pected to start with energy higher than protons. This feature may, indeed, serve to discriminate between alternative theories.

Much work will evidently be needed in the difficult field of turbulent motion either to prove or disprove the present hypothesis, and it is in the hope of interesting others in it that I have put it forward in this preliminary manner.

[1] See, for example, Fermi, *Phys. Rev.*, **75**, 1169 (1949).
[2] *Phil. Mag.*, **34**, 94 (1917).
[3] *J. l'Ecole Polytech.*, **7**, 319 (1808).
[4] *Phil. Trans.*, **150**, 133 (1860).
[5] *Proc. Roy. Soc.*, A, **84**, 247 (1910).

THE SCIENCE OF TSETSE CONTROL

By Dr. R. S. MORRIS

TSETSE control should never be divorced from research, though it may fall into the two categories—long-range and applied. Long-range control is devoted to the extermination of tsetse, whether concerned with the transmission of trypanosomiasis or not. Like pure research, it has great potential value; but the problems of human and animal trypanosomiasis often assume dangerous proportions, demanding the immediate application of remedial measures. In this applied work the scientific side tends to be elbowed aside; yet the need is no less and the range considerably wider than in long-range control. For urgency demands that attention be focused on the tsetse, only inasmuch as it is a menace to man and his animals. Each problem must be assessed at its true value in relation to the welfare and activities of the local people and to the economy of the country as a whole. Consideration has to be given to factors governing the transmission and spread of infection. Measures must be appraised and selected to give the greatest degree of relief in the shortest time, and, a point often overlooked, to fit in with the life of the people with the least disturbance and without leaving a burden of costly maintenance.

Such an ideal is not attainable at once, and its attainment may well be delayed rather than hastened if empiricism is allowed to replace the disciplines of scientific technique. The necessity for applied control to produce results demands the checking of every step and process by systematic recording of observations. Much of value is lost through omission to do this. The admirable settlement scheme at Anchau might have afforded much information on applied entomology, but there are no published data, such as the incidence of tsetse and trypanosomiasis before and after control, which might guide the worker elsewhere. Critical analysis of results is necessary for progress; it is equally important for making one's experiences available to others.

Research and Practice in the Gold Coast

The applied aspect of tsetse control has guided the work of the trypanosomiasis campaign in the Gold Coast since its inception in 1937. The problem was extensive and urgent. The Northern Territories were involved in one corner of a pandemic of sleeping sickness stretching across the Volta Rivers to the Upper Niger, with 30,000 square miles of country showing 5–15 per cent of the populations infected. Two vectors, *Glossina palpalis* R.D. and *G. tachinoides* West., were responsible, both requiring the evergreen fringing forest of rivers and streams as permanent habitat and therefore strictly riverine in their distribution. This brought a further complication by causing depopulation along the Black Volta and its larger tributaries, where the disease had long been severe, and overcrowding on the watersheds, with resulting land hunger and erosion.

A problem of such magnitude and far-reaching effects required drastic measures for its control, and this demanded research. Meanwhile, the urgency of the situation was met by mass treatment of patients, and a system of protective clearings which aimed at excluding tsetse from the main points of contact with man, water-holes and river crossings, but which left the greater part of the fly-belt untouched. This effected substantial reductions in the amount of sleeping sickness (60–80 per cent in five years), but the decline was not progressive. However, valuable information was gained. Standardized records of the incidence of tsetse in clearings and in adjacent fly-belt and of the sleeping sickness-rate in the localities concerned were kept for three districts, the area of observation totalling 3,000 square miles. A positive correlation was found between the length of clearing and the reduction in tsetse incidence, and between the amount of clearing done in an area and the general fall in the infection-rate. In other words, we were enabled to know exactly what we were doing, to predict the results of various applications of clearing and, consequently, to select methods appropriate to each problem[1].

This information explained the inadequacy of small-scale measures for the control of serious epidemic trypanosomiasis. First, *G. palpalis* and *G. tachinoides* move freely along open river banks at all seasons, so that clearings even three to five miles in length are traversed regularly by small numbers of flies (this is also experienced with *G. palpalis* in Kenya), half-mile clearings are entered by as much as 25 per cent of the adjacent fly-belt population, and clearings of 200 yards or less may cause an increased incidence of tsetse at the point they are designed to protect. Secondly, localized small clearings do not embrace all the points of man–fly contact where transmission of infection occurs. Thirdly, for small clearings to be effective, all the woody vegetation should be cut; this is expensive and may result in river-bank erosion and silting of water-holes. Finally, small clearings cannot control animal trypanosomiasis nor correct the evils arising from the maldistribution of the population.

Research gave a method for eradication by exploiting the habit of these tsetse communities of spreading extensively along the rivers during the favourable climatic conditions of the rains, but contracting to very limited and well-defined foci during the adverse period of the dry season. The tsetse communities are most vulnerable at the time and location of their concentrations. A study of the plant associations of the dry-season habitats was started in 1929 [2], continued by J. L. Stewart on the Nabogo River during 1932–36 [3], and extended during the present investigations to cover the whole inland savanna zone of the Gold Coast. It was found that these concentration sites were characterized by the presence of certain species of trees and shrubs, limited in number, and that the list of these 'indicators' could be used as a consistent standard for clearing. The argument was

that if those species of trees and shrubs were essential to the formation of dry-season habitat, their removal would make such places untenable to the tsetse for four to six months of the year. Do this throughout a complete river system and, with no dry-season retreats, the whole tsetse community would die out. This is the principle of 'selective clearing'[1]. It was first applied during 1941–42 to the Kamba River, draining 600 square miles of Lawra district. The results were convincing, for there was rapid disappearance of the dense colonies of *G. palpalis* and *G. tachinoides* throughout the River. Routine observations at a number of points on three rivers, with control catches on the uncleared Volta, have provided a full record. Points on the Kamba which had shown pre-clearing catches of 2,700–7,500 tsetse a year gave figures of 1–6 flies in 1943, the year after clearing (standardized to 240 boy-days catching per year). Wet-season migration brings very small numbers of flies up the lowest five to ten miles of river from the Volta, but no farther. In 1948 it took 240 boy-days to catch a tsetse on the Kamba beyond migration range, while the control catches through the year averaged 83 flies per boy-day.

After this demonstration, selective clearing was extended over the whole of the Lawra District and is being applied to the remaining areas of endemic sleeping sickness in the Northern Territories, where 2,300 square miles of country have now been reclaimed from tsetse. The method has been adopted by the French in the neighbouring Upper Volta Territory, and is being considered for the problems of Northern Nigeria.

In contrast to protective clearings, the eradication of the tsetse causes a rapid and progressive decline in the amount of sleeping sickness, Lawra District showing a 98 per cent reduction of pre-clearing incidence by 1948. Equally important, the people are returning to the depopulated parts of the cleared rivers in increasing numbers, and they are doing this solely in response to the attractions of the good land, water and grazing offered by the river valleys. Highly organised and financed resettlement schemes have been avoided, so as to keep this aspect of tsetse control within the compass of the natives and to encourage their initiative and independence. What has been done in Lawra can be done anywhere, without special grants or additional staff.

Maintenance is a factor that may become decisive in large-scale operations, since clearing methods requiring annual maintenance will, as the area is extended, involve so much supervisory staff and funds as eventually to limit the amount of work that can be undertaken. So selective clearing was taken to the point of eradicating the fly-belt vegetation itself, a project that was possible because we had to deal with the limited number of 'indicator' species only and were working to the natural units of river systems. A virtual alteration of the plant associations of the rivers, from closed evergreen riparian forest to open tree–grass associations has been attained, and it gives such stability to the clearings that, aided by farming, about half are now permanently reclaimed and require no maintenance, the remainder being on a three-yearly rotation of weeding. This is considered the greatest step forward in the work. Labour for maintenance is provided by the local native authority, with only one African supervisor required for 1,000 square miles of territory. Thus our whole effort and resources can be devoted to a progressive plan of attack on the tsetse.

Discussion

The control of trypanosomiasis involves two questions: the choice of techniques and the planning of their application. Techniques may be directed against the trypanosome, by mass treatment or prophylaxis, or against the vector, by tsetse control. Measures against the parasite leave behind the tsetse, and their results, however spectacular, cannot be permanent so long as any sources of infection remain. Elimination of the tsetse ensures complete and stable control of both human and animal trypanosomiasis. Here again, with artificial methods, such as insecticides, control is unstable so long as sources of reinfestation remain; it is through biological means, interference with hosts or habitat, that the greatest successes have been achieved.

Outstanding examples of control through host interference are the sleeping sickness settlements of Tanganyika and game control in Southern Rhodesia[5], in which the natural food of *G. morsitans*, game, has been permanently replaced by man or cattle on which the fly cannot maintain itself. Alteration of habitat can vary from sheer felling of all woody vegetation, as in barrier clearings or the tribal turnouts of Tanganyika, to refined forms of partial clearing by removal of limited components of the plant associations forming the tsetse's habitat. The advantages of cheapness, ease of maintenance and conservation of vegetation that arise in partial clearing are offset to some extent by the difficulty of defining a standard for such work that can be applied over a wide and variable terrain. Arbitrary lengths and breadths are inapplicable to such complex biological problems, and personal judgment, as in discriminative clearing, depends on that variable, the human factor, with inevitable inconsistencies and difficulties of standardization. Consistency is best attained by a biological measure, such as Jackson's clearing of tsetse concentration sites (personal communication) or the list of indicator plants in selective clearing. Tsetse control thus becomes a work of scientific precision, with an exact formula to be followed instead of being a matter of judgment and opinion.

Application of techniques should be planned on consideration of the tsetse as a vector, and knowledge of where its control can be most effective. If a quite localized control can be done sufficiently well to eliminate the trypanosome, the tsetse elsewhere cease to matter. The geographical distribution and the epidemiology of sleeping sickness suggest that severe epidemics can exist only in certain environments, for there are large areas where man and tsetse are in contact yet infection is absent, despite opportunities for its introduction[6]. An exacting complex of factors is evidently necessary for the spread and development of the disease, and these conditions are not fulfilled everywhere. It should be possible to eliminate sleeping sickness permanently from a country by locating these epidemic foci and 'sterilizing' them by the complete eradication of the tsetse. Areas of lighter infection, which commonly surround and are subsidiary to true epidemic foci, can be dealt with by less drastic measures. This is the plan of operations in the Gold Coast, and it is proving effective.

[1] Morris, K. R. S., *Bull. Ent. Research*, **37**, 201 (1946).
[2] Pomeroy, A. W. J., and Morris, K. R. S., *Bull. Ent. Research*, **23**, 501 (1932).
[3] Stewart, J. L., Gold Coast No. 1, 1937 (Govt. Printing Dept., Accra).
[4] Fairbairn, H., *Trop. Dis. Bull.*, **45**, 1 (1948).
[5] Chorley, J. K., Bull. No. 1419, Ministry of Agriculture and Lands (Salisbury, S. Rhodesia, 1947).
[6] Morris, K. R. S., *Trans. R. Soc. Trop. Med. and Hyg.*, **43**, 165 (1949).