1 Introduction

IMPORTANCE OF BILHARZIASIS CONTROL

General

Bilharziasis is one of the most important public health problems of the tropics and subtropics. As a cause of morbidity, it is probably outranked only by tuberculosis and malaria. Conservative estimates place the number of infected individuals at 150 million.

Accurate data on the ravages of the disease are lacking. There are many reasons for this dearth of information. Most surveys to determine prevalence of infection employ only a single stool or urine examination ; thus a great many positive cases are missed. The number of undetected cases will vary depending on the nature of the population group—they have been estimated to constitute between one-third and half of the actual total. Infections of long standing are less liable to be diagnosed by such methods of examination, since the extensive inflammatory reaction causes many eggs to be trapped in the tissues and never to reach the lumen of the intestine or bladder. The intradermal test will disclose a higher percentage of positives, but the number of non-specific reactions limits its value. Some of the newer serological tests are being adapted for field use and may provide more efficient means of determining the prevalence of infection.

Bilharziasis is a notifiable disease in only a few countries. For instance, in 1957 only 216 183 cases were reported to the World Health Organization (WHO). In the western hemisphere, Puerto Rico was the only area to report cases. Mortality figures are extremely low.

Bilharziasis is a chronic insidious disease, and its symptoms are frequently masked by those of other conditions. Eggs have been found in almost all tissues of the body. Damage is cumulative and, unless the initial exposure is unusually severe, symptoms of the disease emerge slowly. The intensity of infection is extremely variable. In most endemic areas, cases are diagnosed only incidentally when the individual seeks medical attention for some other complaint. As a consequence, many cases go unrecognized and the disease is rarely established as a cause of death. Because of its chronic nature, bilharziasis saps the energy of the individual, reduces his resistance, renders him prone to attack by other infections and lowers his productivity. These deleterious effects are exceedingly difficult to evaluate, but in the aggregate they represent a social and economic burden of great magnitude.

Compared to many other infectious diseases, little over-all progress has been achieved in the control of bilharziasis. In only a few areas have substantial inroads been made on the disease. This lack of accomplishment may be attributed to a number of factors. Among them are lack of basic data on the occurrence and importance of the disease, lack of more efficient control procedures, failure to develop better methods because of limited research, insignificant progress in providing sanitary facilities, inattention to proper water management in irrigated areas, insufficient funds, and—to some extent—the dearth of adequately trained personnel. These are some of the deficiencies which will have to be overcome in many endemic areas before substantial progress can be made in checking the disease.

Geographic Distribution of the Human Schistosomes

Schistosoma haematobium, *S. mansoni* and *S. japonicum*, the three major species of schistosomes which infect man, are widely distributed. *S. haematobium* occurs in Africa and south-west Asia ; a small focus is found in southern Portugal and similarly in India. *S. mansoni* is distributed in parts of Africa, south-west Asia and the western hemisphere. *S. japonicum* is an oriental species. In addition to these three, *S. intercalatum* has been reported from localized foci in Central and West Africa ; and *S. bovis* and *S. mattheei*, lower animal schistosomes, have been reported from man in parts of Africa, with the latter species reaching a prevalence of 40% in some parts of the Transvaal.

S. haematobium and *S. mansoni* are widely distributed in Africa. In North Africa, the former is found in Morocco, Spanish Morocco, Algeria, Tunisia and Egypt. *S. mansoni* is also endemic in Egypt; a few foci occur in Libya. *S. haematobium* occurs in Mauritius. Both species are found in almost all other countries of Africa, although *S. haematobium* is more widely distributed.

In south-west Asia, *S. mansoni* occurs in Israel, Yemen, Aden and Saudi Arabia, while *S. haematobium* has been reported from Aden, Saudi Arabia, Yemen, Israel, Lebanon, Syria, Turkey, Iraq and Iran. The focus of bilharziasis in Maharashtra State in India, apparently due to *S. haematobium*, represents the only occurrence of this species in south central and south-east Asia, although it is possible that other foci may yet be found.

In the western hemisphere, *S. mansoni* is endemic in the Dominican Republic, Puerto Rico, Vieques, French St Martin, Antigua, Guadeloupe, Martinique and St Lucia. In Venezuela, the species is distributed in the States of Aragua, Carabobo, Miranda, Maracay and the Federal District. It is found in Surinam, and occurs in Brazil in the States of Pará, Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, Bahia, Minas Gerais, Espirito Santo, Rio de Janeiro, São Paulo, Paraná and the Federal District.

In south-east Asia, *S. japonicum* has recently been discovered in Thailand. An autochthonous case has been reported from Laos. There is a focus of long standing in the Celebes. In the Philippines, this species occurs in the islands of Luzon, Leyte, Samar, Mindoro, Mindanao and Bohol. *S. japonicum* is found in lower animals in China (Taiwan), but human cases have not been discovered. In Japan, the parasite occurs on the main island of Honshu in the Prefecture of Chiba, Ibaraki, Saitama, Yamanashi, Shizuoka and Fukuyama. On the island of Kyushu, it is found in Saga and Fukuoka Prefectures.

In mainland China, *S. japonicum* is endemic in the Provinces of Kiangsu, Chekiang, Hupeh, Hunan, Kiangsi, Anhwei, Kwangtung, Kwangsi, Fukien, Szechwan and Yunnan.

With this extensive distribution, it is highly probable that the disease may occur in additional localities, especially in isolated areas as yet unsupplied with health facilities. Extension of the disease to free areas is possible in certain instances, since some molluscan intermediate hosts are known to occur outside the presently recognized endemic areas.

Identity and Geographic Distribution of the Intermediate Hosts

In the past there has been disagreement concerning the identification and nomenclature of certain molluscs which transmit bilharziasis. The problem is, indeed, a difficult one, but recently progress has been made in reaching a more uniform understanding. The establishment by WHO of a central laboratory of malacology in Copenhagen was a major step in this direction. In the western hemisphere, a study group is preparing a guide for the identification of the Planorbidae involved in the transmission of the disease in the Americas, and the establishment of a central laboratory in the western hemisphere is being planned. In spite of these developments, additional knowledge is still required concerning the identification of the molluscan intermediate hosts and their distribution. Another factor of importance in the epidemiology of the disease is the varying susceptibility of known vector species to schistosome infection. Certain strains of intermediate hosts have been shown to be almost completely resistant to infection with some strains of schistosomes. The situation is of considerable potential significance and requires further study.

The molluscan intermediate host species named below include those considered to be involved in the transmission of the disease on the basis of natural or experimental infection or epidemiological evidence. Some of the more important intermediate hosts are illustrated in Fig. 1-3. Certain other snails outside known endemic areas have been shown experimentally to be susceptible to infection.

MOLLUSCAN INTERMEDIATE HOSTS OF *S. MANSONI* IN THE AMERICAS

Australorbis glabratus : Dominican Republic, Puerto Rico, Vieques, French St Martin, Antigua, Guadeloupe, Martinique, St Lucia, Venezuela, Surinam, Brazil

A. tenagophilus : (syn. *A. nigricans*) : Brazil

Tropicorbis stramineus : (syn. *T. centimetralis*) : Brazil

MOLLUSCAN INTERMEDIATE HOSTS OF *S. MANSONI* IN AFRICA

Biomphalaria pfeifferi : Africa south of the Sahara, Malagasy Republic

B. choanomphala : Lake Victoria

B. smithi : Lake Edward

B. stanleyi : Lake Albert

B. alexandrina : Egypt

B. angulosa : Tanganyika, Northern Rhodesia, Republic of South Africa

B. sudanica : Sudan, Uganda, Kenya, Tanganyika, Central African Republic, Ghana, Congo (Leopoldville)

MOLLUSCAN INTERMEDIATE HOSTS OF *S. HAEMATOBIUM* IN AFRICA

Bulinus (Physopsis) africanus : Ethiopia ?, Kenya, Tanganyika, Mozambique, Northern Rhodesia, Southern Rhodesia, Republic of South Africa

B. (Ph.) globosus : Africa south of the Sahara

B. (Ph.) nasutus : Uganda, Kenya, Tanganyika, Zanzibar, Pemba

B. (Ph.) abyssinicus : Somalia

B. (Ph.) jousseaumei : Gambia, Senegal, Portuguese Guinea

B. (*B.*) *truncatus* : Morocco, Algeria, Tunisia, Egypt, Sudan, Ethiopia, Mauritania, Mali, Chad, Ghana, Nigeria, Congo (Brazzaville)
B. (*B.*) *guernei* : Gambia, Senegal
B. (*B.*) *coulboisi* : Burundi ?
B. (*B.*) *cernicus* : Mauritius
B. (*B.*) *forskalii* : Nigeria ? Malagasy Republic ?
B. (*B.*) *mariei* : Malagasy Republic ?
B. (*B.*) *senegalensis* : Gambia, Senegal
Planorbarius metidjensis : Spanish Morocco

MOLLUSCAN INTERMEDIATE HOST OF *S. HAEMATOBIUM* IN EUROPE

Planorbarius metidjensis : Portugal

MOLLUSCAN INTERMEDIATE HOST OF *S. MANSONI* IN SOUTH-WEST ASIA

Biomphalaria sp. : Israel
B. pfeifferi : Yemen, Saudi Arabia, Aden Protectorate

MOLLUSCAN INTERMEDIATE HOSTS OF *S. HAEMATOBIUM* IN SOUTH-WEST ASIA

Bulinus (*B.*) *truncatus* : Turkey, Lebanon, Syria, Israel, Iraq, Iran, Yemen, Saudi Arabia
Bulinus (*B.*) *reticulatus* : Aden Protectorate
Bulinus (*B.*) *beccari* : Aden Protectorate

MOLLUSCAN INTERMEDIATE HOST OF *S. HAEMATOBIUM* IN SOUTH CENTRAL ASIA

Ferrissia tenuis : India

MOLLUSCAN INTERMEDIATE HOSTS OF *S. JAPONICUM* IN THE ORIENT

Oncomelania nosophora : Japan
O. hupensis : Mainland China
O. formosana : China (Taiwan)
O. quadrasi : Philippines

Life-Cycle of the Parasites

The adults of *S. mansoni* and *S. japonicum* commonly inhabit the mesenteric veins, although occasionally they are found in aberrant locations. On the other hand, the adults of *S. haematobium* usually occur in the veins of the pelvic plexuses. In the egg-laying operation, the paired worms proceed down to the terminal venules, and the female worm extends without leaving the gynaecophoral canal of the male in order to lay her eggs adjacent to the walls of the intestine or bladder. By mechanical and chemical means, the eggs pass into the tissues, many of them to reach the lumen of the intestine or bladder, but some to be held up by local inflammatory reaction. Those not so arrested are passed in the faeces or urine, by which time the miracidium contained within the egg has reached maturity, and is ready to hatch if and when the egg reaches water.

On hatching, the miracidium attacks a suitable molluscan host. If it fails to contact a susceptible snail, the miracidium dies—usually in less than 24 hours. Once penetration has been effected, the larva finds its way to the head, foot, mantle, tentacles or other location within the snail, loses its cilia and transforms into a sacculate sporocyst. The sporocyst in turn produces within its cavity a secondary generation of sporocysts which migrate to the lymph sinuses of the digestive gland of the snail. Here cercariae develop within the daughter sporocysts, from which they escape through a birth-pore. When mature, these cercariae emerge from the snail and attack a suitable mammalian host. The cycle within the molluscan host requires approximately four weeks in the case of *S. mansoni*, six weeks for *S. haematobium* and seven weeks or more for *S. japonicum*.

Penetration of the skin of the definitive host is aided by the discharge of lytic ferments from the penetration glands. Entrance is usually effected quite rapidly and may occur within less than 10 minutes. Those cercariae which fail to contact a mammalian host are shortlived and usually die within 48 hours. During the process of penetration, the cercaria loses its tail. The passage through the subcutaneous tissues is usually effected within 24 hours, and the cercaria, now properly termed a schistosomula, finally reaches a venule from which it is carried by the venous circulation to the heart. Via the pulmonary artery, it is carried to the lungs, and thence crosses the capillary bed to reach the arterial circulation through which it is transported to various parts of the body. Except in rare instances, those cercariae which reach aberrant locations never develop further. It is only those which are transported to the arteries of the abdominal viscera, and are able to reach the mesenteric veins, that continue their development and reach maturity. From the mesenteric veins, the larvae reach the intrahepatic vessels where they continue to develop until sexual maturity is approached. They mate and, depending on the species, the worms then migrate to the mesenteric veins or to the veins of the pelvic plexuses, where egg production begins. The period between infection and recovery of eggs from the stools or urine of the definitive host may comprise 30-40 days, but frequently is much longer.

Bionomics of the Snail Hosts

Aquatic snails

General

Schistosoma haematobium and *S. mansoni* are both transmitted by freshwater snails belonging to the family Planorbidae. The species involved in the life-cycle of the former parasite are (with two exceptions) members of the sub-family Bulininae, whereas those involved in the life-cycle of the latter parasite are members of the sub-family Planorbinae.

The proven intermediate hosts have been listed previously (see pages 14-15).

Although the biological characteristics and the relationship with the environment differ considerably in the case of the various snail species, these aquatic forms possess a number of ecological features in common which have an important bearing on their control. The more important of these common ecological characteristics are discussed in the paragraphs which follow; and further reference to them is made in chapter 3 (see pages 69 *et seq.*).

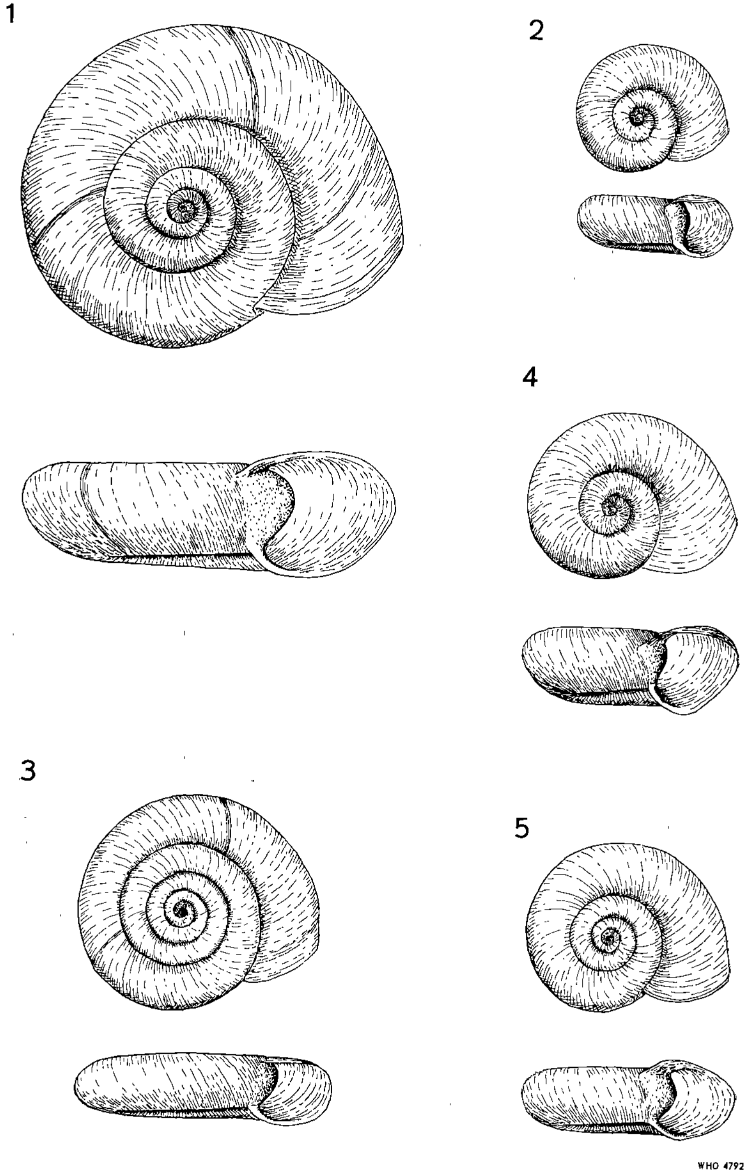
Habitat

In general the aquatic snails that transmit bilharziasis occur in shallow waters near the shores of lakes, ponds, streams and irrigation channels. They usually occur in shallow water owing mainly to the more favourable conditions for food, shelter and oviposition found nearer the surface. Consequently, in small or shallow bodies of water, whether static or flowing, such as small streams, ponds, marshes and swamps, the snails may often be found throughout the habitat. Some of the pond and lake species of *Biomphalaria* may be found in much deeper water; but such colonies tend to have only an indirect effect on the transmission of bilharziasis.

Although aquatic snails may be found on a wide variety of different kinds of substratum, they require organic material for food and, in the absence of water plants particularly, mud rich in decaying organic matter appears to be a usual characteristic of their natural habitat. However, they are perfectly capable of adapting themselves to life in conditions where the only substratum consists of stone or concrete, provided that a sufficient growth of unicellular algae occurs thereon to provide them with nutriment.

Aquatic snails are markedly more abundant in waters containing a rich growth of suitable species of water plants; but such vegetation is not an essential feature of the habitat. Its favourable effect is, however, shown by the fact that the distribution of the snails in ponds tends to follow the pattern of the vegetation—living or dead, bottom, floating or emergent.

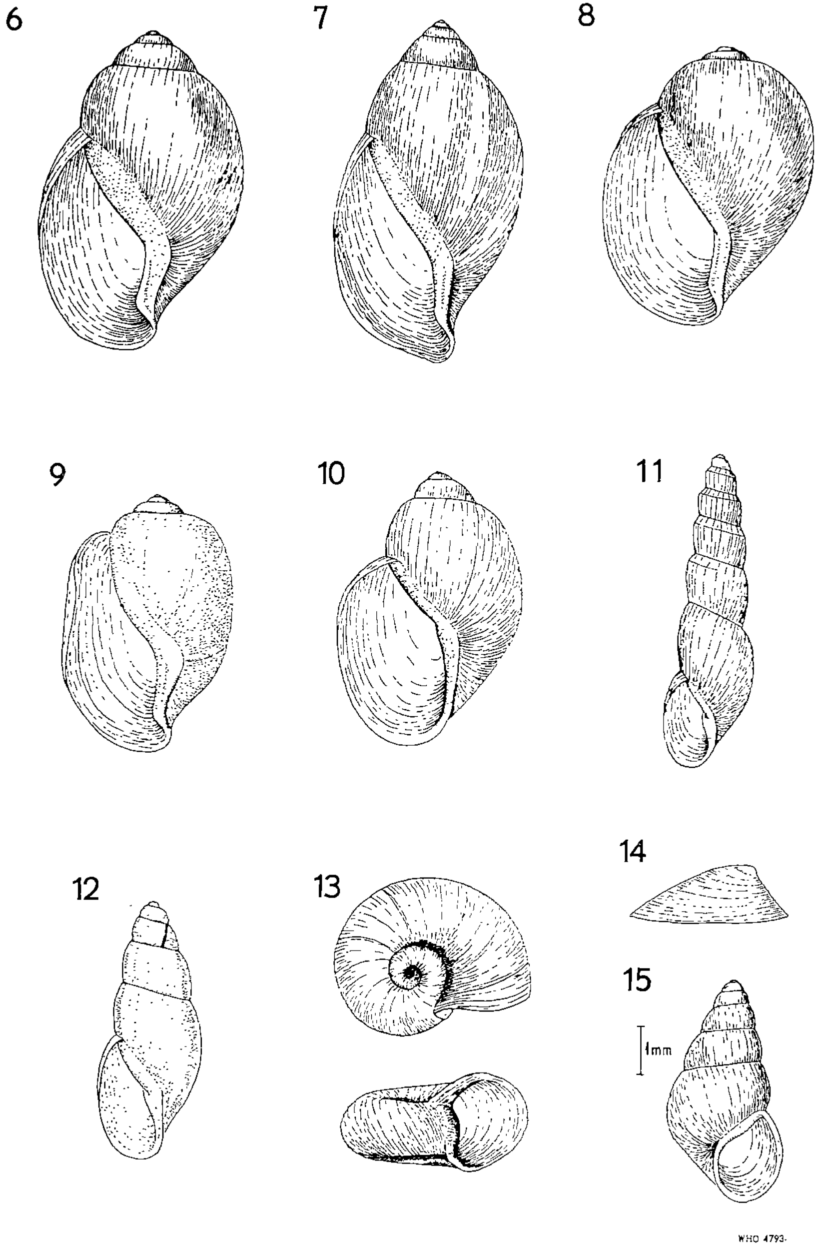
FIG. 1. INTERMEDIATE HOSTS OF *S. MANSONI*



1. *Australorbis glabratus*, Brazil
2. *Tropicorbis stramineus*, Brazil
3. *Biomphalaria sudanica*, Uganda
4. *B. pfeifferi*, Southern Rhodesia
5. *B. alexandrina*, Egypt

Magnification : 2 × natural size

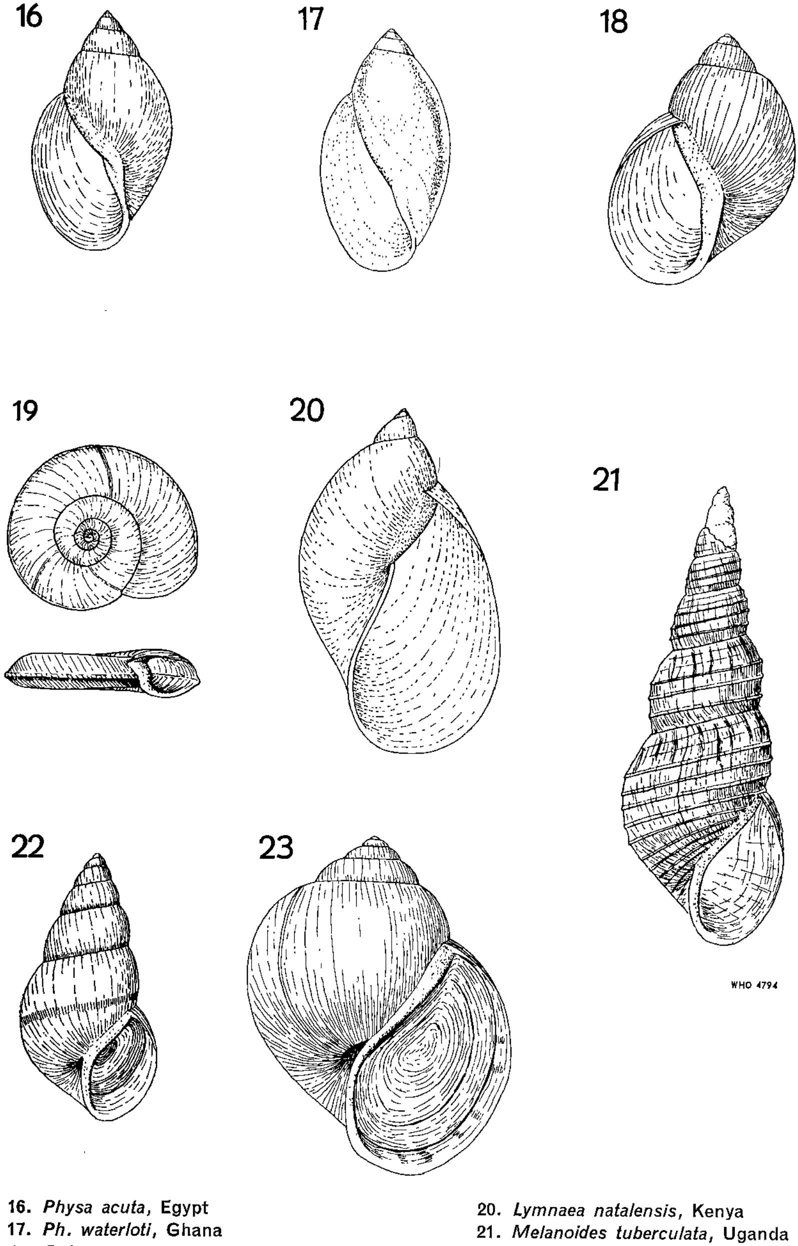
FIG. 2. INTERMEDIATE HOSTS OF *S. HAEMATOBIUM* AND *S. JAPONICUM*



6. *Bulinus (Physopsis) africanus*, Kenya
7. *B. (Phys.) nasutus*, Tanganyika
8. *B. (Phys.) globosus*, Angola
9. *B. (Phys.) abyssinicus*, Somalia
10. *B. (Bulinus) truncatus*, Egypt
11. *B. (B.) forskalii*, Sudan
12. *B. (B.) senegalensis*, Gambia
13. *Planorbarius metidjensis*, Portugal
14. *Ferrissia tenuis*, India
15. *Oncomelania quadrasi*, Philippines

Magnification : Nos. 6–10, 13 : 2.5× ; Nos. 11–12 : 3× ; Nos. 14–15 : 6.5× natural size

FIG. 3. ACCOMPANYING SPECIES



16. *Physa acuta*, Egypt
17. *Ph. waterloti*, Ghana
18. *Bulinus tropicus*, Southern Rhodesia
19. *Planorbis planorbis*, Egypt
20. *Lymnaea natalensis*, Kenya
21. *Melanoides tuberculata*, Uganda
22. *Cleopatra bulimoides*, Egypt
23. *Pila ovata*, Uganda

Magnification: Nos. 16–22: 2.5× natural size; No. 23: natural size

Water with only a very gentle current is preferred by all species of aquatic snail hosts, but some species find suitable habitats in standing water. They are almost invariably absent from fast-flowing water. Wave action, fast current and floods all have inhibiting effects on the establishment of aquatic snail colonies.

Permanent or semi-permanent water is an essential feature of the habitat of aquatic intermediate hosts of bilharziasis. It may, however, be very much restricted at certain times of the year; so that snails which are widely spread during the wet season may be confined to small isolated pools during the dry season.

When stranded on dry land by a falling water level, or when so exposed by the evaporation or drainage of the water in the habitat, a large proportion of aquatic snails die. Prolonged exposure, rapid fall of water level, absence of shade, and low relative humidity all tend to increase the death-rate and to accelerate death. The species and strains of water snails that transmit bilharziasis show great variation in resistance to dry conditions. Some strains show remarkable resistance to desiccation, survival out of the water for periods of 3-11 months having been recorded in experiments. Aquatic snails may occur in temporary pools in parts of Africa and South America which dry up for several months during the hot season, obliging the snails to aestivate; not all individuals survive this dry period, but a proportion do so and repopulate the habitat when it is once more filled with water. Desiccation is, of course, ultimately lethal to all species of both adult and young aquatic snails, and even more rapidly so to the relatively sensitive eggs. Where the subsoil water level and relative humidity are low, desiccation can be used as a means of control; but great care must be exercised to ensure that no damp pockets remain in which the snails may find conditions sufficiently favourable for survival.

Owing to their remarkable resistance to desiccation, aquatic snails may be readily transported for considerable distances in mud adhering to the bodies of water buffaloes, or to the roots of transplanted shrubs and trees, or in water skins. In this way they may be enabled to colonize habitats in areas formerly free from them—as, for example, isolated oases. They can also be transported for long distances in mud adhering to the bills and feet of wading birds.

In this connexion it must be remembered that a single individual is capable of producing young and can therefore quickly re-colonize a habitat.

All snails that transmit bilharziasis appear to show a high degree of tolerance to variation in the temperature of their habitat. Although the optimum temperature for these molluscs lies between 22°C and 26°C, different species vary greatly, and the threshold of favourable temperature generally lies between 12°C and 18°C. The maximum, however, is scarcely above 32°C. Nevertheless, the snails are able to withstand for a considerable period of time both relatively low and relatively high extremes of temperature, ranging from a little above freezing point to well above blood heat; they do not, however, breed at such temperatures. They are rapidly killed by freezing and by temperatures in the region of 50°C.

The opinion has been widely prevalent that the aquatic snail hosts of schistosomes are unable to live in complete darkness. This is now known to be untrue; but, under natural conditions, light has an important effect in ensuring the growth of the unicellular algae and other microscopic plants which provide the snails with most of their food. Certain specific differences in light reactions appear. Thus *Australorbis glabratus* occurs in both exposed and shaded habitats but definitely appears to enjoy direct sunlight. African planorbids and bulinids, on the other hand, appear to prefer lightly shaded habitats and to avoid direct sunlight by hiding under leaves or floating debris.

Acidity and high salinity of the water are inimical to the snails.

All species of intermediate snail hosts of schistosomes tend to be more abundant in waters lightly or moderately polluted with decaying organic matter or with human faeces and urine; and are therefore considerably more abundant near human habitations where such fouling occurs. Heavy pollution of any kind, on the other hand, discourages their establishment.

In considering snail habitats it is important to realize that microhabitats frequently exist, in which conditions occur that are more favourable to the snails than those found in the main body of water concerned.

Habits

Water snails in general are able to subsist on a variety of different food and exercise little apparent choice. The young snails, having as yet a small and feebly developed masticatory apparatus, are obliged to feed upon unicellular organisms or very small soft organic particles. Unicellular green algae appear to be the preferred food of the newly hatched snails. Older snails subsist partly on vegetable matter and partly on the microflora of their environment. It is rare that water snails attack the healthy tissues of living water plants, except in the absence of all other food, since they seem to prefer partly decayed vegetable matter. Where water plants, stones, concrete surfaces, or any other firm substratum is covered with an encrusting growth of algae, snails may be seen browsing thereon. In some cases decaying organic matter of animal origin may be eaten; and this seems to be more common among planorbids than among bulinids. The ability and willingness of these snails to eat almost any organic material offered to them is largely responsible for the correlation found between human pollution and refuse and number of snails; in other words, mild pollution has an enriching effect on the general environment rather than a specific effect on the snails.

Both bulinids and planorbids are strictly aquatic in their habits and seldom leave the water voluntarily unless it becomes unsuitable in some way.

Snails which become stranded out of the water by rapid change of level make little or no attempt to escape back into the habitat, although their degree of activity would enable them to do so. Similarly, snails exposed to desiccation by drainage or drying of the habitat make no active attempt to escape exposure by burrowing into the substratum, even though this may be soft enough to allow them to do so. Individual snails, however, in the course of their ordinary movements on soft mud or by deposition of silt often become partially or entirely buried by accident.

The normal reaction to dessication is simply the withdrawal of the body within the shell and the formation of a layer of mucus over the opening. Unlike the amphibious oncomelaniid snails, the aquatic bulinids and planorbids have no operculum, and are therefore not so effectively able to seal the opening of the shell under dry conditions.

Life-cycle

Aquatic intermediate snail hosts of schistosomes are without exception hermaphroditic and capable of self-fertilization, although cross-fertilization between different individuals usually takes place. The eggs are laid intermittently during the period when the water is warm enough. The minimum temperature for oviposition varies considerably from one species to another, and even from strain to strain. Eggs are sometimes laid singly, but more often in batches of from five to 40, each batch being enclosed in a mass of jelly-like material.

The eggs hatch, under suitable temperature conditions, in from one to three weeks. The young snails feed almost exclusively upon unicellular green algae and other micro-organisms which they find growing on surfaces of water plants and inanimate substrata. As their size increases they may indulge in other organic food. Sexual maturity is reached in from one to four months according to conditions of food supply and temperature.

The life-span does not generally exceed 12 months and is generally very much less. During the whole of its life, the snail continues to increase in size.

Effect of seasonal and climatic changes

Seasonal and climatic changes have a profound effect upon the life-cycle of intermediate snail hosts. Rainfall cycles are among the more important climatic factors which affect the life of the snails. Constant rainfall maintains water levels, with resulting uniformity of molluscan environmental conditions ; whereas cyclic rainfall leads to cyclic changes in water levels and sometimes to floods, which are reflected in life-cycle and population changes. Rainfall also influences the relative humidity of the atmosphere, which has important effects upon the survival of the snails out of the water.

Reproductive cycles and population cycles depend not only on rainfall and water level but also on temperature. Regular cyclic temperature changes affect the length of the breeding season. In certain areas, the period of time during which the water is warm enough to permit oviposition, development and growth is only sufficient for the production of one generation. In latitudes where the warm season is longer, several generations may be produced, or breeding may even continue all the year around. Thus *Bulinus truncatus* in northern Iraq produces only a single generation annually, while in central and southern Iraq and in Egypt it produces two or more generations each year. *Australorbis glabratus* in parts of north-east Brazil continues to breed all the year round ; in others breeding is limited by a long dry season.

In areas where all three factors—rainfall, water level and temperature—remain constant, there are no great cyclic shifts ; small ones may occur, although they are irregular or erratic. In these areas breeding takes place all the year round. In areas where seasonal rainfall, water level or temperature cycles occur, reproductive and population cycles of aquatic snail hosts may be pronounced, particularly as the result of the influence of these factors on egg-laying. Reproductive and population cycles naturally lead to seasonal fluctuations in the transmission potential of the snails and therefore to the infection risk to man. Favourable ecological conditions are most necessary for the young snails during the weeks immediately after hatching, since they are less resistant than the adults to changes of temperature and to desiccation.

In areas with a pronounced warm season snails hatched early in the season become mature before the onset of cooler weather, whereas those hatched late in the season do not reach sexual maturity before the next warm season. Vector species which occur in more equable climates do not show seasonal variation of growth to the same extent.

Fluctuation in adult populations of intermediate snail hosts as well as in reproductive cycles and in the proportions of young and mature individuals may also be caused by seasonal changes in rainfall, water level and temperature. It is essential to know the regular seasonal fluctuation in the snail population in order that a normal seasonal decrease in numbers may not be mistaken for the effect of control measures.

Amphibious snails

General

S. japonicum is transmitted by amphibious snails which belong to the genus *Oncomelania*. The four known intermediate hosts have been listed in a previous section. The intermediate hosts in the Celebes and Thailand are unknown. The biological characteristics and the relationships with the environment in the case of the four known species are intimately related to the problem of controlling these snails. Some of the important features have been outlined below.

Habitats

Unlike the aquatic planorbids and bulinids, the snails which transmit *S. japonicum* are amphibious in habit. It appears that originally these snails inhabited poorly drained flood plains. With the agricultural development of these areas the snails are able to adapt themselves to certain types of habitats that are left : poorly tilled rice fields ; sluggish streams ; secondary and tertiary canals and drains of irrigation systems ; swamps ; roadside ditches, etc. The vegetation in these sites plays an important role by moderating temperatures, suppressing evaporation, and maintaining a suitable humidity in the micro-habitat.

Habits

In most respects the reactions of the amphibious snails to variation in the diverse environmental factors in water is similar to that shown by the aquatic snails. On land they tend to avoid strong light and, if there is sufficient moisture in the habitat, this accounts for much of their activity by day. Desiccation has less effect on adult amphibious snails than upon aquatic snails, but affects oviposition, and the eggs which are laid near water level are very susceptible to drying.

Marked specific differences exist in relation to egg-laying sites. Thus *Oncomelania quadrasi* prefers to lay its eggs at or above water level on a solid substrate, e.g., coconut husks, whereas *O. nosophora* is more apt to lay eggs in the water and prefers soil as a substrate.

Newly hatched snails pass through an aquatic stage which lasts for 2-3 weeks, but a large portion of the older snails' active life is spent out of the water, on wet surfaces. In some cases they have been observed after rain or heavy dew browsing on plant surfaces more than two metres above the ground.

Oncomelania spp. appear to show preference for food rich in cellulose. They feed on the algae and decaying organic matter which occur on moist soil above the water level, and on the micro-organisms found on living and dead vegetation in shallow water.

Decaying organic matter, mainly of vegetable origin, assists in the formation of a suitable substratum for the snails and provides additional food material.

If the surfaces on which the snails are moving become dry, the body is withdrawn into the shell, the operculum closes the opening, and the snail can usually aestivate until conditions are suitable for activity to return. The *Oncomelania* species found in the temperate zone often spend 2-4 months in hibernation. With the higher temperatures in the tropics, the snails survive for much shorter periods of drying.

Life-cycle

In these snails the sexes are separate, copulation takes place repeatedly, but a single fertilization of a virgin female is sufficient to ensure fertile eggs throughout her life. The eggs are laid singly, partly embedded in soil near the margin of the water or on bits of vegetation and other debris. The mucus layer of the egg is covered with a protective mixture of soil and snail faeces.

The incubation period for the eggs varies from 10 to 25 days, and this wide range increases the chances of the colony's survival. The young snails grow at the rate of 0.25-0.50 mm per week but as they approach maturity, after about 7 weeks, the rate of growth becomes much slower. Under optimum conditions the snails reach maturity in 11-15 weeks. Observations indicate that each adult female lays about two eggs every five days during her adult life.

The life-span of these snails varies with the species. In the case of *O. nosophora* in Japan, a few snails under observation lived for five years. Other data indicate that the average span of the " spring " generation in the field may be about four months, but that a good many survive the winter and can live for more than 12 months. *O. quadrasi* in the Philippines has a much shorter life-span, reaching 25-35 weeks. The more detailed data available on this snail show that the average female lives for 65.8 days and the male for 47.6 days.

Effect of seasonal and climatic changes

Amphibious schistosome snails, like aquatic species, are profoundly and similarly affected by seasonal and climatic changes, particularly by rainfall cycles.

Water-level cycles affect oviposition and also have an influence on the development of snail food. A gently rising water level favours the hatching of the eggs and the development of the young. In Japan, because of annual water-level and temperature cycles, only one major generation of *Oncomelania* is produced each year. In the Philippines, on the other hand, where the temperature is fairly constant, reproduction is continuous where there is little fluctuation in precipitation. In areas where there is a definite dry season the snails do not occur. Thus, in conditions of year-round even temperatures there is correlation between reproduction rates and rainfall.

Relation between bionomics and control

All the bionomic factors mentioned are related to a proper understanding of the measures that must be taken to obtain control of either aquatic or amphibious snails. In fact, effective reduction or elimination of these snail populations depends upon alteration of conditions in the habitat in such a way as to render it inimical to the molluscs, either by changing the original environment or by introducing molluscicides. One of the major difficulties in achieving snail control is the high reproductive potential of the molluscs which enables a few survivors rapidly to repopulate a habitat. For example, it is possible for a single fertilized female *Oncomelania*, which happened to be perched high on the dry bark of a sapling at the time of a molluscicide application, to survive and repopulate a suitable habitat within a fairly short period of time.

Direct Effects on the Health of the Population

The direct ill-effects of bilharziasis upon the human host are generally underestimated, owing to the fact that it is a chronic disease which runs a long and insidious course. Since it is neither directly contagious nor rapidly fatal it tends to attract less attention, both from the general public and from the health authorities, than do many other diseases which are ultimately of less importance. Prior to the institution of thorough and systematic surveys, available information in endemic areas rarely gives an adequate measure either of its true prevalence or of its importance as a cause of disability and death. A relatively limited number of severe cases in which heavy infection of long standing has produced spectacular pathological effects often monopolize the picture.

The relative benignity of the disease is, however, entirely misleading. Bilharziasis not only decidedly and often profoundly affects the physical capacity of the majority of infected persons, but also lowers their resistance to other infections, hence producing a marked reduction of their productive capacity.

The proportion of clinical cases and of serious complications to the number of persons infected is therefore an important factor in estimating the direct effect of bilharziasis upon a given population. It is essential in obtaining a quantitative assessment of human incapacity and of the resulting financial burden imposed by the disease.

The determination of this ratio requires not only investigation of the prevalence of bilharziasis throughout the endemic area, but also the long-term study of extensive series of clinical cases in order to determine the progress and prognosis of the disease in relation to the characteristics of the infected persons and the environment in which infection occurs. Hospital statistics are rarely a sufficient guide, since they list only complaints, and the inhabitants of an endemic area will not ask for treatment for the conditions such as haematuria, occasional diarrhoea and mild abdominal pain which characterize the early stages of the disease, because they generally consider these to be normal.

The disease: infection ratio and hence the apparent severity of bilharziasis vary considerably, not only from one endemic area to another but also from one locality to another within the same area, where apparently similar human populations, environmental conditions and prevalence obtain. The reasons for this state of affairs are complex and not well understood. The nutritional status of the human host modifies the pathological manifestations, and immune response to the infection varies, taking sometimes the form of increasing adjustment to the infection, and sometimes that of developing hypersensitivity to the antigenic substances produced by the parasite. Strains of the parasite differing in virulence may well exist in different areas. Many other factors no doubt also contribute to this variability.

The earliest stages of bilharziasis in man, before the worms have reached maturity, produce relatively unimportant signs, which are usually disregarded. A transient skin lesion may follow invasion of the cercariae, followed by cough and other transitory pulmonary reactions as the parasites pass through the lungs. A little later, when the young worms are growing to sexual maturity in the liver, such minor toxaemic symptoms as loss of appetite, malaise, headache, fever, and temporary enlargement and tenderness of the liver may occur. The major symptoms and pathogenic effects, however, which are not observed until the worms have reached sexual maturity and oviposition has begun, are mainly due to the presence of the eggs in the tissues and to the irritation and reaction caused thereby. Such lesions may be of two kinds—closed or open. In the former, which occur principally in the liver, lungs and bladder, the eggs are trapped in the host tissues and are unable to leave the body; while in the latter, which occur principally in the intestine and bladder, the eggs are passing through the tissues, from which they eventually escape to the exterior. Closed lesions are generally more serious than open lesions, and may produce indirect effects upon the heart and some of the major blood vessels.

Since serious lesions are due to the effect of the eggs in the tissues, a high rate of infection is very pathogenic and may sometimes be fatal. On the other hand, light infections may be essentially symptomless and lacking in obvious pathogenic effects. All grades of severity occur between these two extremes. The higher the degree of infection and the more frequent the occurrence of re-infection, the more serious will be the damage to the host.

Immunity and toxic-allergic reactions play an important and little understood role in pathogenesis. Immunity frequently operates to reduce the appearance of symptoms in infections of long standing. On the other hand, severe toxic-allergic reactions may complicate the issue.

In the case of *S. haematobium* infection, the principal lesions occur in the wall of the urinary bladder, but may extend to the ureters, the kidney, the urethra and the genitalia. Terminal haematuria is the most conspicuous early sign, but tends to disappear as the lesions become more advanced. Pain on micturition, with frequency and incontinency, is a constant and increasing factor. Lower abdominal pain, bladder colic, weakness and emaciation are characteristic. Pyogenic secondary lesions often occur.

In the case of infection with *S. mansoni* or *S. japonicum* the principal lesions occur initially in the wall of the intestine, particularly the caecum, colon and rectum. Dysentery with abdominal pain is often severe. Later, closed lesions in the liver and lungs are frequent, with resulting enlargement and disfunction of liver and spleen, and arterial obliteration in the lungs leading to secondary effects upon the heart. Toxaemic symptoms, especially in *S. japonicum* infections, are more frequent and severe than in *S. haematobium* infection.

Anaemia is often observed in all forms of bilharziasis ; but whether it is due to the disease or to accompanying malnutrition is not certain.

Infection is almost always acquired early in life, usually in the first decade. Constant re-infection and slow development of immunity produce a tendency to maximal infection in age-groups ranging from 12 to 20 years.

Physical weakness and reduction of the ability to work, increasing with the severity of the infection, is characteristic to some degree of all bilharziasis patients ; and, especially in children, may be coupled with retardation of mental development and intellectual dullness. Incapacity is progressive. Thus infected persons may be grouped in four categories, as follows :

(1) Those with *light* infections, who display slight or occasional symptoms and are able to work normally.

(2) Those with *moderate* infections, who display more marked and frequent symptoms, and on account of weakness are incapable of hard work.

(3) Those with *severe* infections, who display recurrent or continuous symptoms of a disabling character and are consequently often absent from work.

(4) Those with *very severe* infections who, in addition to continuous, severe disabling symptoms, display ascites and/or emaciation, and who, therefore, are permanently unable to work.

This depressing sequence of events remains unchanged unless treatment is given. The drugs at present available are not perfectly satisfactory since a 100% cure-rate is rarely obtained, rest and cessation of work is necessary during treatment, and relapses are frequent. Nevertheless, mass treatment of the infections appears to prevent the development of more severe manifestations.

Indirect Effects on Agriculture and Economy

In the final analysis the distribution of the molluscs which serve as the intermediate hosts for the human schistosomes is largely determined by hydrographic and climatic factors. In many areas where the transmission of bilharziasis could occur, there is too little water for too short a time under natural conditions to support extensive human and livestock populations and thus favour the full development of the agricultural potential. The introduction of water into such areas tends to build up human, animal and snail populations ; and this often leads to a marked increase in snail-borne diseases. In still other endemic areas, low-lying, poorly-drained terrain, which is supplied with too much water, often offers ideal habitats for snails.

In the first type of area mentioned above, water for domestic use and irrigation is essential for development. In the second type of area, land reclamation and water management tend greatly to reduce the extent of the snail habitats and to increase agricultural production.

Irrigation agriculture is a highly specialized type of farming which requires industrious and healthy settlers if the full potential of the area is to be realized and if it is to form a base for industrialization and improved standards of living. Such a base depends on the extent to which each farm worker is able to produce beyond the point of mere subsistence. Poor health is one of the factors which limits the farmer's production.

Bilharziasis is not a rapidly fulminating, dramatic disease which causes a high, direct mortality. On the contrary, it is a chronic insidious infection with debilitating effects which results in a reduction in the capacity of the infected person to contribute to the local and national economy. For this reason, diseases such as bilharziasis tend to hamper an economy to a greater extent than do the more highly publicized and greatly feared diseases.

Relation to Development of Soil and Water Resources

Spread of infection

Due to the fact that precautions are not usually taken nor control measures instituted during the early phases, most soil and water-resource development programmes in endemic areas cause the spread of bilharziasis. In rare instances, however, careful planning in the initial stages of schemes and the subsequent use of suitable agricultural methods and strict water management during their operational phase, have reduced the extent of the snail habitats and lowered the incidence of the disease. These exceptions lead in to the discussion of environmental control in chapter 3 (see page 63).

In dry areas of the first type mentioned in the preceding section, the intermediate hosts and man are either entirely absent or limited in their distribution. Even if a few snail habitats exist, ecological and climatic conditions often sharply limit the length of the transmission period. The introduction of water into formerly inhospitable places often opens them up for invasion and settlement by both snails and people. The resulting association almost invariably also allows introduction and spread of snail-borne diseases of man and his livestock. When water is supplied to areas where only occasional foci formerly occurred, the following changes usually take place : (1) the area becomes capable of supporting greater snail and human populations ; (2) the number and extent of the sites where transmission of snail-borne diseases can occur is greatly increased ; (3) the length of the period of such transmission is extended.

In some of the poorly-drained areas on the coastal plain of parts of East and West Africa, intermediate hosts may be very common but the characteristics of the habitats tend to limit human contact. In such areas reclamation by drainage may greatly reduce the extent of the snail habitats. At the same time, however, the advantage gained in this respect may be offset by increased human activity in the area and correspondingly greater human contact with the snail colonies that remain in the drainage canals and other residual habitats. In Leyte, in the Philippines, the poorly-drained endemic area had a dense human population. Water management and soil resource development in experimental areas there, without a corresponding increase in the human population density, brought about a decrease in transmission, more or less proportional to the reduction of transmission sites.

Prevalence and intensity of infection

There is convincing evidence that the development of soil and water resources, especially in the dry areas of endemicity, usually produces an increase in the prevalence of bilharziasis. In this respect bilharziasis is a man-made disease.

For example, before perennial irrigation was provided in four Egyptian provinces in 1934 the percentage of the population infected with bilharziasis ranged from 2% to 11%. When another survey was made there three years later, it was reported that the prevalence had risen substantially and then ranged from 44% to 75%. In the former Belgian Congo the prevalence had risen in one area from between 3% and 4% to between 30% and 35% within a year after the introduction of irrigation. Similar difficulties have been encountered in irrigation schemes in Sudan, Iraq, Kenya, Tanganyika, Southern Rhodesia and elsewhere.

The quantitative measurement of the intensity of schistosome infection in a given population is a great deal more difficult than the determination of prevalence. For this reason, the evidence available on this point is generally both indirect and incomplete. Nevertheless, it may reasonably be deduced from the known facts that high prevalence is generally correlated with high intensity and severity of infection ; and *vice versa*. Thus, in Egypt it has been stated that bilharziasis is the most serious public health problem of the country ; but that, since the institution of control measures, fewer severe cases and fewer cases with serious complications are seen in the clinics. In the Congo area just mentioned, it has been stated that the severity of the cases increased with the prevalence. While it might be expected that this would be so, with apparently greater opportunity for exposure to cercariae and a greater number of worms in each infected individual, statistically valid data proving that high prevalence and high intensity and severity of infection are correlated have not yet been obtained.

GROUPS WITH SPECIAL INTERESTS IN BILHARZIASIS CONTROL

Public Health Authorities

The public health authorities in an endemic area have the primary responsibility of determining whether the bilharziasis problem is a serious one and, if it is, of deciding the nature and extent of the measures to be taken.

In a known endemic area of bilharziasis, physicians may make a presumptive diagnosis on the basis of clinical signs and symptoms ; but, since several other disease syndromes simulate those of bilharziasis, and since in many lightly infected patients the characteristic symptoms are lacking, unsupported clinical diagnoses are unreliable and laboratory diagnosis is essential.

As has been already pointed out earlier, for a number of reasons the prevalence of bilharziasis tends to be underestimated in endemic areas, as does also its direct effect upon the population. It is an insidious chronic disease, many of the early effects of which are regarded as normal by uneducated patients who, therefore, do not complain of being ill.

Even where figures concerning incidence and prevalence have been collected by reliable methods, their significance may not be understood. Thus there is often uncertainty as to where the disease was contracted ; and the rate of infection tends to vary from one locality to another and from one year to another, in addition to variation due to sex, ethnic group and occupation.

It is the responsibility of the public health authorities to ensure that accurate and reliable data are available concerning the prevalence, extent and distribution of bilharziasis within their territories. Children of school age generally form the best group for examination, since they usually have a high infection rate, do not travel much (and so raise doubts as to where they may have contracted the disease), and show few, if any, differences due to occupation.

Such a cross-sectional picture of the status of the problem is not, however, sufficient evidence upon which to base a true assessment of the situation. A long-term approach is essential in the case of chronic diseases such as bilharziasis if their importance is to be properly understood. It is therefore necessary also to follow a series of adult cases in a community in order to determine the course and prognosis of the disease in the population involved and in the environment in which the disease arises.

It is further necessary for the public health authorities to establish accurate and reliable morbidity and mortality rates for the disease. The extent to which this is possible will depend upon the availability of health units to persons living in bilharziasis foci, the health education level of the population, the degree of effort which is devoted to the finding of cases, and the state of development of the medical staff and facilities.

The ratio existing between the incidence of patent disease and the incidence of infection is a very important factor in judging the situation, and one which it devolves on the public health authorities to determine.

The extent to which immigration and other population movements occur may also affect the gravity of the situation. Spontaneous human interchange, government population transfers and resettlement projects, together with the occurrence and extent of bilharziasis in the country of origin of immigrants must all be taken into account. In an area in which any of these factors is operating on a large scale, the distribution and prevalence may depend more upon such human problems than upon snail distribution, despite the fact that it is conceded that the intermediate hosts must be present to obtain local transmission.

The elucidation of any local factors causing aggravation of incidence is also the responsibility of the public health authorities. Among these may be mentioned the concentration of a previously scattered, partially infected population in dense communities ; the development of irrigation for agricultural purposes ; the development of freshwater fisheries ; and increase in immigration of infected persons into the area.

All such statistics must be related to the size of the human population and to the extent of existing medical facilities.

It is the responsibility of the public health authorities to compensate for any factors tending to increase the prevalence of bilharziasis or to increase the risk of human infection by providing sanitary equipment, adequate facilities for treatment, health education and, above all, by promoting an anti-bilharziasis campaign based on rational snail control measures. Any movements tending to increase the concentration of the population will facilitate these tasks ; but it must be remembered that such concentration, unless proper control measures are taken, tends also to cause an increase in prevalence.

In respect of health service facilities, the concentration of medical and nursing personnel relative to the area of the endemic region and the number of inhabitants, the size of the health service budget, and the occurrence of other endemic diseases must be taken into account. Some of these diseases may have social repercussions on the bilharziasis problem by compelling the health authorities to reduce the material effort devoted to bilharziasis ; but their prevention may, on the other hand, aid also in the prevention of bilharziasis.

It is obvious from what has been said that bilharziasis control measures need to be integrated both into the health programme of the country and into the general economic programme. The evaluation of the economic burden is therefore of cardinal importance. Every step taken towards lessening this burden will not only diminish suffering and prolong human life, but will also increase productivity and promote prosperity. The public health authorities, upon whom rests the responsibility of presenting their anti-bilharziasis proposals in the most favourable light before the financial authorities, therefore must bring every available economic argument to bear in its favour. A control programme, especially one directed against so unspectacular a disease as bilharziasis, must be put forward as a profitable enterprise so that it may not only attract the necessary financial support but also be given its due place in the priorities to be considered by governments in the use of their available funds. Estimates of the economic losses due to the disease, and of the benefits which will accrue to the prosperity of the country by its control, can be used to great advantage by administrators in obtaining sanction for the cost of control measures, considered purely as a worthwhile investment, quite apart from the moral issues.

It has been estimated that in Egypt bilharziasis lowers the productivity of the population by 33% ; in 1953, the economic loss due to this factor was reported to be \$57 000 000. In the preceding year in Japan the cost of bilharziasis to the nation was calculated at \$3 000 000.

Any such estimate of the economic burden involved must be made on a rational basis, that is to say, on the long-term follow-up of a large number of representative cases in order to determine the duration and severity of each spell of illness referable to bilharziasis. These data permit the calculation of the frequency rate of illness, the severity rate (total number of days of illness) and the disability rate (number of days of illness per person). From these figures it should be possible to estimate the number of man-days lost per year and hence the economic loss sustained by the community. The economic loss to the community will also include the cost of medical care and treatment of victims of the disease, as well as that due to lowered working capacity, without reference to specific periods of illness with absence from work. It is essential to differentiate the effects of bilharziasis from similar effects due to other illnesses and infections—a procedure which is facilitated by the establishment of control groups.

In any snail control campaign, there should be close liaison between public health authorities and other interested agencies. In irrigated areas, the irrigation officials have an important role to play in any control scheme and should be consulted in the planning stages in order that their cooperation may be assured. Agricultural agencies also have an interest in snail control, and their assistance should be solicited. In many endemic areas, snail control measures are so intimately linked with the type of crop production, the design and maintenance of irrigation systems, and water management, that such schemes cannot be intelligently planned or effectively carried out without the active co-operation of these other agencies. It is the responsibility of health authorities to take cognizance of this fact and to work closely with other interested organizations.

Agencies that Plan and Finance Soil and Water Resource Development

Most of the places where bilharziasis is a serious problem are located in what are often called " underdeveloped areas ". In such areas it is feasible for soil specialists to determine the location and extent of the soils which would be suitable for agriculture ; meteorologists and hydrologists have available, or can obtain by observation, data on the rainfall and water production capabilities of the watersheds which could supply these soils. Agricultural experts can predict, or determine on experimental farms, those crops which can best be grown, and can estimate their probable yield. Engineers can use these data to plan irrigation and drainage schemes and estimate the cost of their construction and operation. Basic data of this type can be utilized by economists to calculate how such a project will affect the local and national economy. While these studies and estimates do not always turn out precisely as expected, this method of approach is a logical and straightforward one. Therefore, in the name of economic development, and with the aid of population and political pressures, it is often relatively easy to obtain funds for such schemes.

On the surface it appears somewhat incongruous that in such detailed programmes provision is rarely made at the planning stage either for analysis of the diseases present in the area, or for estimates of the effect of the scheme on their prevalence, or for consideration of the relative merits of initial institution of preventive measures, as compared with use of control measures after the scheme has been constructed. As a result, the implementation of plans for economic development often produces health problems more rapidly than public health budgets and trained personnel can control them. There is considerable evidence that basic environmental sanitation and vector control measures should be incorporated in such schemes.

Even when public health agencies have been consulted at the planning stage they have not infrequently contributed to this unsatisfactory state of affairs by providing inadequate or unconvincing information on current prevalence of relevant diseases and on potential health dangers, and by suggesting impractical control measures.

This lack of mutual understanding of the problems involved leads to an impasse in which the planners appear to be unrealistic visionaries and the public health authorities appear to be stubborn obstructionists. The primary function of chapter 2 of this monograph is to present methods which should be considered in attempts to improve this situation.

In the light of this argument, it is believed that countries contemplating the development of irrigation schemes and other water resource projects should establish a strong central authority for planning, constructing and administering them. This authority should have broad delegated powers under the law, and should not be directly responsible to the usual administrative agencies. The decisions taken by the authority should be based on the advice received from the appropriate government experts or through the technical assistance programmes of international agencies. The authority should control all aspects of the scheme, including the establishment of water-use practices based on actual need, the control of the volume of water used on each farm, the improvement and maintenance of the distribution system, the siting of villages and the enforcement of sanitary and vector control measures. It should be able to forbid agricultural practices known to encourage the transmission of disease. Such co-ordinated direction should increase crop yields, assist in preventing the loss of land by waterlogging and increased salinity, raise the standard of living, and improve the health of the people.

Irrigation and Agricultural Experts

For bilharziasis control, such personnel are involved in relation to the following aspects :

Design and construction of irrigation systems

The snails that serve as the intermediate hosts for bilharziasis are most apt to thrive in irrigation schemes and drainage systems that have been poorly designed, constructed and maintained. Therefore, in all bilharziasis areas special attention must be given to designing and constructing systems which provide for complete control of the water, easy and efficient maintenance, effective application of molluscicides, and reduced operating and control costs.

Irrigation management and water use

Improper water management and primitive methods of water use in irrigation schemes located in bilharziasis areas inevitably produce conditions that encourage snails. Fortunately, practical and effective methods for improving these conditions and for reducing the transmission of bilharziasis have been found in some areas. The application of these measures is discussed in chapter 3.

Agricultural methods and crop production

In most underdeveloped areas greater progress has been made on the engineering aspects of irrigation than in the use of the water provided. This is particularly true of the use of water on farms, the selection of crops and the farming methods employed. While the engineering aspects are carried out as public works which are in the hands of specialists, primitive agricultural practices and poor irrigation methods at the water-user level are common in many areas. These not only prevent the full development of the agricultural potential, but they are also important factors in the development of snail habitats.

Water and soil conservation

The spread and increase in prevalence of bilharziasis is not necessarily confined to areas where irrigation schemes are expanding. This tends to occur in any relatively dry endemic area in which man undertakes to increase the amount of water that is retained, or uses certain methods of soil conservation. For example, in many of the countries in West Africa and south of the Sahara, a great effort is being made to conserve run-off water and to prevent erosion. Such efforts, like irrigation development schemes, are essential for economic progress. At the same time, unless precautionary measures are taken, they frequently lead to a marked increase in the number and extent of suitable habitats for snails. The presence of an increased snail population, together with water pollution and human contact, make such areas ideal centres for bilharziasis transmission.

The authors of this monograph are aware of the necessity for water- and soil-resource development programmes; but it is their responsibility to draw attention to the inherent dangers and to suggest ways that may be useful in preventing bilharziasis, in order that appropriate control measures can be included as an integral part of the planning of such projects.

AVAILABLE METHODS OF BILHARZIASIS CONTROL

Mass Treatment of all Human Cases

If all infected persons could be found and successfully treated, and all reservoir hosts eliminated, the schistosomes which infect man would rapidly disappear. At the same time such measures would make speedy rehabilitation of the infected persons possible, and would assist in eliminating the complications that arise from these chronic infections. Unfortunately, the limitations of such an approach toward control tend to counterbalance the advantages. Fundamentally, the success of this method is restricted by the fact that the drugs available lack the necessary efficiency and tend to be toxic and difficult to administer. In general, infections with *S. japonicum* and *S. mansoni* are the most difficult to eliminate. Responses in persons infected with *S. haematobium* are much better, if the full course of treatment is given. However, the value of mass treatment as a *control* measure has other serious limitations.

In attempts to conduct mass treatment campaigns in *S. mansoni* and *S. haematobium* areas, it has been found that the following factors are involved.

(1) Multiple examinations are necessary if all infected persons are to be found ; but, since this is often impracticable, a large number of cases are generally missed.

(2) A relatively large number of the cases discovered do not complete the course of treatment, either because of the toxicity of the drugs and the resulting unpleasant side-effects, or because working time and therefore wages are lost by frequent clinic attendance and necessary post-treatment rest periods.

(3) A number of those completing treatment suffer relapses.

(4) Contact with infested water usually continues so that the patients are subject to re-infection.

Data from areas where patients have been followed for adequate periods of time, and where the points mentioned have been considered, indicate that only 20%-40% of infected persons are cured. In these circumstances, the missed and relapsed cases and the re-infected persons have been able to maintain transmission where the initial prevalence has exceeded 10%. In *S. japonicum* areas, relapses after treatment are even more common, and reservoir hosts will continue to supply eggs for the infection of snails. There is increasing evidence that reservoir hosts are also important in some of the *S. mansoni* areas.

Environmental Sanitation

In areas where man alone serves as the definitive host and as the source of the miracidia which infect the snails, the practice of strict measures to prevent the pollution of water should terminate transmission. In most of the bilharziasis areas, facilities for the disposal of human excreta are completely absent or, at best, inadequate. Usually the resulting polluted water is used for bathing, drinking and all other domestic purposes. It would be difficult to contrive a better way of ensuring the transmission of bilharziasis and other filth-borne diseases. For this reason, environmental sanitation is a highly-desirable, multi-purpose measure that must be considered essential in any disease control programme.

As with all the other practicable anti-bilharziasis measures, the effectiveness of environmental sanitation in achieving control of the disease has its limitations. In many areas there appears to be little hope of effective disease control by this method until the general economy, education and standards of living reach higher levels. In any population where the annual income is low, and bare existence is the primary objective, it is difficult for environmental sanitation to become a part of daily life. Sanitary measures will be relatively unproductive unless the people of a given community are interested in, and convinced of the importance of, good sanitation.

While adequate supplies of potable water markedly decrease the prevalence of many filth-borne diseases, this measure is of limited value in the struggle against bilharziasis since this infection is not commonly acquired through drinking-water. Sanitation has its limitations, especially in restricting the transmission of *S. japonicum* and *S. haematobium*. With *S. japonicum*, the reservoir hosts tend to maintain the infection in the snails even in the absence of eggs from human hosts. With *S. haematobium*, the eggs are passed in the urine, and the provision of facilities for excreta disposal has less effect than with faecal-borne diseases.

In the transmission of all human schistosomes, the universal epidemiological factor of the affinity between children and any body of water must also be considered. The juvenile section of the population has the highest prevalence rates, is the least co-operative in any programme for the disposal of excreta, and is the major source of the infection in the snails. Unless safe washing, bathing and recreation facilities can be provided to entice children away from snail habitats, conditions will persist which more or less ensure the continuance of transmission.

Prevention of Human Contact with Water

This method of control is irrevocably related to the previous topic and has some additional implications. It is true that bilharziasis could be prevented if man did not come into contact with infested water. On the other hand, it is this very lack of contact with water that tends to make the desert untenable for man, his animals and his crops. In supplying water to arid areas, primary consideration is given to providing, at minimum cost, as many people and as much land as possible with adequate quantities of water of satisfactory quality for agriculture. Often little thought is given during the planning and constructional phases of an irrigation scheme to the fact that in a typical area the distributory canals serve not only as a source of water for crops, for bathing, and for all other domestic purposes, but also for the disposal of human excreta and wastes. As pointed out earlier, this ensures the spread and high prevalence of filth-borne diseases.

In irrigated and poorly drained areas farmers suffer from an occupational hazard in that they are constantly exposed to schistosome cercariae. This hazard can sometimes be reduced ; but it is difficult to eliminate all contact with infested water. This is particularly true in areas where small, hand-cultivated holdings are primarily devoted to subsistence farming. Such conditions will not change so long as present population pressures, low man-hour production ratios, lack of industrialization, and primitive agricultural practices remain.

It is even more difficult to prevent children from coming into contact with infested water ; and it must be remembered that initial contact with infested water almost invariably occurs during childhood. It follows that avoidance or prevention of contact in older population groups has little or no beneficial effect.

Snail Control

It is evident that complete eradication of the molluscan intermediate hosts would effectively put an end to the transmission of bilharziasis in any given area. However, for a number of reasons which will be discussed later, such a measure also has its limitations. In most endemic areas the control of the intermediate snail host populations offers the best opportunity for the reduction of bilharziasis transmission ; and is generally most effective when combined with one or more of the other methods. Since this is a monograph dealing with snail control, the means by which it can be achieved will be described more fully in chapters 3 and 4.

Conclusion

The points emerging from this discussion are thus :

(1) all known methods of control obviously have both advantages and disadvantages ;

(2) the method or methods selected for application in a given area will depend upon local conditions ;

(3) in most areas snail control will be the most effective single measure, but often a combination of methods will be advantageous.

METHODS OF APPROACHING THE PROBLEM

In any area in which bilharziasis occurs an orderly approach to the problem is essential. The various steps in such an approach are indicated below.

Assessment of the Problem

The first step is to consider the situation with regard to the transmission of this disease in all its aspects and implications. This involves the collection and codification of all available information on human infection; transmission; and the identity, habitats, populations and seasonal fluctuations of the intermediate host. At this stage data may well be limited to hospital records and pathological laboratory returns; if available, such data may provide a preliminary indication of the extent and gravity of the problem.

Determination of the Extent and Severity of Human and Snail Infection

If preliminary consideration of the situation in the light of existing information indicates that bilharziasis is actually or potentially a serious health hazard, the next step is to organize and carry out a series of surveys over the whole of the area involved, as follows:

(1) In order to indicate the limits of the area of occurrence of the disease and so avoid unnecessary expense in the subsequent, more costly investigations, a preliminary survey using some of the newer serological methods may be carried out.

(2) Faecal and urine examination of selected population groups, particularly schoolchildren, may then follow.

(3) Assessment of the clinical severity of the disease, and the morbidity and mortality rate for which it is responsible must then be made.

(4) Next, identification of the snail host is necessary, since most areas support numerous species of molluscs that do not transmit the infection.

(5) Finally, investigation of the geographical distribution and seasonal fluctuation of the snail host, with regard both to population numbers and to infection rates, must be investigated.

At the end of this stage it should be possible to map both the endemicity of the disease and the distribution of the snail host.

Factors in Deciding on a Control Programme

Sufficient data will now be available to enable a decision to be taken as to whether a control programme is necessary and, if so, whether it is feasible. The two separate groups of factors to be taken into account at this stage are as follows.

Economic implications of disease versus control costs

Endemic bilharziasis invariably involves loss of productive capacity due to absenteeism and reduced working capacity. In estimating the cost of the control programme it is important to take into account the fact that this will of necessity be a long-term project, since no short-term programme has any effect at all.

Social and indirect effects of disease

When the health of a human population is improved by the reduction or elimination of chronic bilharziasis, benefits accrue both to the individuals and to the community which cannot easily be assessed in economic terms but which are nevertheless both tangible and of great value. All-round improvement in well-being and mental and physical efficiency usually follows.

There may also be collateral benefits that do not stem from the improvement in human health, such as improved crop yields, and control of other snail-borne diseases in man and domestic animals.

Selection of Methods of Attack

The information collected to determine the extent and intensity of human and snail infection (see page 41) should also enable a decision to be taken as to the most suitable method of attack. The various possibilities have been indicated on pages 38-41; and this matter is considered further, in more detail, in chapter 2.

Essential Preliminary Studies

Before any control work is started it is of the utmost importance that suitable and adequate data should be collected, since without such data no evaluation of the effect of the campaign can be made, nor is it possible to improve the methods used on the basis of experience. The nature of the information needed, which includes a variety of facts about the snail host, about the disease in man, about human activities in relation to land and water use, and about environmental conditions, is set forth more fully in chapter 2.

Necessity of Follow-up Studies

After control has been commenced it is necessary to collect further data in order to be able to evaluate its effect upon the situation. Repeated checks on snail population density and infection rates, and on the prevalence and severity of human infection, are most important. But observations on the impact of the measures on trematode infections in domestic animals, and their general effect on human activities, domestic animals, crops, and wild fauna and flora are also required. *It is essential that the data should be collected by the same methods and in the same manner as during the preliminary studies, in order to facilitate statistical comparison of the situation before, during and after control.* These matters also are treated in more detail in chapter 2.

Health Education

It should not be overlooked that the successful application of any control measures requires informed co-operation from the human population. This is not usually difficult to achieve since the sympathies of the people can readily be enlisted from the outset by a suitable campaign to make them aware of the nature of the problem, and of the reasons which underlie the action being taken. Further detail on this matter is outside the scope of this monograph, but it may not be out of place to remark that, while every modern method (cine-film, especially of the cartoon type, distribution of pamphlets and posters, lectures, radio and television broadcasts, demonstrations) should be employed, experience has shown that informal talks to small groups by sympathetic individuals trained in this aspect of health education, which provide the opportunity for question and answer, are most effective in the long run.

STAFF TRAINING REQUIRED

It is evident that professional staff will be needed to plan and direct the campaign. In addition to medically qualified personnel, irrigation and sanitary engineers and medical zoologists will be required.

To carry out control measures effectively against bilharziasis, however, many less highly qualified staff must be trained to perform the various operations involved. The required skills are not very specialized. In addition to qualified and experienced direction at professional levels, two kinds of personnel are necessary: laboratory technicians, and field workers. These must be able to collect snails, carry out simple mapping procedures, collect and examine faecal and urine samples from the population, and apply the control measures devised.

Anti-malaria personnel are often able to transfer to this work with relatively little additional training, and can be used if available.

It should be emphasized that reliability and perseverance are more valuable qualities, particularly in field workers, than a high degree of skill or intelligence.

Training of personnel is a continuous process. Apart from the need for expansion there is always wastage ; but, provided that an initial cadre of trained individuals can be established, this can be done on the job and need present little difficulty or additional expense.