2 Snail Control in the Reduction of Bilharziasis

DEFINITION OF OBJECTIVES

The primary objective of all bilharziasis control operations is interference with transmission of human infection. In so far as snail control is concerned there are two levels at which this may be attempted : (1) by complete eradication of the snail intermediate hosts which, it is evident, would effectively break the life-cycle and make further transmission of the disease impossible ; and (2) by sufficiently thorough and extensive snail control measures to reduce transmission to a level at which the rate of new human infection (as measured by the incidence of the disease in children) is significantly reduced or stopped altogether.

In the existing state of knowledge respecting the ecology and distribution of the snail hosts and the effect upon them of molluscicidal and environmental control techniques, the second is the only practical proposition.

If infection rates in man and snail, together with opportunities for human contact with infested water, fall below their respective threshold, total interruption of transmission will have been achieved.

It cannot be stressed too strongly that snail control must be a long-term operation if it is to be successful.

ORGANIZATION OF A BILHARZIASIS CONTROL PROGRAMME

The accumulation of knowledge in an area where bilharziasis occurs and the subsequent organization and execution of a control programme should take place in a well-established and logical series of steps.

The initial stage consists in establishing the endemicity of the disease and estimating the prevalence of human infection. The distribution of cases is mapped, and analysis is made in relation to sex, age, social status and occupation. Evidence of severity of infection is obtained from clinical signs in infected persons and from autopsy records. Study of human activity and habits assists in locating important foci of transmission.

Later, more detailed information is collected, some of which is quantitative, and which involves not only the human but also the molluscan host, the identity of which must now be determined.

A decision is then reached as to whether an attempt at control is necessary and feasible. Sufficient data should now be available to enable this to be done with reasonable confidence. If this is found not to be the case, further investigation will be needed.

If adequate resources are available and the gravity of the problem justifies further action, the next step is to proceed to the selection of the measures to be used in the control programme. At present it is generally conceded that bilharziasis control is most successfully and economically achieved if the attack is concentrated primarily on the snail intermediate hosts. This interferes with the transmission of infection to man, or interrupts it, thus reducing or eliminating the human disease. It is the approach to control directed at the snail intermediate hosts that is dealt with here.

Just before the control programme begins, quantitative data required for evaluation of the results of the programme must be meticulously collected. The two primary indices are the prevalence of the snail hosts and the prevalence of schistosome infection in the human population, particularly the younger age-groups. It is by their effect on these two indices that the efficacy of the control measures must be judged; and thorough and accurate pre-control observations and records are therefore essential.

The control programme may now be put into effect. The collection of accurate and reliable quantitative data in relation to the two primary indices must continue both during and after the campaign, in order that progress may be properly assessed.

This need for accurate carefully-recorded information cannot be too strongly emphasized. Much effort has been completely wasted in the past because schistosome control methods, though well-intended, were not accompanied by the collection of the quantitative data necessary for judgement of the efficacy and efficiency of the work.

In the following sections the steps just mentioned are reviewed more fully. The necessary techniques are described in later chapters.

INVESTIGATION OF THE DISEASE IN MAN

Establishment of Endemicity

The first step is to search for infected people by means of random stool or urine examinations in clinics, in hospitals, or in occasional surveys among schoolchildren, villagers, or other convenient groups. Records from hospital pathological laboratories are often a valuable source of preliminary information. Some of the newer and more specific serological techniques may be of value for survey purposes.

Determination of Distribution

Before a rational decision as to control can be made or a suitable plan envisaged, the extent of the endemic area must be established. This can be done by examining relatively small numbers of stool and urine specimens from a large number of localities in the suspected area. Such data need not necessarily be quantitative since their only object is to define more precisely the limits of the infected area. Mapping of the results while this work is in progress will assist in the selection of places to be added to the study.

Determination of Prevalence

Prevalence data will provide an important measure of the magnitude of the control problem ; they can indicate the places at which control efforts may need to be concentrated ; and they can give strong indications as to the location of the snail intermediate hosts when the distribution of the vector species is not uniform. The over-all prevalence of infection is obtained by determining the percentage of infected persons of all ages and both sexes in a selected series of localities scattered throughout the endemic area. This is done by examining faeces and urine from a statistically suitable number of persons in each locality ; calculating the percentages infected ; and, on the basis of these data, calculating by extrapolation the estimated over-all prevalence for the endemic zone. Particular attention should be given to the prevalence in children, since this provides a measure of recent infection.

Determination of Severity

While prevalence is being determined, an estimate can be made of the relative severity of the infection. This cannot be done quantitatively, since

the available criteria of sickness due to bilharziasis are very difficult to reduce to terms that can be judged by quantitative methods. However, the prevalence of signs and symptoms usually associated with bilharziasis can be recorded in sample population groups. In addition, clinical records, morbidity data, mortality data and autopsy records can be utilized to estimate the impact of the disease upon the human population. From such information it can usually be deduced whether the infection is producing a marked frequency of overt disease. It must be remembered, however, that bilharziasis is subtle in its manifestations, and that damage resulting from infection may go undetected if only superficial judgements are made.

Study of Relationship between Human Activity and Transmission

Since schistosome transmission is always closely bound up with human habits and occupations, it is essential to take these into account in envisaging and planning anti-snail measures. Information of this type is of particular importance in locating important transmission sites.

INVESTIGATION OF THE SNAIL HOST

Usually the discovery of autochthonous cases leads to search for, and implication of, the snail intermediate host. In any given endemic area one species of snail is primarily responsible for the transmission of each species of schistosome. Occasionally, more than one vector is involved. Often, closely related snails, which do not serve as intermediate hosts, will also be present; and differentiation of these forms from the intermediate host or hosts is important.

The control plan depends very heavily on information relative to the snails, since these are to be the object of attack. It will be necessary, at least in the early phases of the snail investigations, to have advice and help from specialists, because snail control involves attacking the snails in their habitats with a minimum of disturbance to man, his crops and his animals. Such an attack calls for an intimate and detailed knowledge of the local snails. The usual sequence of investigation is as follows.

Search for Possible Vectors

Initially there must be a widespread search for snails which might be involved. In the Orient the hosts are operculate snails belonging to the genus *Oncomelania*. In other areas the hosts are usually pulmonate snails belonging to the sub-families Planorbinae and Bulininae; but *Ferrissia tenuis*, belonging to the family Ancylidae, is said to serve as the interme-

diate host for *S. haematobium* in a focus in India. This mollusc and closely related species are found in other endemic areas and should not be ignored. The recognition of the species of snail which is transmitting the disease in a given area requires the skill and experience of a field biologist who must know which snails to seek and where they are likely to be found.

Proof of Involvement

When snails suspected of harbouring the schistosome are found they must be tested to find out whether, in fact, they can convey the infection. Proof that a particular species of snail transmits the disease, by demonstrating that it can pass the infection, requires the expert assistance of an experimental biologist. Three methods of approach are possible.

Examination of wild snails for naturally-acquired infection

Specimens collected throughout the endemic area can be examined for naturally-acquired schistosome infection by the inspection of crushed individuals. The method used in making examinations by crushing snails is given on page 190. This can demonstrate whether schistosome infections are harboured, but will not conclusively prove that the schistosomes found are indeed the species infecting man, since the cercariae of schistosomes infecting domestic and wild animals resemble those of the human parasites.

In searching for naturally-infected wild snail hosts it should be constantly borne in mind that not only may the occurrence of the snails be a seasonal phenomenon but also infection with schistosome larvae may show seasonal fluctuation. Therefore it might be necessary to search for infected snails through a period of at least one year.

Infection of laboratory animals with wild cercariae

Infection of schistosome-free laboratory animals with cercariae collected from naturally-infected snails permits the rearing of the adult worms, which can be more readily and certainly identified than the larvae and immature forms. It is necessary, however, to have available a stock of schistosome-free test animals, usually rodents, together with the means of maintaining and handling them. Accurate identification of the adult parasites is also required.

Infection of healthy snails with miracidia from human infections

Additional proof that the real intermediate host has been found comes from infection of uninfected snails with miracidia obtained from human infections and the subsequent emergence of cercariae which can be used

to complete the life-cycle in the laboratory as described on page 191. This is the most certain procedure, but requires that the snails be reared in the laboratory free from infection and maintained up to eight weeks after exposure to miracidia so that the cercariae can develop.

Identification

If the trials outlined above indicate that a snail species can serve as the intermediate host, it then becomes desirable to obtain positive specific identification. This may be done locally if a sufficiently skilled malacologist is available. Otherwise specimens should be sent to a central reference laboratory such as the WHO Snail Identification Centres under the direction of Dr G. Mandahl-Barth at the Danish Bilharziasis Laboratory, Danmarks Akvarium, Copenhagen, Denmark, and under the direction of Dr W. Lobato Paraense at the Instituto Nacional de Endemias Rurais, Belo Horizonte, Brazil.

Methods for collecting the snails, transporting them to the laboratory and preparing them for identification are outlined in chapter 5.

Specific identification of the suspect or proven intermediate host may not be absolutely essential to the development of a snail control programme. It is only necessary to have adequate proof that a recognizable, but not necessarily identified, species is the host. In any event, positive identification should follow as soon as possible, since the biology of the species incriminated may have some bearing on control procedures.

In some localities incrimination of the snail host is not very difficult since there is only one species belonging to the taxonomic group to which the known hosts belong; and the number of other schistosomes which might be confused with the schistosomes of man is very limited. In other localities, however, the task can be very difficult indeed and may require both the expenditure of considerable time and effort and the aid of specialists.

Delineation of Area of Occurrence

As the evidence implicating the intermediate host accumulates, the distribution of the suspected snails may be plotted on the basis of widespread collections. If the prevalence or severity of human infection seems to warrant it, all potential or known habitats for the snails should be mapped. Such information will not only assist in evaluation of the magnitude of the problem but will also be needed should snail control be attempted later.

It is essential to discover the exact distribution of the snail hosts, since this will indicate the true limits of the zone in which transmission can occur. This information is required in order to select the control methods giving the best cost-efficiency ratio, and to determine the feasibility of a control

programme. The distribution of the snails is established by systematic search of all bodies of water, together with all moist areas if *S. japonicum* is involved, by persons trained in snail detection and recognition of species. Usually it is necessary to bring sample collections to the laboratory for confirmation of field identification. It is not necessary accurately to measure the density of the snail populations at this time; although it is valuable to record a rough estimate of the snail density for each habitat detected in order to gain a useful impression of the habitat preferences of the snails, which can be taken into account later when reliable population density studies are planned.

These snail searches for the purpose of establishing the geographic limits of the intermediate host must be carried out at regular intervals throughout at least one full year, since there may be considerable variation in distribution of the snails from season to season. In some areas snail distribution may also vary from year to year.

Study of Bionomics

Before any valid decisions can be taken in connexion with a programme of snail control, a systematic study of the bionomics of the snails must be instituted, since anti-snail measures can only be effective and efficient if they are based on sound and thorough knowledge of snail habits and ecology. Here again, the expert assistance of a field biologist is necessary, since the investigations required involve familiarity with the snail life-cycle and a broad understanding of freshwater biology and ecology. Included in the study should be the reproductive habits, life-span, seasonal cycle and population trends, capacity to withstand drying or life out of water, habitat preferences and other characteristics of the snails; the impact upon them of seasonal, climatic, topographic and hydrographic conditions; and the variations in prevalence of snail infections from place to place and from season to season.

Such evidence gives important indications as to the time and places of transmission, and can assist greatly in the selection of points and seasons at which the snails can be attacked. It also provides a rational foundation upon which assessment of the prospects of successful control through a campaign directed against the snail host can be based.

It is not possible to specify all the procedures to be used in obtaining this information concerning the snails; but some further details regarding procedures and techniques are set forth in chapter 5. As already stated, it is highly desirable that the investigations be directed by a trained biologist.

In addition to the biological studies involved, it will be necessary to have detailed information on certain other factors. The amount, distribution and types of all bodies of water and damp and marshy areas within

the endemic region should be investigated and mapped. Seasonal variation in rainfall and annual amount of rainfall are both important in relation to snail control measures, their chances of success and the time at which they should be attempted. Other climatic factors, such as the amount of solar radiation, daily and seasonal temperature variations, and humidity, are also important.

FACTORS DECIDING A CONTROL PROGRAMME

Discovery of the magnitude and importance of the endemic area, and implication and investigation of the intermediate host, may logically be followed by an inquiry as to whether a control programme is desirable and feasible.

It is not possible to consider whether control measures are to be instituted without giving some thought to the nature of the campaign envisaged. To some extent, therefore, the decision discussed in this section should be taken in the light of the subject-matter of the following section.

The data which will by now have been gathered concerning the distribution, prevalence and severity of the disease, together with the information obtained on the transmission of the parasite from snail to man and man to snail, should not only enable a sound decision to be taken as to whether a snail control programme is a practicable means of reducing the disease in man, but should also assist in planning the control scheme and selecting the measures to be used. Thus, information concerning distribution and extent of endemic foci is essential in considering problems of logistics; prevalence data are necessary to indicate the places where control efforts may have to be concentrated; and severity data will assist in the formulation of decisions as to the magnitude and urgency of the problem.

Although this latter decision depends primarily upon epidemiological and biological considerations it will, of course, also be profoundly affected by economic factors. Some estimate should therefore be made at this stage of the cost of any proposed anti-snail programme and of the benefits which it is likely to bring in terms of human welfare and economic advantage.

CHOICE OF METHOD

Decision as to the need for snail control is followed by selection of the method or methods to be used. The information which should by now have been amassed will permit a rational choice of anti-snail measures to be made. It is tempting to avoid some of the delay and expense that the collection of such information entails; but there can be no doubt that it

is very unwise to proceed without such information. All control experience so far has emphasized the need for this, and failure of some control projects in the past can be attributed to the inadequacy of such background knowledge. Available methods of snail control are outlined below, together with certain factors which must influence the choice of method.

Available Methods of Snail Control

The snails are generally conceded to be the weakest link in the schistosome life-cycle, and a wide variety of methods for their control has been proposed. Most of the approaches to snail control can be grouped under the headings of environmental control, chemical control, and biological control. These may now be briefly considered.

Environmental control

It is apparent that since the vector snails all require water, at least for breeding, reduction in the size and number of potential breeding-areas will reduce the total population and so tend to reduce human infection. Thus, engineering effort and good land management and farming practice can be very useful.

Essential bodies of water can be made less suitable for the vector snails by such techniques as weed clearance, and good ditch and stream management.

Chemical control

Experience with molluscicides, especially since 1945, has shown that they can effectively control the snail intermediate hosts in many types of habitat.

Successful snail control by means of molluscicides alone has been shown to be possible in certain areas in Japan, Brazil, Venezuela, Egypt, Southern Rhodesia and other areas.

Therefore, enough is now known about the use of molluscicides to allow their more energetic and widespread employment in endemic areas to be considered.

Biological control

This method for snail control has long had a wide appeal. It has been suggested that snails might be controlled by predators such as ducks, fish, insect larvae and leeches ; by competitors such as the snail *Marisa cornuarietis*, which in Puerto Rico has rendered some habitats unsuitable for the

schistosome vector *Australorbis*; or by parasites and diseases of snails, which might keep down their numbers.

With the possible exception of *Marisa* introduction in Puerto Rico, trials of such methods in general, however, have not been encouraging and at present there is no practical technique for the application of biological control against the snail hosts of schistosomes in endemic areas situated on large land masses.

Importance of Understanding Life-Cycles of Parasites and Intermediate Hosts

The life-cycle of the snail intermediate hosts of bilharziasis, the production of cercariae, and the transmission of the infection are all affected by seasonal and hydrological changes. Unless these relationships are understood, control measures are apt to be ineffective and there will be a waste of funds. The factors which affect the combination of circumstances that result in human infection vary in each area. For this reason the discussion which follows cannot be considered as being specifically applicable in every endemic area; but the basic principles are everywhere the same.

In the temperate zones not only is the number of snails greatly reduced during the winter, but also many of them hibernate and do not produce cercariae; the water is cold enough to discourage human contact; and snail control measures during this period have been found to be both unnecessary and ineffective. In the spring the surviving snails become active and have a major egg-laying period that extends well into the summer. The number of infected snails, and the time of development of the cercariae are all factors that are related to the intelligent application of any type of control measure that may be considered for such areas. They are more intimately related to the timing of molluscicide application than to habitat control.

In warmer climates the variations in the snail population density and in cercarial production often are as extreme as those in the temperate zone. This is fortunate because it tends to limit the period during which molluscicides must be applied. However, in the areas where temperature and hydrological conditions encourage an almost constant high snail population density, together with high cercarial production rates and frequent human contact with infested water, molluscicides must be applied more often, or combined with measures that reduce the snail-producing potential of the habitats.

In those warm climates in which changes are sufficient to produce marked differences in the bilharziasis transmission pattern from season to season, the basic causal factors are usually hydrological. Under these circumstances, the lack of water may produce conditions in many habitats similar

to those that occur in the winter of the colder climates. The snails aestivate and some of the vigorous members of the colony, which are sufficiently protected against desiccation and lethal temperatures, usually survive and repopulate the area when the water returns. In areas where the infections in aestivating populations have been studied, it has been found that the snails with well-developed trematode infections usually die during this period of stress. Those that happen to have young infections may survive, and the parasite aestivates along with the snail. With the return of the water, the surviving snails become active and soon begin to lay eggs. Any young larval forms present in the snails continue their development, and may begin to produce cercariae within from two to four weeks after the return of the water. The number of snails that will produce cercariae during this period is usually small; therefore the number of infective larvae in the water tends to be low. The time which elapses between the hatching of the eggs and the development of the new generation of snails to the egg-laying stage depends on conditions in the habitat, but usually involves a period of from four to six weeks. If the water contains miracidia, the young snails will become infected, but the development of the infection to the cercaria-producing stage requires a similar period of time. A relatively safe period may therefore be expected in some habitats, lasting for approximately six to eight weeks after the return of the water. On the other hand, any extension of the period when water is present in the habitats after cercarial production has started prolongs the transmission period and usually increases the prevalence and intensity of the infection. This has happened in parts of Egypt where basin irrigation has been converted to perennial irrigation.

It must be emphasized that these are general statements. The actual patterns produced by the relationship of the climatic and hydrological factors to those of the parasite-snail cycles cannot be determined without careful study of the population dynamics, with particular reference to the seasonal prevalence of the infections. This latter factor not only varies in different areas but may also vary in the same area from year to year.

In some irrigation schemes, where aquatic snails are the intermediate hosts, water used to initiate irrigation after the summer closure has a very heavy silt load. Studies made in these habitats before the institution of control measures showed that the silt tended to check the growth of aquatic vegetation and the increase of snail populations in the canals for two or three months. As the water became clearer the snail population densities steadily increased, finally reaching and maintaining a high level until the following closure period. Certain canals in some systems contain water during the summer or winter closure, to serve as the water supply for the people and their domestic animals. Without control these serve as the habitats for numerous snails, and the concentration of human activities along them tends to increase their capacity and importance as transmission sites.

Somewhat the same pattern occurs in many areas where streams and auxiliary natural bodies of water serve as transmission sites. Flushing after heavy rains or floods usually causes a great reduction in the number of snails present. During the dry periods the snails must aestivate in many of the habitats and these do not serve as transmission sites at this time. However, there is necessarily increased human contact with the bodies of water that remain. If these relationships last long enough to produce an infected snail population, the stage is set for transmission.

Circumstances in some areas allow transmission only occasionally, with periods of a year or more intervening. If the danger signals are known, major control efforts can be concentrated on the elimination of the conditions that produce transmission, and special precautions can be taken when circumstances indicate that they are needed.

In other areas the water-use and water-contact patterns of the people in the area determine the location of the major transmission sites and the snail habitats that require control measures.

The most rational water-usage and agricultural practices contribute materially to the reduction of the snail habitats through the collateral effects of good drainage, weed control, crop management and sound irrigation procedures. This topic is further discussed on pages 85-120. It may be remarked here, however, that any measures of this kind require the co-operation of the irrigation authorities, the agricultural authorities and the farmers ; and that in order to obtain such co-operation it is necessary for the persons involved to have some understanding of the principles discussed in this section.

Making the Actual Choice

Bilharziasis endemic areas are remarkably diverse. They range from the temperate zone to the tropics ; from areas where cold or lack of rainfall confines transmission to very short periods to warm, wet areas where it can occur almost continuously ; from flowing water in streams and canals to static waters in swamps and pools which may dry up during five to seven months of the year ; from habitats where aquatic snails spend their whole life in the water to those where amphibious snails spend most of their life on damp soil. It is obvious from these examples that seasonal, climatic and hydrological changes have marked effects on the life-cycle of the intermediate hosts, on the production of cercariae and on the transmission of the infection. The changing characteristics of each area will influence the choice of control methods and the periods most suitable for their effective application. The basic observations needed for making these judgements have been outlined in the preceding sections of this chapter. Unfortunately, in many areas such observations have often not been made.

The most effective methods used in the control of snails range from a variety of engineering and agricultural techniques to the application of molluscicides. The selection of the method or methods must depend on an assessment of the local conditions and the cost of the control measures, compared with the data obtained from an analysis of the economic stress caused by snail-borne diseases.

In some circumstances snail populations can be reduced or eliminated by drainage, filling, water management, modification of agricultural practices and similar environmental measures. In other circumstances this can be done only by the application of molluscicides. The more common situations often involve thousands of square miles of difficult terrain which may include habitats in streams, pools, reservoirs, swamps, irrigation canals, rice-fields, drainage ditches and similar places. For these reasons effective control at reasonable cost in most areas can be obtained only by a combination of methods, involving both modification of habitats and application of molluscides to the remaining colonies.

If a combination of methods is to be used, it is necessary to consider the order in which they should be implemented. For example, in dealing with a very heavily infested area, or with an outbreak of epidemic proportions, the intensive use of molluscicides may be required until more permanent measures can be instituted. On the other hand, in many areas certain measures directed toward habitat reduction or elimination will be the most logical initial step, followed by the application of molluscicides to residual colonies.

Importance of Realizing the Limitations of any Method of Snail Control

The choice of a method, or methods, for snail control in a given endemic area will be influenced by many factors including the ecological peculiarities of the area, the snail species being attacked, climatic conditions, the habits of the people, agricultural practices and crops, the economic resources available, and last but not least, the objectives of the control programme.

Each method has its limitations, which must be considered in the light of the particular circumstances which prevail in the area under consideration. A method which is very useful in one area may be completely unsuitable in another.

The methods of snail control differ both in efficacy for various situations and in the nature of the results. Thus, some measures, such as ponding and filling of snail habitats, are permanent and, though expensive, may be economical in the long run. On the other hand, drainage ditches require continual maintenance, and molluscicides must usually be applied regularly, sometimes for years on end.

It is therefore essential to study in detail each area in which snail control is to be attempted in order to get the information necessary to permit a good choice of method.

Specialist Assistance Required

After the vector snail is recognized and adequate information concerning its distribution, habits and ecology is obtained, the method for control is chosen. This decision, since it involves consideration of many factors, will also require the advice of specialists. When control by environmental methods is contemplated, someone skilled in water management and sanitation must be consulted. Consideration must also be given to the relation of human attitudes, customs and agricultural practices to the changes that would have to be made.

When control by means of molluscicides is contemplated, aid is required from a biologist who can judge whether the snails of a given area can be successfully attacked by chemicals. He must also be able to select the chemical or chemicals best suited to the situation. Finally, he must be able to choose the most suitable method and period for applying and evaluating each chemical used. Study and pilot testing will generally be necessary before some of these decisions can be made.

Necessity of a Continuing Programme

An essential ingredient in any snail control programme is a long-range plan. In some situations it is comparatively easy to recognize the intermediate hosts and to take steps against them. Once the location of the snail habitats is known, it may be comparatively easy to distribute a molluscicide, especially if no serious effort is made to measure the efficiency of the work done. Similarly, such things as weed control and canal clearing may have a dramatic effect on a snail population.

However, these efforts, even if they are effective, will be wasteful unless they are part of a well-considered long-range plan. The snails have an extraordinary capacity to reproduce, and a few surviving or introduced snails can repopulate a habitat in a surprisingly short time. Hence, though a single application of a molluscicide or a short-term programme may reduce a snail population to a low level, the snails may rapidly return to their former abundance when the control efforts stop. Once a snail control programme is begun it must be continued indefinitely unless eradication of the snails is achieved. Otherwise the effort and expense may come to naught when the control is relaxed and the snail population has a chance to recover.

In order to avoid unnecessary expenditure, an initial large-scale programme should not be undertaken until the most effective measures have been indicated by a small-scale pilot project or projects.

Although snail eradication can ultimately eradicate bilharziasis and obviate the necessity of further snail control measures, in practice it is an objective beyond reach in most endemic areas. The first reason for this statement is that the tools and methods now at hand are not adequate to assure snail eradication in any but small isolated endemic foci; one can often kill all but a few of the snails, but eliminating the last ones is difficult and costly; and any missed snails can repopulate the area when control is stopped. The second reason is that, since snails can be carried from place to place by man, domesticated and wild animals, and even on inanimate objects, the snails may be re-introduced into a habitat from which they have been cleared.

EVALUATION OF PROGRESS

The necessity of accurate assessment of the effect of any control scheme which may have been undertaken has already been emphasized above. The operations involved, which fall into three phases as outlined below, are essentially a continuation and standardization of the collection of information which was necessary to permit sound decisions as to the need for and nature of a snail control programme.

Pre-Control Observations

Regardless of the method of snail control chosen, it is necessary before initiating *any* control action to establish a basis for evaluating the effectiveness of the procedure from both the biological and the economic points of view. All too often, snail control efforts have been made without provision for objective evaluation, with the inevitable result that the value of the effort could only be guessed at, and its cost relative to disease prevention and other benefits remained unknown.

General nature of data required

Much information will already have been accumulated as the endemic area has been delineated, the snail host incriminated, and the basic epidemiological and biological knowledge gathered. Nevertheless, immediately before snail control is undertaken, certain further data must be gathered for the specific purpose of assaying the usefulness and efficiency of the programme. This information must be quantitative, and suitable for statistical analysis, yet it must be the sort of information that can be collected with reasonable speed and economy if the attempt at control is to be kept within bounds of reasonable cost. In other words, it is necessary

to measure conditions existing before control measures are used so that one can return later, make the same measurements again, and judge the effect of the control measures used by comparing the two sets of data.

From the short-term point of view, assessment of the usefulness and economy of a snail control programme can be made by accurate observation of the effect which it has on the prevalence and distribution of the snails. In the long view, of course, the test of a control programme can only be its effect on the prevalence and severity of human schistosome infection. Therefore, before a control effort, data should be gathered on snail populations and human infections that can be compared with such data gathered after institution of control measures. All the data must be strictly quantitative and must have the greatest possible reliability consistent with reasonable economy. To facilitate this aim, all techniques should be as simple as is consistent with accuracy. Moreover, they must not vary. In other words, the pre-control and post-control data must be gathered in exactly the same way in order to be strictly comparable. Procedures should therefore be selected which can be standardized and repeated; and they should not subsequently be changed, regardless of temptations to improve them with the passage of time and the acquisition of new information.

Specific criteria

There are three prime indices of the efficacy of snail control measures—namely, the effect on the snail population, the effect on the disease in man, and the effect on trematode infections in domestic and wild animals. These may now be further discussed in their turn.

Effect on the snail population

The snail population records should consist of data on population density in a series of selected areas within the control zone. These areas should include typical habitats and should be spaced throughout the endemic area. The data should show the relative population density in some form such as the number of snails per unit area (quadrat samples), the number of snails which can be collected under standardized conditions by a man in a unit of time, or some other method of known statistical validity. Methods for gathering such data are given in chapter 5. In addition to this information, the exact geographical and seasonal distribution of the snails should be established after intensive search in all potential habitats and throughout the year—if this has not already been done during the preliminary investigations.

The snail index permits a relatively rapid and inexpensive assay of the effectiveness of the measures in reducing the snail populations; but this, of course, is only a means to an end. Protection of the human population

is the ultimate aim of the programme, and hence the next index is the more important.

Effect on the human population

The second criterion with which to judge the value of a control effort is its effect on human schistosome infection. The prevalence in a selected sample of the population is determined accurately by faecal or urine examinations or both before control is instituted. The nature and composition of the population sample will depend on local factors. In general, young children are a favourable group, not only because they are more accessible, but also because the earliest indication of interruption of transmission of the disease will be a marked decline in the prevalence in the youngest age-group. The index will be of little value, however, unless two conditions are strictly observed. In the first place, the population sample used for the study must have the same age and sex composition each time the measurement is made. In the second place, the measurement must be repeated every year for a minimum period of from three to five years. Methods for collecting the human prevalence data are given in chapter 5.

The human prevalence index provides a way to measure the impact of the snail control activities on the number of infections in the human population. This procedure, though expensive, is essential. It is unwise to judge the value of either chemical or environmental control measures until they have been in effect for at least three years, since snail destruction is only gradually reflected in a decline in prevalence of human infection. However, successful interference with the transmission of the disease due to the reduction of snail populations will ultimately be shown by a gradual decline in the prevalence of infection in man.

Effect on trematode infections in domestic and wild animals

A third criterion which can be used in some endemic areas is the prevalence of other trematode infections which may be important in man or in domesticated, or even wild, animals. Since these infections are also transmitted by snails, their prevalence is linked, to some extent at least, with snail destruction. Since some of the animals have a relatively short life-span, changes in transmission rates are more quickly detected in them. Schistosome infections in domesticated or wild animals are more likely to be correlated with human schistosome infections than are other trematode infections, but fascioliasis and other trematodiases may be useful in certain areas. In general, the method for study of worm prevalence in these animals is the same as for humans. However, since domestic animals are usually kept for only a few years and come readily to autopsy, data may depend on post-mortem examination more often than on faecal examination, and are to that extent both more reliable and more rapidly obtained.

Consideration of trematode infections in domestic animals has another advantage, in that it may bring aid to the project from those who are responsible for the welfare of these animals, and thus may influence the nature of the decision as to control. It may also increase the interest of the rural population in the project.

Observations during Control

When the necessary preliminary data are at hand, the control effort may begin. Although evaluation, for the most part, must wait until the control effort has been in effect for a significant period of time, some observations during the early part of the programme will be useful. If a molluscicide is being used it will be important to monitor the concentration and distribution of the chemical, if this is possible, and to observe the responses of the snails, other aquatic animals, and aquatic plants to the treatment. The effect upon crops should also be carefully observed. If environmental control is attempted, it should also be possible to study the responses of the snails to the changing habitat.

Post-Control Observations

The post-control snail measurements can begin as early as one day after a chemical treatment, and should continue for a number of months at least. Regular, carefully repeated snail collections, using the standardized techniques in the appointed places with precision, will reveal the changing status of the snail population, and will demonstrate not only the degree of destruction of the population but also the time at which it begins to rebuild, and the rate of repopulation. On the basis of such data it is possible to determine when further steps are required.

In the case of environmental control, systematic snail collections may be harder to repeat exactly since, due to the environmental changes which have taken place, some of the successive collections may not be strictly comparable.

Changes in prevalence of human infection can only be detected more gradually. Usually, repetition of the faecal and urine collections need only be made at yearly intervals. Conditions vary in accordance with the initial prevalence but, in general, it is not safe to judge the effect of a control programme on the basis of the age-distribution prevalence within a period of less then three years. Continuation for a longer time is desirable and often necessary.

In addition to assisting the evaluation of the control measures, the post-control measurements will also indicate when molluscicidal treatment should be repeated.