]
19.12.61	0	0	0	0
22.12.61	0	0	0	0
28.12.61	0	0	0	0
3. 1.62	0	0	0	0
9. 1.62	1.25	0	0	1
16. 1.62	12.6	1.8	0	2
17. 1.62	Treated with Bayer 73			
23. 1.62	0	0	0	0
30. 1.62	3.8	0	0	1
6. 2.62	0	0	0	0
13. 2.62	28.0	0	2.0	4
20. 2.62	437.5	0	0	6
27. 2.62	120.0	1.3	56.0	8
6. 3.62	157.0	0	512.0	7
13. 3.62	313.0	3.5	52.5	9
20. 3.62	285.0	385	1 220.0	17
29. 3.62	142.5	55.7	331.0	21
5. 4.62	122.5	13	164.0	14
10. 4.62	147.5	299	93.3	16
17. 4.62	253.3	152.7	219.0	13
24. 4.62	110.0	131.5	110.0	32

[a] For location of these canals see Fig. 1.
[b] 93 plots were searched each week.

portionally small. Taking these factors into account the minimum percentage kill achieved by the treatment can be estimated as $1779 \times 100 \div 1782 = 99.8\%$ at the $P = 0.975$ level of significance.

The sampling technique and analysis of results described above allow an estimate of the kill to be made with a reasonable degree of confidence but unless the whole of the area was exhaustively sampled it would never be possible to estimate the kill as 100% by this method. A sequential method of sampling was therefore adopted, 240 mud samples being taken each week following treatment. In addition to this routine mud-sampling technique, other techniques had to be used because of the smaller numbers of snails present and their very different distribution after treatment; thus hand-searching, dipping with nets and sieving of the bottom mud were also carried out.

REPOPULATION BY THE VECTOR SNAIL *B. PFEIFFERI*

No *B. pfeifferi* were detected anywhere in the New Area by any of the sampling methods until two months after treatment. However, since the drainage area marked in Fig. 1 was flooded during the time of treatment in November 1961, it is thought that a few snails were washed out of the irrigation canals and so avoided the molluscicide in untreated, standing water. From several of such small foci, which were not detected at the time of molluscicide application, snails reinvaded three of the secondary canals and their associated tertiary canals. The first snail to be found was collected on 9 January 1962 from canal B_2-B_{10} near the drainage area. One week later, 17 snails were found in the same canal and four more in canal C_3-C_{18}. Focal control was then attempted by applying Bayer 73 with stirrup pumps at an estimated concentration of 3 p.p.m. to both foci. Although all snails were apparently killed where Bayer 73 was applied the canals were soon reinfested, probably because other pockets of snails were not detected.

Only six weeks after the first snail was found, and despite the attempted focal control, very large numbers of snails were present in canal B_2-B_{10}. Four weeks later three secondary canals contained dense populations of *B. pfeifferi*. The results of weekly hand collections from these three canals are shown in Table 3, where the comparative density is given in terms of numbers collected per man-hour search. In May 1962 estimates of the absolute density were made by marking out quadrats of about 2 m^2 and counting all snails in each quadrat at a time when the canals were dry. The results from a series of 10 such quadrats taken from one canal are given in Table 4. The estimated density at this time was about 100 times greater than the mean density estimated at the same time in the control area, and far greater than estimations of the pre-treatment density given in Fig. 3. The data show that, starting from a few survivors of molluscicide treatment, there was a dramatic resurgence of *B. pfeifferi* and the numbers swung far beyond their former level.

TABLE 4

ESTIMATION OF THE DENSITY OF *B. PFEIFFERI* IN THE SECONDARY CANAL B_2-B_{10} ON 26 MAY 1962 [a]

Size of quadrat (m²)	No. of snails
3	969
3	886
3	589
3	763
3	991
3	302
2	240
2.5	201
3	107
3	132
Total: 28.5	5 180

[a] Arithmetic mean = 182 snails/m².

Despite this resurgence in part of the treated area no *B. pfeifferi* were found in any of the four reservoirs or in any of the other canals in the New Area until seven months after treatment. Thereafter, increasing numbers of snails were found in all parts of the area. Twelve months after treatment the whole of the treated area was reinfested although no resurgence was observed except in the three canals previously described.

REPOPULATION BY OTHER SPECIES OF SNAIL

The operculate snail *Melanoides tuberculata tuberculata* was present in very large numbers before treatment, but only a few specimens have been recorded during 12 months of collecting after treatment.

Bulinus tropicus, also present in large numbers before treatment, was not found until seven months after treatment.

Lymnaea natalensis, although very widely distributed, rarely occurs at high density. Within a few weeks of molluscicide application this species was still found in many places in the treated area. It seems that some of these snails were able to survive the application of molluscicide by crawling out of the water among damp grass by the side of the canals, so avoiding the chemical.

REINTRODUCTION OF SNAILS

During 12 months following treatment the means of reintroduction of snails to the area were studied. Two screens were placed across the intake to sample snails coming in from the river, and to help assess whether this means of reintroduction was of any importance. One ninth of the total incoming volume of water was sampled in this way, one screen sampling the water from the surface to a depth of 20 cm and the other from 20 cm to 40 cm. Only six specimens of *B. pfeifferi* have been recovered. In view of this result, and from the observation that snails were not found in the upstream part of the irrigation system soon after treatment, it is considered that, during the period covered by the observations, reintroduction of snails from the river was unimportant compared with other means of dispersal.

COST OF THE TREATMENT

It is important that the cost of using a molluscicide on a large scale should not be prohibitive. The application technique which has been described minimizes the cost of labour, and by far the greatest expense is that of the molluscicide. Altogether 232×10^6 litres (8.2×10^6 cubic feet) of water were treated with Bayer 73 at a concentration of 1 p.p.m. For this, 330 kg of molluscicide were required at a cost of £660.

DISCUSSION

One of the aims of the experiment was to attempt elimination of the vector snail, *B. pfeifferi*, from a large area by a single molluscicide treatment. The difficulties of eliminating all snails from a given area are considerable, and a less ambitious aim is generally adopted in pesticide work. However, in the area under study, the snail habitats are well known, clearly defined and easily accessible. It appeared likely that, providing toxic amounts of molluscicide were applied to all reservoirs and canals, there would be no survivors. The validity of this aim has been demonstrated. *B. pfeifferi* was not found in any of the reservoirs or in many of the irrigation canals until seven months after treatment; *B. tropicus* was not found anywhere, except in small numbers, until more than seven months after treatment; and *M. t. tuberculata*, formerly the most abundant species of snail, has rarely been recorded since treatment. On the other hand, *B. pfeifferi* reappeared in part of the treated area only two months after treatment and very quickly recolonized some of the canals, where the density soon swung beyond its former level. This colony of snails apparently originated from small pockets of survivors in drainage pools which escaped treatment.

It is likely that better results can be achieved if the application of molluscicide can be timed to coincide with the beginning of the dry seasons rather than with the beginning of the rainy seasons. Firstly, during the dry seasons there are very few pools of standing water where snails might escape treatment; and, secondly, it is now known that there is little or no multiplication of snails during the rainy seasons. Fig. 3 shows the seasonal fluctuations in snail density and their association with rainfall; the density level decreases during the rainy seasons but increases after the rains. Thus to achieve maximum control it would be logical to apply molluscicides at the end of a rainy season before the subsequent increase in snail density. It is intended to follow up the work described in this paper by testing the effectiveness of two applications of molluscicide annually, timed to coincide with the end of the rainy seasons.

It is expected that a saving of about one-third of the cost of molluscicide can be gained by using a somewhat different technique of application from that used in the present work. The reservoirs were filled with water treated with Bayer 73 at 1 p.p.m. and this treated water was allowed to stand for about 24 hours; snails living in the reservoirs were exposed to a concentration × time product of about 24 p.p.m.-hours, while snails living in the canals downstream of the reservoirs were exposed to smaller amounts of molluscicide. In a future application a different treatment regime will be tried; the reservoirs will be treated to achieve a final concentration of 0.3 p.p.m. of Bayer 73, and booster applications will be made at the outlets of the reservoirs to give at least 1 p.p.m. in the canals.

Many authors (e.g., McCullough, 1962; Pimental, 1957) comment on rapid increases of populations of aquatic snails. In a study of the life-history of *Australorbis glabratus* Pimental observed that: "*A. glabratus* populations, because they possess a high maximum birth rate, can recover from almost catastrophic environmental situations in a relatively short time. With only a few surviving snails as a start, a stream could be re-populated to near maximum population level in about 3 months." Pimental's calculations, based on breeding experiments with *A. glabratus* under near optimal conditions, are very close to describing the observed resurgence of *B. pfeifferi* in part of the treated area at Arusha Chini.

Resurgences of snail populations following chemical treatment have not received attention. However, many arthropods which are pests of economic importance have shown such resurgences soon after chemical treatment. Ripper (1956) lists about 50 species out of about 5000 of economic importance which have so far shown resurgences; thus Ripper et al. (1950) reported resurgences of aphids following treatments with non-selective insecticides. Paraoxon used commercially produced within a fortnight of application the most enormous cabbage aphid outbreak ever seen in England although mortality of aphids at the time of treatment was very high.

Of the possible mechanisms responsible for resurgences the most common is the removal of a particular predator or parasite or a complex of predators and/or parasites by non-selective chemicals. The red spider mite, *Metatetranychus ulni*, rare in England until 1922, acquired pest status following spraying of orchards with tar oil which destroyed anthocorid bugs, ladybird beetles and predacious mites but not the overwintering eggs of *M. ulni*, (Massee & Steer, 1929; Massee, 1954). In some instances a particular predator or parasite has been positively identified as being responsible for the natural control of a pest species. Huffaker & Spitzer (1953) studied the cyclamen mite, *Typhlodromus reticulatus* Ond. and/or *T. cucumeris* Ond. in field strawberries in California. These workers showed that removal of predatory mites by both hand and chemical methods resulted in cyclamen mite increases. According to Nicholson (1958) ". . . the application of insecticides causes relaxation in the operation of some natural check, which is demonstrated by the well-known fact that pests increase in abundance rapidly for a time when chemical control is discontinued. This acquired ability to multiply is often due to direct destruction by the insecticides of natural enemies which had previously held the pest in check; or to indirect reduction of these enemies because of increased difficulty in finding their food, the pests. This ability of pests to return towards, and even to swing beyond, the original degrees of abundance when the use of insecticides is discontinued is unfortunately an undeniable characteristic of chemical control. There seems no possible explanation other than that reduction in density has relaxed the intensity of density-induced resistance to multiplication ". While the ability of some pests to increase in numbers soon after chemical treatment is undeniable, Andrewartha & Birch (1954) deny the need to invoke " density-dependent " factors.

The observed resurgence of *B. pfeifferi* could have been influenced by the removal of a complex of parasites and predators. The analogy with insecticide work leads to a consideration of those animals, plants or both which might seriously influence the snail's capacity for increase under natural conditions, and whose removal might relax natural control. Michelson (1957), in a review of the literature on parasites and predators of freshwater mollusca, listed algae, fungi and bacteria as well as representatives of most of the major phyla of the animal kingdom. Among this array of parasites and predators Michelson could not find sufficient quantitative data to suggest any organism or group of organisms which might be used for biological control of snail populations.

Bayer (1954) found such a high rate of trematode parasitism among wild *B. pfeifferi* that he suggested the conservation of water fowl, definitive hosts of echinostomes, as an aid to bilharziasis control. Olivier & Barbosa (1954) and Barbosa & Olivier (1958) have shown that infected *Australorbis glabratus* are more susceptible to environmental changes than are uninfected snails. Infection resulted in higher death-rates and fewer births. Other papers dealing with the effect of trematode parasitism on the mortality and reproductive capacity of aquatic snails are quoted by Abdel Malek (1958) who states that " these [digenetic] trematodes are probably the most important organisms that parasitize bilharziasis vectors ". Paulini & Pellegrino (1957) showed that infected *A. glabratus* were nearly twice as susceptible to copper sulfate and sodium pentachlorophenate as uninfected snails. Thus survivors of molluscicide treatment may well be parasite-free individuals with a high potential for increase.

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The molluscicide dispenser illustrated in Fig. 2 is a modification of a design supplied by Shell Development Co., Modesto, Calif., USA.

RÉSUMÉ

Cet article est consacré à la description d'un essai de molluscicide effectué sur une grande échelle, dans une exploitation sucrière de la Région Nord du Tanganyika, pour juger de son efficacité contre les mollusques aquatiques. La propriété d'une surface de 3000 ha est divisée en deux zones: la première, d'acquisition ancienne, possède un système d'irrigation indépendant de la seconde zone, d'exploitation plus récente. Au mois de novembre 1961 la zone nouvelle a été traitée par du Bayer 73 à la concentration de 1 p.p.m.; la zone ancienne n'a pas été traitée et a servi de témoin.

L'application du molluscicide a été faite au moment où se produisaient d'abondantes chutes de pluie. Dans la majeure partie de la zone ainsi traitée l'on n'a découvert pendant les 7 mois suivants aucun spécimen de *Biomphalaria pfeifferi*, hôte de *Schistosoma mansoni*. Cependant, dans une zone d'écoulement des eaux qui fut inondée au moment du traitement, celui-ci ne fut que partiellement efficace. De ce foyer, des mollusques ont rapidement envahi et repeuplé les canaux voisins. Quatre à cinq mois après le traitement, la densité de *B. pfeifferi* dans certains de ces canaux était environ cent fois supérieure à celle de la zone témoin. Ce rapide accroissement d'une population de mollusques sévèrement réduite par les molluscicides peut être comparé aux phénomènes rapportés dans certains travaux sur les insecticides.

L'auteur pense que la destruction, par les molluscicides, des parasites et prédateurs, et en particulier des trématodes parasites peut conduire à un retour rapide des mollusques issus de quelques survivants.

Dans la zone témoin les populations de mollusques ont diminué pendant les siasons des pluies et augmenté pendant les saisons sèches. Ces données incitent à conseiller un traitement bi-annuel à la fin des saisons des pluies. L'auteur a l'intention de compléter la présente expérimentation par l'évaluation de l'efficacité d'un tel traitement.

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