Trends and Perspectives
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1. Focus attention on developing and growing topics in parasitology.
2. Identify new and old problems in need of research.
3. Explain how results from one area of biology might have some bearing on current studies in parasitology.
4. Present teachers and students with concise summaries of recent discoveries and new theories.

None of the articles will take the form of a detailed historical survey of the literature. In seeking contributions for the series, the editors have urged authors to present clear and stimulating personal points of view about those topics which have excited their curiosity and imagination. The editors hope that a wide readership will gain enjoyment and benefit from this enterprise.
Caribbean schistosomiasis

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INTRODUCTION

Caribbean-based research on schistosomiasis made a significant contribution to the early development of the understanding of this disease. A report by Patrick Manson in 1902 of the presence of lateral-spined schistosome eggs in the faeces of a patient from Antigua, lead to the first confirmation of endemic schistosomiasis in the Western Hemisphere and, indirectly, to the taxonomic separation of Schistosoma mansoni and S. haematobium (Sambon, 1907; Leiper, 1918).

More recently, the region again achieved international prominence in the study of schistosomiasis through the activities of two research and control groups. The Departments of Health of Puerto Rico and the United States initiated pilot control programmes in Puerto Rico in 1953, and the Research and Control Department of the Ministry of Health, St Lucia, began activities supported by the Rockefeller Foundation, MRC (UK) and the Government of St Lucia in 1965.

The successes achieved by these groups in the control of schistosomiasis, and in contributing to bio-medical research and control technology, are well known and will not be reviewed here. However, the consequences of this success for a more general perception of Caribbean schistosomiasis are central to the theme of this article.

The termination, or severe curtailment, of control activity in St Lucia and Puerto Rico has been viewed as an indication that schistosomiasis is no longer of regional significance. This perspective is based on the fundamental misconception that successful control in some countries is equivalent to control in the region.

The reality is very different. The status of the disease in some areas is undescribed and factors relevant to transmission and control, such as the role of alternative intermediate hosts and the significance of schistosomiasis as a zoonosis, have not been adequately quantified. The majority of endemic countries have not implemented comprehensive control measures, and the legatees of successful control have to cope with maintenance technology which is largely inappropriate to their resources. Even those countries from which the disease is currently absent cannot be isolated from the regional significance of schistosomiasis, since, in the absence of preventative measures, the persistence of infection poses a real threat of introduction.

The aim of this article is to examine the perception of schistosomiasis as a regional problem requiring regional solutions. First, by reviewing the current status of schistosomiasis, its intermediate hosts, and its control throughout the region, with particular emphasis being given to those countries on which information is least accessible. Second, by indicating those subject areas on which new information is required. Third, by examining the future prospects for control.
Table 1. Socio-economic and demographic data on the Caribbean region (1979)

(USA data included for comparison. Sources: Commonwealth Secretariat Basic Statistical Data on Selected Countries with Populations less than $5 \times 10^6$ (1981) and World Bank Gross National Product, Population and Growth Rates (1981).)

| Country               | Gross National Product/capita/annum US$ (market prices) | Land area (km$^2$) | Population density persons/km$^2$ |
|-----------------------|--------------------------------------------------------|--------------------|----------------------------------|
| Antigua-Barbuda       | 1150                                                   | 440                | 168                              |
| Bahamas               | 2770                                                   | 13938*             | 17                               |
| Barbados              | 2680                                                   | 430                | 557                              |
| Belize                | 980                                                    | 22965              | 6                                |
| Cuba                  | N.A.                                                   | 114525             | 85                               |
| Dominica              | 580                                                    | 750                | 109                              |
| Dominican Republic    | 1030                                                   | 48442              | 109                              |
| French Guyane         | 2690                                                   | 90000              | 0.7                              |
| Grenada               | 650                                                    | 344                | 317                              |
| Guadeloupe            | 3740                                                   | 1779               | 184                              |
| Guyana                | 650                                                    | 214970             | 4                                |
| Haiti                 | 250                                                    | 27750              | 177                              |
| Jamaica               | 1110                                                   | 11424              | 189                              |
| Martinique            | 4150                                                   | 1110               | 292                              |
| Montserrat            | 1310                                                   | 85                 | 129                              |
| Netherlands Antilles  | 3830                                                   | 1010               | 249                              |
| Puerto Rico           | 2840                                                   | 8891               | 399                              |
| St Kitts-Nevis        | 820                                                    | 310                | 161                              |
| St Lucia              | 840                                                    | 616                | 198                              |
| St Vincent            | 480                                                    | 389                | 272                              |
| Suriname              | 2480                                                   | 162000             | 2                                |
| Trinidad and Tobago   | 3910                                                   | 5128               | 224                              |
| Virgin Islands        | 5370                                                   | 500†               | 210                              |
| USA                   | 10610                                                  | 9160454            | 24                               |

* Includes uninhabited islands.
† Major inhabited islands only.
N.A., Not available.

For the purposes of this article the Caribbean region is considered as: all the islands in the Caribbean Sea and those adjoining mainland areas which are politically, historically and culturally associated with the islands (i.e. Belize and the Guyanas). This partly artificial division excludes two continental Latin-American countries, Brazil and Venezuela, with endemic schistosomiasis.

The Caribbean region, as defined above, includes several hundred islands divided among more than 20 governing units. The region has a complex political and cultural history which has resulted in intra-regional heterogeneity of ethnic origins and cultural alliances. This heterogeneity extends to economic and demographic variation between countries: the Gross National Product in 1979 ranged from more than US $5000 to less than US $250 per capita; the population of some countries is less than $10^6$ whilst in others it approaches $10^7$; the national population density ranges from 0.7 to 557 persons/km$^2$ (Table 1). Standards of sanitation, domestic water supplies and health delivery services reflect this heterogeneity in socio-economic development.
THE CURRENT DISTRIBUTION OF SCHISTOSOMIASIS

Examination of the published literature indicates that although schistosomiasis is currently endemic in 8 (historically 10) Caribbean countries, 80% of the bibliography is concerned only with St Lucia and Puerto Rico. This section attempts to give a more balanced overview of the status of the disease in the region.

Localities at which transmission has ceased

Infection was last recorded in the French half of the tiny Netherlands/French island of St Maarten/St Martin (95 km²) in 1929 (Hoffman, 1929). A recent survey of the island showed that no snail habitats remain; even in the wettest areas surface water persists for only a few days following heavy rain (Prentice, 1980). Construction programmes, involving major deforestation, appear to have caused hydrological changes affecting areas of standing water. Hydrological changes were also associated with the interruption of transmission in the neighbouring island of St Kitts (Ferguson, Richards, Sebastian & Buchanan, 1960). A scheme introduced in the 1940s to provide domestic water supplies diverted natural mountain streams and destroyed snail habitats in the low-lying areas. The last clinical cases were seen in 1955 (Health Department Annual Reports, 1956–66) although uninfected Biomphalaria glabrata persist in two isolated foci (Prentice, 1980).

The resort island of Vieques off Puerto Rico is the only Caribbean site of successful, deliberate eradication of schistosomiasis from an entire island (Ferguson, Palmer & Jobin, 1968). The Puerto Rico Health Department, with technical assistance from the U.S. Public Health Service, initiated an eradication programme in 1954. Using a combination of mollusciciding (sodium pentachlorophenate) and mass chemotherapy (sodium antimony tartrate), interruption of transmission to children was achieved by 1962. The island remains schistosomiasis-free although B. glabrata persists.

The Leeward Islands

The three islands on which transmission has ceased are of limited land area (< 200 km²) and consequently offered a very limited number of suitable snail habitats. The fragility of their aquatic ecosystems appears to have been a major pre-disposing factor to the interruption of transmission in the two incidental cases. Two other islands, Antigua and Montserrat, in which infection is currently hypo-endemic are also small (280 and 85 km², respectively) and favoured with few natural snail habitats. The prognosis for control in these two countries would appear to be good.

Water impoundment projects in Antigua, with concomitant improvements in sanitation and protection of water supplies, have already reduced the incidence of schistosomiasis but have also provided B. glabrata with new artificial habitats (Prentice, 1980). A serological (ELISA) and coprological (modified Ritchie) survey revealed a 10% (n = 303) prevalence of infection, the youngest positive case being 12 years old (Tikasingh, 1982). Montserrat has the distinction of being the most recently recognized Caribbean focus of schistosomiasis, the first case being
identified when a returning visitor was examined at the Hospital for Tropical Diseases in London in 1968. A seroprevalence of 11% (n = 317) was recently reported from two communities, each associated with a separate watershed (Tikasingh, Wooding, Long, Lee & Edwards, 1980; Tikasingh, 1982). Two individuals under 15 years old were positive. *B. glabrata* appears to be rare outside of the two identified foci (Pointier, 1975; Prentice, 1980).

The remaining countries with endemic schistosomiasis are appreciably larger, ranging in land area from St Lucia’s 614 km² to the 48442 km² of the Dominican Republic.

**St Lucia**

The first indigenous case of schistosomiasis in St Lucia was recognized in 1925, and for 30 years all subsequent cases were similarly confined to the Soufriere Valley area, although *B. glabrata* occurred throughout the island (Vintner, 1964). This case distribution suggests that at the beginning of this century schistosomiasis in St Lucia was hypo-endemic at a single locus, a supposition supported by the results of the 1914–24 Rockefeller Foundation hookworm control campaign which detected no schistosome eggs in 100000 stool examinations island-wide (Prentice, 1980). By 1960, however, cases were identified throughout the island, a distribution attributed to the dispersion of infected people from Soufriere when that town was razed by fire in 1956 (Wells, 1964). In recent years the broad alluvial valleys lying between the rugged volcanic mountains have become important transmission foci. These valleys are the major cultivation sites for bananas, the single most important export, and have permanent natural river systems associated with banana root drainage channels. The latter may form extensive networks (800 km of drains in Cul-de-Sac Valley alone) and provide ideal artificial habitats for the dissemination and persistence of *B. glabrata* (Sturrock, Barnish & Upatham, 1974). Being flat areas in an essentially mountainous country, the valleys have become densely populated with consequently intensive domestic and recreational use of local water courses. In 1965 a schistosomiasis control programme was initiated by the St Lucian government and the Rockefeller Foundation, with financial assistance from the Medical Research Council of the United Kingdom. Under the Directorship of Dr Pip Jordan, the Research and Control Department (Ministry of Health, St Lucia) adopted an innovative approach in simultaneously pursuing both the goals implicit in its title. Instead of establishing a single national control protocol, a sufficiently daunting task at a time when applied control methodology was still in its infancy, a variety of control strategies was implemented in ecologically isolated watersheds throughout the island. An emulsifiable concentrate of 25% niclosamide (Bayluscide: Farbenfabriken Bayer AG, West Germany) was applied first as an area-wide molluscicide and later as a focal treatment in the Cul-de-Sac Valley (Sturrock, 1973a, b; Sturrock et al. 1974). Surveillance of transmission was achieved in part using a locally developed sentinel-snail technique (Upatham, 1972). Over a 4-year period the incidence of infection in 1 to 10-year-old children fell from 22 to 4·3% in treated areas but remained at 20% in a comparison area (Jordan, 1977; Jordan, Barnish, Bartholomew, Grist & Christie, 1978). In a 1 to 14-year-old cohort the prevalence fell from 34 to 23%, but rose from 39 to 62% in a cohort from the comparison area. Similar results were obtained in Riche Fond Valley where
protected domestic water supplies were provided to the majority of dwellings (Unrau, 1975). Over a 5-year period incidence fell from 31 to 12% for a 1 to 10-year-old population and, although prevalence in the 1 to 14-year-old cohort was only minimally reduced from 47 to 42%, it did not show the substantial rise from 39 to 62% recorded in the comparison cohort (Jordan, Woodstock, Unrau & Cook, 1975; Jordan, Bartholomew, Unrau, Upatham, Grist & Christie, 1978). Hycanthone (2.5 mg/kg) was offered to all infected persons in the Marquis Valley, and over a 2-year period the incidence of infection fell from 18.8 to 4.1% in a 1 to 10-year-old age group from a high transmission-rate area (Cook, Woodstock & Jordan, 1974; Jordan, 1977). The comparative design of this ‘experimental valley’ approach, not only fulfilled the control objectives of the programme but also contributed materially to fundamental knowledge of schistosomiasis control. The extent of this research contribution is reflected in the more than 200 scientific articles published during the Department’s 15-year life, although the phenomenal industry of the small group of resident workers is perhaps more fairly represented by the 14 volumes of internal reports. These findings were used to select appropriate strategies for control throughout St Lucia and, when the Department closed in 1981, the risk of disease was considered minimal and prevalence at traditional foci was less than 2% (Fourteenth Report, R & C Department, Ministry of Health, St Lucia, 1981). The recrudescence of transmission remains a permanent threat, and the maintenance of control is the continuing responsibility of the Government of St Lucia.

**Guadeloupe and Martinique**

*S. mansoni* occurs in only two other Lesser Antillean islands of comparable size to St Lucia: Guadeloupe and Martinique. These French overseas Departments, together with the schistosomiasis-free dependencies of Marie Galante, St Barthélemy, St Martin and La Désirade, comprise the French Antilles.

Guadeloupe comprises two closely apposed, but topographically and geologically distinct islands separated by a tidal causeway. The Northeastern island of Grande Terre is low-lying and coralline while Basse-Terre in the Southeast is mountainous and volcanic. *B. glabrata* occurs commonly throughout both islands but schistosomiasis transmission is highly focal in the former and ubiquitous in the latter (Deschiens, Lamy & Mauze, 1953; Courmes, Audebaud & Fauran, 1964). The distribution of infection appears to reflect the differing accessibility of snail biotopes to the human population (Golvan, Houin, Combes & Lancastre, 1977). Grande Terre has few permanent snail habitats due to a lack of rainfall and the porosity of its coralline substratum (Pointier & Combes, 1976). *B. glabrata* becomes seasonally abundant in artificial ponds and regions of littoral hyposaline mangrove swamps when diluted by rainwater run-off (Pointer, Salvat, Deplanque & Golvan, 1977; Pointier & Théron, 1979). Neither habitat is closely associated with human habitation although the latter may provide a suitable environment for rodent reservoir hosts (see below). In Basse-Terre *B. glabrata* is present in high altitude streams and ponds feeding the extensive river system, but is rarely found in the broad mature rivers which flow through inhabited areas (Rioux *et al.* 1977). In these regions the snails inhabit an extensive network of ancient canals, flumes and channels – some dating back to the 18th Century – which was built to power the
water mills of the sugar industry. Increased use of these waterways in recent years for domestic and irrigation purposes has resulted in increased human contact, and these areas now appear to be the main foci for *S. mansoni* transmission (Golvan et al. 1977).

During the period 1977–1980 coprological (modified Ritchie and Kato techniques) and serological (IFAT) surveys were conducted of both islands (Ancelle, Foulon & Ancelle, 1980). The results showed that 4% of the total population were excreting *S. mansoni* eggs and 25% were seropositive. The distribution of cases follows the established patterns, with infections occurring throughout both islands, but most commonly in the canalized regions of Basse-Terre. In one of the latter districts 36% of children under 9 years old were infected. These findings confirm that active foci of schistosomiasis transmission persist in Guadeloupe.

Schistosomiasis was first recognized in Martinique at the beginning of the 20th Century (Letulle, 1904; Lahille, 1906). Irrigation ditches and natural streams in the low-lying coastal regions of this mountainous, volcanic island have been implicated in transmission (Deschiens, 1951; Tribouley, Tribouley-Duret, Bernard, Apprion & Pautrizel, 1975). During 1977–78 coprological (modified Ritchie and Kato) and serological (IFAT) surveys were conducted throughout the island (Foulon, Villon, Diaz & Derville, 1979). The overall prevalence of infection was 12% as determined by both methods. Prevalence was correlated with the irrigated areas of the North, and occupationally correlated with agriculture. National control programmes have not been initiated but it has been suggested that transmission is naturally declining due to the competitive exclusion of *B. glabrata* by the less susceptible intermediate host, *B. straminea* (Guyard & Pointier, 1979; Pointier, 1982) (see below). Whether or not this is the case, active transmission would appear to be indicated by the prevalence of 6.6% infection in children under 4 years old (Foulon et al. 1979).

**Puerto Rico**

Puerto Rico is the smaller of two Greater Antillean countries in which schistosomiasis is endemic. This associated State of the USA shares with St Lucia the distinction of having successfully controlled schistosomiasis transmission. The socio-economic status of Puerto Rico, however, is very different from that of St Lucia (see Table 1), and appears to have had a major impact on the local ecology of schistosomiasis. When infections were first identified (Gonzalez-Martinez, 1904) they were confined mostly to agricultural workers in sugar cane areas (Faust, 1933), but recent synoptic surveys based on the intradermal-antigen response have failed to show any significant difference between prevalence in rural and urban areas (Kagan, Négron, Arnold & Ferguson, 1966; Ruiz-Tiben, Cox, Clark & Greenberg, 1973). In all other endemic areas of the region, as elsewhere in the developing world, schistosomiasis is predominantly a disease of the rural poor. The higher standard of living in Puerto Rico also has an apparent influence on the pattern of water contact. A water contact survey in 1966 revealed that 51% of exposures were recreational, this proportion rising to 85% in the early 1970s (Jobin & Ruiz-Tiben, 1968; Hiatt, Cline, Ruiz-Tiben, Knight & Berrios-Duran, 1980). This distribution implies a diminishing need to use natural water systems for domestic purposes as household water supplies become generally available. In contrast to other epi-
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demiological features, the geographical distribution of schistosomiasis appears to have remained relatively constant, the infection occurring throughout the island with the highest prevalence in the South East (White, Pimentel & Garcia, 1953; Kagan et al. 1966; Ruiz-Tiben et al. 1973).

Pilot projects were initiated in the municipalities of Guayama and Arroyo, (Jobin, Ferguson & Palmer, 1970), Patillas (Palmer, Colón, Ferguson & Jobin, 1969) and Vieques Island (see above) in 1953. The main strategy in each case involved area-wide mollusciciding with sodium pentachlorophenate (6 mg/l in streams; 10 mg/l in standing water) followed by habitat management. In all the municipalities, stibophen (Faudin) was available in clinics until 1957, when chemotherapy was abandoned because of unacceptable toxicity (Cline, Rymzo, Hiatt, Knight & Berrios-Duran, 1977). In the mainland areas the ampullarid predator snail Marisa cornuarietis was introduced into reservoirs at an approximate density of 0.3 snail/m² in an attempt to control B. glabrata by biological means. Over the 15-year period of control, the prevalence of infection in 6-year-olds from all experimental areas, fell from 10-20% in 1953 to 0-0-6% in 1966 (Jobin et al. 1970). These data are less impressive, however, when comparison is made with the municipality of Caguas in which no specific attempt was made to reduce the incidence of schistosomiasis. Over the same 15-year period, the prevalence in 6-year-olds in Caguas fell from 6-0 to 1-2% (Ferguson et al. 1968). This reduction was attributed to urbanization and economic improvements, with attendant sophistication of water supplies and destruction of intermediate host habitats. The median family income in Caguas was above the national average and higher than in the experimental municipalities (Jobin et al. 1970).

In 1968 an island-wide control programme was initiated, based on the mollusciciding techniques developed in the 15-year, pilot studies (Negrón-Aponte & Jobin, 1979). Recognizing the need for precise evaluation of control procedures, the San Juan Laboratories of the Centre for Disease Control and the Puerto Rico Health Department initiated a prospective community study in the municipality of Boqueron in an highly endemic region of Southeastern Puerto Rico (Hiatt et al. 1980). As a result, 70% wettable niclosamide powder was distributed on an area-wide basis, and the mollusciciding programme supported by canalization, drainage and other forms of habitat management. During the first 5 years of control the prevalence in the study cohort fell from 37 to 34%, although the horizontal age prevalence remained unchanged. Significantly, the incidence of infection fell dramatically from 17 to 1%. These data were interpreted as indicating that transmission within Boqueron had been interrupted, but infection could still be acquired from visits to neighbouring endemic areas and, in the absence of chemotherapy, pre-control infections still persisted due to the longevity of S. mansoni in well-nourished hosts (Hiatt et al. 1980). Whatever the reasons, the results indicate that schistosomiasis persists in Puerto Rico. Intradermal-antigen surveys from 1963 to 1979 have shown a progressive reduction in reactors of 6 to 7-year-olds from 24 to 5% (Negrón-Aponte & Jobin, 1979), but infections in this young age group still occur. Morbidity due to schistosomiasis is vanishingly small; no objective clinical signs were observed in any of the infected individuals during the Boqueron Project (Hiatt et al. 1980), but outbreaks of clinically severe disease still occur sporadically (Hiatt, Sotomayor, Sanchez, Zambrana & Knight, 1979).
The research and control activities in Puerto Rico have contributed to understanding of the nature of schistosomiasis, particularly its clinical and immunological aspects, but one might question the applicability of the control procedures to less economically developed countries of the region.

The Dominican Republic

The Dominican Republic is the only other Greater Antillean focus of schistosomiasis. The country occupies the eastern two-thirds (48,000 km²) of the island of Hispaniola, which it shares with Haiti. Broad alluvial plains are situated in the south-east and, to a lesser extent, north-central regions of the Dominican Republic, while the remainder of the island is dominated by four massifs rising to 3175 m in the Cordillera Central. The sugar-cane areas of the Southeastern plains are the major localities of schistosomiasis transmission.

The first indigenous case of schistosomiasis was recognized in the town of Hato Mayor del Rey in 1942, more than 30 years after identification of the other major Caribbean foci (Ponce Pinedo, 1944). The absence of earlier records, and the apparent uniqueness of the Hato Mayor focus, have led to the conclusion that the infection was of recent introduction. The introduction has been attributed to the immigration of agricultural labourers from Puerto Rico.

A WHO coprological survey of Hato Mayor 10 years after the initial discovery revealed that 21.4% (n = 243) of 5 to 15-year-old children were infected (Olivier, Vaughn & Hendricks, 1952). Infected B. glabrata were detected in the river Pana-Pana where it flowed through the town, although uninfected specimens were present elsewhere in the same watershed. The intermediate host snail at first appeared to be confined to this single, and potentially controllable, water system. Hopes of a rapid eradication programme were confounded, however, by the ominous presence of a single specimen in the unrelated Jagua riverlet. Area-wide mollusciciding control measures were initiated in Hato Mayor in 1953 (Vaughan, Olivier, Hendricks & Mackie, 1954).

By 1972 two additional foci had been identified in the eastern plains of the Dominican Republic (Vargas Castro, 1973). The coprologically determined prevalence of infection was 1.9% in Hato Mayor, 4.9% in El Seibo and 12.2% in Higuey, with substantially higher prevalences revealed by intradermal antigen testing. Control measures were implemented and it is claimed that by 1976 less than 1% of faecal specimens from any focus contained schistosome eggs (Divison Epidemiologia, Santo Domingo, 1973 and 1977).

There are currently 5 foci in which active transmission occurs and at least 20 other regions which have the potential for transmission (Vargas de Gomez, 1981). B. glabrata is present in numerous water systems throughout the south-eastern plains, and in northern and southern central regions (Etges & Maldonado, 1969; Gomes & Vargas de Gomez, 1976; Raccurt, Sodeman, Majon & Boncy, 1982). Surveillance and control programmes are being developed by the Instituto de Investigaciones en Bilharzia (Universidad Autonoma de Santo Domingo) and the Division Epidemiologia (Seccion Salud Publica, Santo Domingo).
Suriname

Suriname, with a land area of 162000 km², is the largest country with endemic schistosomiasis within the area considered by this study. Situated on the northeastern margin of South America between Guyana and French Guyane, Suriname is the only mainland territory considered in this article. Indigenous cases of schistosomiasis were first recognized in the General Hospital of the capital, Paramaribo (Flu, 1911). Over the period 1956–1972 coprological surveys were conducted to determine the extent of infection (van der Kuyp, 1961, 1969, 1979a, b, c).

Suriname is shaped like an irregular rectangle running north to south, with the Atlantic Ocean on its northern margin and sharing its southern border with Brazil. A narrow coastal strip of fluvio-marine alluvial clays is separated by an acid-quartz sand savannah from the lateritic soils of the mountainous interior and hinterland. The coastal strip represents only 10% of the land area but is inhabited by 88% of the population (van der Kuyp, 1979b). Schistosomiasis transmission is normally limited to this coastal region and is specifically confined to a 1200 km² central zone characterized by exposed marine shell deposits – 'shell ridges' – running approximately parallel to the coast (Giglioli, 1964; van der Kuyp, 1961). It is estimated that 130000 people, 35% of the population, are at risk in this region which represents only 0.75% of the total land area. The suitability of this area for schistosomiasis transmission is not a simple function of the presence of aquatic habitats. Suriname is well served with natural water systems, including a number of massive rivers flowing north from the mountainous interior. These waters have a high tannic acid content (pH 5.4 ± 0.5) and poor ion-exchange capacity, which makes them unsuitable as habitats for *B. glabrata* (van der Kuyp, 1961, 1980b, Heinemann, 1971). The shell ridges modify these waters to approximate neutrality (pH 6.9 ± 0.6) and supply free electrolytes, particularly calcium ions, thus providing the only natural habitats for *B. glabrata* in Suriname (van der Kuyp, 1974, 1977a; Heinemann, 1971; Reijenga, 1971). The geology of this area has also contributed to its exploitation as the premier rice growing area since the elevated, well-drained shell ridges are very suitable for housing and road construction adjacent to the fertile alluvial deposits. The rice-fields and peridomiciliary drains and ditches are currently the major foci for schistosomiasis transmission (Heinemann, 1971; Reijenga, 1971; van der Kuyp, 1980a, b).

Human agency has also modified the distribution of schistosomiasis in Suriname. In the absence of gravel deposits, roads outside the shell ridge area are often surfaced with pulverized shell material. The run-off from these roads modified the adjacent water bodies into suitable habitats for *B. glabrata* (van der Kuyp, 1979b). The extent of this influence is indicated by gradients of pH and calcium ion concentration which extend for more than 5 m either side of shell-ridge roads (van der Kuyp, 1980b). Human activity was also implicated in the development of the only transmission focus in the Savannah region. In 1967, infections were identified in the town of Albina, situated on the west bank of the Marowijne River which separates Suriname from French Guyane (van der Kuyp, 1971a, b). Infection was most prevalent in one small area of the town and correlated with proximity to a drainage system containing infected *B. glabrata*. Intermediate host snails were
absent from all other urban waterways and from the Marowijne River which received the drainage effluent. The snail habitats had a higher pH and calcium ion concentration than local natural habitats, and this was attributed to the inflow of soapy, neutral waters from the laundry and kitchens of an adjacent military camp. The higher prevalence of infection in children suggests epidemic, rather than endemic, transmission and supports the assumption that this focus was of recent origin.

The Bureau of Public Health, with technical and financial assistance from the Pan American Health Organisation, has been engaged in control activities since 1972. Selective chemotherapy, based on coprological case detection, has substantially reduced the prevalence of infection, as has the introduction of mechanization of rice culture (personal communication: Dr E. Caldeira-Comvalius, Director Schistosomiasis Control Programme, Bureau voor Openbare Gezonheidszorg, Paramaribo, Suriname). Active transmission still occurs, however, and the cost of maintenance control by chemotherapy cannot be reduced below the substantial cost of case detection.

**INTERMEDIATE HOST STATUS**

*Biomphalaria glabrata* is the major intermediate host of *S. mansoni* in the Caribbean region. Two other species of this genus, *B. straminea* and *B. havanensis*, have been shown to be at least partially susceptible to infection with *S. mansoni* in Brazil, Haiti, Grenada and Martinique (Rodrick & Paraense, 1981; Michelson, 1976; Paraense, 1975; Richards, 1973). Unfortunately, the taxonomy of these planorbid snails is confused and there appears to be doubt as to which of the latter two species is actually susceptible (Malek, 1969, 1975).

The effect of shell-ridges on the distribution of snail habitats in Suriname has already been described, and it appears that the distribution of *B. glabrata* in other mainland areas of the Caribbean is similarly governed by the availability of qualitatively suitable aquatic habitats. Perhaps the most obvious parallel is found in Venezuela, where *B. glabrata* is confined to the Costa-Cordillera region of limestone outcappings (Giglioli, 1964). In French Guyane and Guyana the lateritic soils ensure that the natural water systems have a mean pH of 5-7 and are free of *Biomphalaria* spp. The roadside drains of the suburbs of Cayenne, the capital of French Guyane, have an elevated pH of 8-1 due to the buffering effects of municipal effluents and these drains provide an artificial habitat in which *B. glabrata* thrives (Floch & Fauran, 1957; Sturrock & Sturrock, 1970).

Whereas the mainland distribution appears to be determined by the limited availability of suitable habitats, the Caribbean islands appear to be homogeneously suitable for colonization by *Biomphalaria* spp. The current discontinuous distribution of *B. glabrata* in the islands is perhaps a function of both land movement and snail dispersion (Prentice, 1980). It is apparent from Table 2 that this species has been reported from 17 island localities but that schistosomiasis is endemic in only 7. This imperfect correlation may be attributed to 4 separate causal factors. (1) The spontaneous cessation of transmission at formerly endemic foci. The incidental interruption of transmission by hydrological changes in St Kitts and St Martin has already been discussed. (2) The deliberate interruption of transmission
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by control programmes at formerly endemic foci. This has occurred only in Vieques, an island municipality of Puerto Rico (Ferguson et al. 1968). (3) The absence of transmission in established intermediate host populations. There are 5 localities in which snail populations have persisted for some years without becoming involved in schistosomiasis transmission. In each case these localities are small (< 150 km²) islands with a notable lack of permanent natural water systems. B. glabrata was deliberately introduced into Curacao as an aquarium specimen in 1941, and 8 years later was established in plantation reservoirs and similarly isolated water impoundments (van der Kuyp, 1949). The record from Aruba refers to a single aquarium population, presumably acquired from Curacao, and the snail may never have become established in open water systems. The snail habitats in Désirade, Marie-Glante and St Maarten are few and transient, and probably offer little opportunity for the simultaneous combination of all ecological factors required for transmission. (4) The absence of transmission in recently introduced snail populations. There are two localities which appear to have been recently colonized by B. glabrata. In both cases it appears inevitable that transmission will occur as the snail populations spread into epidemiologically suitable habitats. A biological survey by the Smithsonian Institution in 1964 first reported the presence of B. glabrata in Dominica. At that time, the snail was confined to ornamental ponds around the capital, Roseau, having presumably been recently introduced in imported aquatic vegetation. Surveys during 1972-78 have documented the subsequent spread of the snail, via fish-culture ponds, to at least two natural water systems of the Roseau Valley (Prentice, 1980). B. glabrata is also assumed to be a recent colonizer of Haiti since it is confined to a few adjacent foci in the Plaine du Nord and the Port-Margot river valley (Robart, Mandahl-Barth & Ripert, 1976; Racourt et al. 1982). The snail is assumed to have entered Haiti from the Dominican Republic via the rift valley between the Cordillera del Norte and the Massif Central.

This analysis offers little comfort to those concerned with schistosomiasis control in the Caribbean region. It would appear that wherever B. glabrata has become established in an area offering suitable habitats, schistosomiasis transmission has inevitably followed. Furthermore, the snail is continuing to colonize new areas of the Caribbean.

It is apparent from Table 2 that whilst B. glabrata is the most important snail host for S. mansoni in the Caribbean, other species may be involved. In Martinique, for example, both B. glabrata and B. straminea may act as intermediate hosts. The occurrence of both species in the same island is unique and has resulted in a controversy as to their relative importance in transmission.

B. glabrata was first reported in Martinique in 1899 when it was present in a single pond in the botanical gardens of the capital, Fort-au-France, presumably having been introduced with ornamental aquatic vegetation (Bordaz, 1899). Surveys in 1953 and 1967 showed the snail to be present in more than 30 localities around Fort-au-France (Dreyfuss, 1953; Gretillat, 1967). In contrast, extensive surveys, between 1972 and 1978 reported snails from only 4 habitats and, although these were widely distributed throughout the island, none of them was adjacent to the capital (Guyard & Pointier, 1979). By 1980 1 of the 4 foci had died out and a new focus was identified in a different region (Guyard, Pointier, Théron & Gilles, 1982).
Table 2. Distribution in the Caribbean islands of Schistosomiasis and intermediate host snail species

(With the exception of the records from the Netherland Antilles all island strains of Biomphalaria glabrata are of demonstrated susceptibility to local strains of Schistosoma mansoni. Confusion exists concerning the taxonomic separation of B. straminea and B. havanensis. Specimens of proven susceptibility to S. mansoni infection are indicated (†).)

| Locality               | B.g. | B.s. | B.h. | Infection status | Source                                      |
|------------------------|------|------|------|------------------|---------------------------------------------|
| Anguilla               | -†   | -    | -    | -                | Prentice (1980)                             |
| Antigua                | +    | -    | -    | +                | Prentice (1980)                             |
| Bahamas                | -    | -    | -    | -                | -                                           |
| Barbados               | -    | -    | -    | -                | -                                           |
| Barbuda                | -    | -    | -    | -                | -                                           |
| Cuba                   | -    | -    | +    | -                | Aguayo & Jaume (1947)                        |
| Dominica               | +    | -    | +    | +                | Smithsonian Institution                      |
| Dominican Republic     | +    | -    | +    | +                | Biological Survey (1964)                     |
| French Antilles        |      |      |      |                  | Vargas de Gomez (1981); Raccurt et al. (1982) |
| Desirade               | +    | -    | -    | -                | Courmes et al. (1964)                       |
| Guadeloupe             | +    | -    | -    | +                | Deschiefs et al. (1953); Pointier et al. (1977) |
| Marie-Galante          | +    | -    | -    | -                | Tribouley et al. (1975)                      |
| Martinique             | +    | +†   | -    | +                | Guyard & Pointier (1979)                     |
| St Barthelemy          | -    | -    | -    | -                | -                                           |
| St Martin              | F+   | -    | -    | F+               | -                                           |
Table 2. (cont.)

| Location               | - | +† | + | - |
|------------------------|---|----|---|---|
| Grenada                |   |    |   | Richards (1973) |
|                        |   |    |   | Malek (1975)    |
| Haiti                  | + | -  | +†| - |
| Jamaica                | - | -  | - | Malek (1969)    |
| Montserrat             | + | -  | - | Pointier (1975) |
|                        |   |    |   | Prentice (1980) |
| Netherland Antilles    |   |    |   | van der Kuyp (1949, 1951) |
| Aruba                  | + | -  | - |   |
| Bonaire                | - | -  | - |   |
| Curaçao                | + | -  | - |   |
| Saba                   | - | -  | - |   |
| St Eustatius           | - | -  | - |   |
| St Maarten             | F+| -  | - |   |
| Puerto Rico            | + | -  | - | Ferguson (1968) |
|                        |   |    |   | Malek (1969)    |
| Vieques                | + | -  | - | Ferguson et al. (1968) |
| St Kitts               | + | -  | - | Ferguson (1960) |
| St Lucia               | + | -  | - | Jordan (1977)   |
| St Vincent             | - | -  | - | Prentice (1980) |
| Trinidad and Tobago    | - | +  | - | Sturrock & Sturrock (1970) |
| Virgin Islands         | - | -  | - |   |

* B.g., Biomphalaria glabrata; B.s., B. straminea; B.h., B. havanensis.
† - , Absent; +, present; F+, formerly present.
This sequence of records might be interpreted as describing the dispersion of *B. glabrata* throughout the island from a single original focus, with the subsequent disappearance of the snail from the majority of localities. The chronology of this dispersion seems highly improbable, however, since the expansion and demise of the snail population would have had to occur during the 5 years from 1967 to 1972. The history of *B. straminea* in Martinique is no less enigmatic. This species was not recognized during the extensive surveys of 1953 and 1967 (Dreyfuss, 1953; Gretillat, 1967), but was first identified by Upatham and Guyard in 1973 (Guyard *et al.* 1982). Surveys during 1972–80 described the snail as very abundant in 57 different localities throughout the island (Guyard & Pointier, 1979; Guyard *et al.* 1982). These reports imply that the snail was rare or absent 16 years ago and then underwent an explosive population expansion.

It has been suggested (Guyard & Pointier, 1979; Guyard *et al.* 1982) that the pattern of distribution becomes more understandable if one assumes that two misidentifications were made during the early surveys. Firstly, that the *B. glabrata* around Fort-au-France (Dreyfuss, 1953; Gretillat, 1967) were actually large *B. straminea* or *Heliosoma*. Secondly, that Gretillat's, *B. havanensis* and *B. peregrina* were *B. straminea*. The assumptions permit the dispersion of both *B. glabrata* and *B. straminea* to occur over the last 80 years. *B. straminea* is further assumed to have competitively displaced its congeneric by more effective exploitation of temporary habitats, as has been described in some regions of Brazil (Barbosa, 1973).

In the present context, the importance of this inter-specific interaction is in terms of its influence on *S. mansoni* transmission. Infected *B. glabrata* were last found in Martinique in 1972, and were confined to a single habitat (Guyard & Pointier, 1979). Cercariaometry, using the method of Théron (1979) indicated the presence of schistosome cercariae in a single habitat containing both snail species in 1980 (Guyard *et al.* 1982). Cercariae were not detected in habitats occupied by *B. straminea* alone, and attempts to artificially infect this species with the local strain of parasite have been unsuccessful (Guyard & Pointier, 1979). Naturally infected *B. straminea* have only once been found in Martinique (Paraense, 1975).

In Brazil, *B. straminea* is unusually sensitive to parasite strain differences (Barbosa & Figueiredo, 1970). This has lead to the suggestion that the snail from Martinique is largely refractory to the local strain of parasite and that transmission has been interrupted for several years (Guyard *et al.* 1982; Pointier, 1982).

However, a coprological survey of the island in 1977–78 revealed a prevalence of 6.5% in children under 4 years of age, which suggests that infection was acquired after 1973 when *B. glabrata* was already extremely rare (Foulon *et al.* 1979). Furthermore, a high prevalence of schistosomiasis was found in many areas from which *B. glabrata* has been absent since at least 1972, and probably for much longer. If, as seems probable, *B. glabrata* was already rare 20 years ago it is difficult to explain the persistence of schistosomiasis, without implicating *B. straminea* in transmission.

The difficulty in finding naturally infected intermediate host snails does not necessarily imply the absence of transmission. In some areas of Brazil where *S. mansoni* is indisputably endemic and *B. straminea* is the only possible intermediate host, extensive and repeated surveys have failed to discover a single infected
mollusc (Dr Gary Rodrick, Department of Comprehensive Medicine, University of South Florida: personal communication).

Theoretical studies indicate that where infection is associated with high mortality rates in intermediate host populations, transmission may still persist although prevalence will be low (May & Anderson, 1978). Juvenile *B. straminea* from Grenada die rapidly after infection with *S. mansoni* from St Lucia (Richards, 1973).

It may be concluded that although *B. glabrata* is the most important species involved in the transmission of *S. mansoni* in the Caribbean, the potential of *B. straminea*, or *B. havenensis*, should not be ignored. Nor should the threat of introduction of other susceptible snail species.

In 1982, *B. tenagophila* was found in an ornamental pond in the botanical gardens of Kingstown, the capital of St Vincent, an island currently free of schistosomiasis (Guyard *et al.* 1982). This snail has been shown to be susceptible to several Brazilian strains of *S. mansoni* (Perez, Hyakutake, Areas & Filho, 1975; Toledo *et al.* 1976). This may be the prelude to the establishment of a new caribbean intermediate host of *S. mansoni*.

**ZOONOTIC SIGNIFICANCE**

Schistosomiasis mansoni is not generally considered to be a zoonosis and, until recently, the Caribbean records of infection in animals other than man tended to support this conclusion. For example, examination of the feral population of African Green Monkeys, *Cercopithecus sabeus*, in St Kitts revealed infections with *S. mansoni* (Cameron, 1928). After the natural abatement of schistosomiasis transmission to humans, however, primate infection was no longer observed although the animals were shown experimentally to still be susceptible (Ritchie, Knight, Oliver-Gonzalez, Frick, Morris & Croker, 1967). This pattern suggests that the paradoxical occurrence of infection in neotropical catarrhyne primates was dependent on the persistence of human infection. The occurrence of schistosome infections in rodents, edentates, primates and marsupials in Suriname was considered to have similar incidental status (Rijpstra & Swellengrebel, 1962; Swellengrebel & Rijpstra, 1965; Heinemann, 1971).

The assumption that only humans were important in Caribbean schistosomiasis transmission had to be re-examined when in 1975 two research groups simultaneously reported that murine schistosomiasis occurred naturally in Guadeloupe (Combes, Léger & Golvan, 1975a; Nassi, Lancastre & Poirot, 1975). The occurrence of reservoir hosts has obvious implications for the epidemiology of human infections, and for the success of control programmes. Because of the novelty and potential significance of this finding the published evidence will be examined in detail.

*Rattus* has always been considered a poor host for *S. mansoni* and various strains of *Mus* are preferred as laboratory hosts. The first question to be considered, therefore, is whether the guadeloupean host–parasite complex differs in compatibility from previously examined systems.

In an attempt to examine the relative specificity of this relationship a trial compared the courses of infections with 1000 cercariae of *S. mansoni* in local *R. rattus* with that in Wistar rats (Jourdane, 1978; Jourdane & Imbert-Establet,
At 4 weeks post-infection the percentage recovery rate of hepatic adults versus initial cercarial exposure was 8–13% in the Wistar rats and 28–37% in R. rattus. This difference has been interpreted as indicating significant variation between the compatibility of the two hosts. Examination of work on other strains of S. mansoni, indicates that these survival values fall within a typical range for this host–parasite system: 10–12% in Sprague–Dawley Rats (Smithers & Terry, 1965; Knopf, Nutman & Reasoner, 1977); 16–34% in inbred Lewis rats and 0–16% in Shermans (Maddison, Norman, Geiger & Kagan, 1970; Maddison, Geiger, Botero & Kagan, 1970).

Furthermore, the validity of this comparison is questionable since it does not compare susceptibility between host strains but between host species, the laboratory rats having been bred originally from R. norvegicus. Field observations in Guadeloupe have indicated that the susceptibility is species-dependent; in a prevalence study at 4 endemic foci 37% (n = 896) of R. rattus were infected but only 22% (n = 117) of R. norvegicus (Combes & Delattre, 1981). Susceptibility trials on laboratory rats should properly be compared with feral R. norvegicus.

Despite the inherent faults in the susceptibility trials they do provide some evidence that the course of infection in guadeloupean rats differs from that in laboratory congenerics. Of the adults recovered from wild rats at 20 weeks post-infection 80–90% were found in the pulmonary arteries (Jourdane, 1978; Imbert-Establet, 1980). This ‘lung shift’, has been induced in various strains of laboratory mice – Manor-Swiss, Carworth Farms and Clark’s strain 051 – infected with Puerto Rican or Egyptian strains of S. mansoni (Geake, 1962; Dickerson, 1965; Hewitt & Gill, 1960). In these mice the shift occurs in response to anthelminthics and usually results in worm pair-separation and death (Hewitt & Gill, 1960), whereas in the rats the lung shift is spontaneous and the fecund adults remain in copula.

The route and purpose of this lung migration are both enigmatic. In mice the successful anthelminthic induction of a shift is age dependent, achieving maximum efficiency at 8–10 weeks of age (Geake, 1962). This age corresponds with the development of extra-hepatic collaterals, which may provide a route for the passive migration of adult worms debilitated by anthelminthics. In an elegant experiment, Warren (1962) induced precocious lung shift by the premature surgical connexion of mouse collaterals.

In summary, it appears that the anthelminthic-induced lung shift in mice represents the passive migration of dead or dying adult worms from the hepatic to the pulmonary circulation. It is possible that the lung shift in guadeloupean rats also results from pathological change which makes the hepato-mesenteric site untenable and causes the worms to move passively to the lungs. Jourdane & Imbert-Establet (1980) have suggested that ‘les poumons représentent pour les Schistosomes un milieu privilégié’, although it is difficult to envisage any mechanism for this protection.

Taken together, these studies indicate that there may be some fundamental features which are specific to the course of murine schistosomiasis in Guadeloupe, but the relevance of these features to the epidemiology of transmission is difficult to assess. The adult worms apparently begin to move from the gut mesenteric site at 6 weeks after infection, and 6 weeks later are almost exclusively found in the pulmonary circulation (Jourdane & Imbert-Establet, 1980). It is improbable that
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eggs deposited by ovogenic adults at the pulmonary site could escape without death of the host, and it is likely that infected rats shed eggs into the environment for a very short period after infection. This temporal restriction on patency brings into question the ability of rats to sustain an enzootic focus of *S. mansoni*, and leads us to examine the ecological evidence for the persistence of murine schistosomiasis in Guadeloupe.

There appear to be two epidemiological situations in which murine schistosomiasis figures in Guadeloupe (Combes & Delattre, 1981). Firstly, the standing waters of isolated upland lakes and freshwater mangrove swamps contain infected *B. glabrata* throughout the year and yet are rarely visited and are unassociated with human habitation (Combes, Leger & Golvan, 1975a, b). In these areas both *R. rattus* and *R. norvegicus* are commonly infected and are believed to maintain the life-cycle of *S. mansoni* independent of human intervention (Golvan & Combes, 1978). The rats have been observed to enter shallow water and actively predate fish and *B. glabrata*, presumably exposing themselves to infection in the process (Combes & Delattre, 1978). Secondly, infected rats have been shown to coexist with infected humans in villages along the banks of rivers (Rioux *et al.* 1977; Theron, Pointier & Combes, 1978). In a survey of the Beaugendre River Valley rats were found to be present throughout the area but were only infected downstream of the habitations of infected humans. This implies that the rats were infected via a human-mollusc-rat route and that infection of humans by the reverse route did not occur. This field observation is supported by experimental evidence that rats are equally susceptible to *S. mansoni* of human and murine origin (Combes & Imbert-Establet, 1980).

In neither of these epidemiological situations do rats have a major impact on human schistosomiasis. In the first, the cycle appears to be entirely enzootic; there is a minimal risk of human infection by cercariae flowing out of upland lakes and into irrigation canals (Combes *et al.* 1975a, b). In the second, the rats seem to be more at risk from infected humans than vice versa, although the rat infections may serve to enhance the local parasite population. The real significance of murine schistosomiasis is not in its current impact on human schistosomiasis transmission but its potential for confounding control efforts. In flowing-water habitats the eradication of human infection might lead to the eradication of associated murine infections (Combes & DeLattre, 1981). This would, however, have no effect on standing-water habitats where rat-maintained *S. mansoni* populations could persist. No control programme has yet achieved eradication of the snail and so the presence of, albeit isolated, murine foci of *S. mansoni* would present a permanent threat of the recrudescence of human infection.

The potential threat of murine schistosomiasis has tended to be regarded as a peculiarly guadaloupean problem with little relevance for control programmes elsewhere. In Brazil, for example, murine schistosomiasis is apparently host specific and parallels rather than potentiates the transmission of human infection (Bastos, Magalhaes, Rangel & Piedrabuena, 1978). However, Nelson, Teesdale & Highton (1962), in an extensive review of the role of animals as reservoirs of schistosomiasis in Africa, showed remarkable prescience in cautioning that we should not be too sanguine about the apparent rarity of murine-maintained cycles: 'The low natural infection rates recorded by Kuntz and his co-workers in Egypt, by Schwetz in the Congo, by Pitchford in South Africa and by ourselves in Kenya...
at first suggest that rodents are of no importance as reservoirs. But we have not yet examined sufficient numbers of the more inaccessible semi-aquatic rodents... it is possible that *S. mansoni* may exist in isolated foci where transmission is maintained in rodents or other animals'.

**FUTURE PROSPECTS**

Control policies and programmes in the Caribbean region have tended to be developed separately and independently, with the aim of reducing incidence in individual countries rather than developing integrated control throughout the region. In order to develop an overall policy for the region, equal consideration should be given to the following three aspects of control: (1) comprehensive control to reduce incidence in endemic countries; (2) long-term maintenance control in countries with low-grade transmission and (3) prevention of introduction to non-endemic areas. This section examines the prospects for achieving this tripartite aim.

The Dominican Republic, Guadeloupe and Suriname have embarked upon, or are about to initiate, comprehensive control. It is probable that at least some of their effort will involve mollusciciding programmes, since these have proven successful in other ecologically similar areas of the Caribbean. Although the technological efficacy of such an approach is indisputable, the appropriateness of these methods to the economic resources of developing countries is less certain. The first 10 years of programmes in Puerto Rico cost between US $0.18 and US $0.69 per capita per annum during the 1950s (Ferguson *et al.* 1968; Palmer *et al.* 1969; Jobin *et al.* 1970). The cost of a comparable programme in St Lucia had risen to US $3.70 per capita per annum by the mid 1970s (Jordan, 1977).

Estimates of annual per capita expenditure on health for selected Caribbean countries in 1979 are shown in Table 3. It is apparent that the majority of countries would be unable to support a national mollusciciding programme from their existing health budgets. The programmes in St Lucia and Puerto Rico both required external financial support and it seems inevitable that any new initiative would place a country in the same recipient role. This has implications for the long-term stability and coordination of control efforts.

Mass chemotherapy is intrinsically less expensive than mollusciciding because it can be integrated into the existing health delivery infrastructure and, therefore, has no additional skilled manpower requirements. In St Lucia the use of drugs was by far the cheapest control method at US $1.10 per capita per annum during the attack phase (Jordan, 1977). The recent development of easily administered anthelmintics of low toxicity and high parasitological cure rate lead Jordan to suggest that 'chemotherapy... holds the key to control in the future'. At present, however, treatment protocols are aimed at the infected individual rather than the infected community, and the development of effective chemotherapeutic control strategies may have to await improved understanding of transmission at the population level (Anderson & May, 1982).

The major disadvantage of anthelmintics is that although they rapidly reduce morbidity and prevalence, they only slowly influence the incidence of infection. Furthermore, chemotherapy alone is unlikely to achieve more than a short-term
Table 3. *Health care expenditure in the Caribbean region*

(USA statistics included for comparison. Source: UN Commission for Latin America, 1980. Statistical Abstracts of the USA, 1981; Institute of Social and Economic Research, University of the West Indies.)

| Country                | Economic efforts: estimated annual health budget as % of Gross National Product (1980) | Estimated expenditure: annual per capita (1979) US$ |
|------------------------|------------------------------------------------------------------------------------------|-----------------------------------------------|
| Barbados               | 5                                                                                       | 134                                           |
| Dominica               | 5                                                                                       | 29                                            |
| Dominican Republic     | 1.7*                                                                                    | 17                                            |
| Guyana                 | 3                                                                                       | 19                                            |
| Haiti                  | 0.7*                                                                                    | 2                                             |
| Jamaica                | 5                                                                                       | 55                                            |
| Puerto Rico            | 5.5                                                                                    | 156                                           |
| St Kitts-Nevis         | 3                                                                                       | 25                                            |
| St Lucia               | 2                                                                                       | 17                                            |
| St Vincent             | 5                                                                                       | 24                                            |
| Trinidad and Tobago    | 2                                                                                       | 78                                            |
| USA                    | 9.4                                                                                     | 997                                           |
| * (1975).              |                                                                                         |                                               |

Reduction in transmission, unless the reduction in incidence is consolidated by, for example, concomitant improvements in sanitation (Anderson & May, 1982). Achieving such improvements is, however, very expensive: in the St Lucia programme the provision of protected water supplies proved to be the most expensive control method (Jordan, 1977). For many developing countries proper sanitation is only one of several developmental goals, and it is unrealistic to expect accelerated introduction of this single aspect of infrastructural development. Paradoxically, therefore, low-cost chemotherapy may be most appropriate to the more developed countries with higher standards of sanitation.

The prospects for developing countries initiating control programmes *de novo* are bleak. The existing control tools are refined and effective but are economically inappropriate. A possible solution lies in the development of integrated control programmes involving a reduction in the prevalence of human infection by chemotherapy and a reduction in snail populations through biological control (see below). Neither type of control method has been adequately tested and indigenously financed and managed control programmes remain a distant goal.

Puerto Rico and St Lucia are the legatees of expensive and comprehensive control efforts, and are both endeavouring to maintain transmission at a low and controlled level. The relatively high living standards, and concomitant high standards of sanitation, in Puerto Rico make this task easier and it appears that this island has effectively consolidated its control gains. St Lucia, whose standard of living is more typical of other less-developed Caribbean countries, is committed for the foreseeable future, to a substantial annual bill for mollusciciding operations since contact with unprotected water supplies is still a domestic requirement for many of the population. The Final Report of the St Lucian Research and Control Department indicated that mollusciciding costs are in the range of US $0.32–2.60
per capita per year, depending on the local topography and demography. Almost two-thirds of the cost of this type of routine maintenance control, based on treatment of habitats identified during a much more expensive surveillance phase, are to cover the purchase of imported molluscicide. In the context of developing countries this means that almost two-thirds of the budget required commitment of scarce foreign exchange resources, and hence even the maintenance phase of schistosomiasis control may be beyond the country’s economic capacity.

Biological control of snail intermediate hosts is a potential low-cost alternative to molluscicide and has received considerable attention in the Caribbean region (see reviews by Ferguson (1977) and Jordan, Christie & Unrau (1980)). Two gastropod species show particular potential in this role. The ampullarid *Marisa cormuarietis* has been shown by field and laboratory observations to predate on and compete with *B. glabrata*, while at the same time modifying the habitat to the disadvantage of the vector snail (Ferguson & Ruiz-Tiben, 1971). Extensive trials in Puerto Rico indicate that *Marisa* is most effective as a competitor in water impoundments such as ponds and reservoirs (Ruiz-Tiben, Palmer & Ferguson, 1969; Jobin, 1970; Jobin *et al.* 1970). One apparent disadvantage, however, is that environments require re-seeding if the competitor population is to be maintained at maximum effectiveness. Even with this proviso the control method is still much cheaper than molluscicide: in one extensive trial the annual cost for control of 100 m$^3$ of impounded water was estimated at US $0.11 using *Marisa* and US $7.80 using sodium pentachlorophenate (Ruiz-Tiben *et al.* 1969). Furthermore, none of the biological control costs require foreign exchange financing.

A South East Asian prosobranch, *Thiara granifera*, has spread extensively in the Caribbean region where it has been observed to replace *B. glabrata* in a variety of natural habitats (Ferguson, 1977). This species does not require re-seeding but instead the r-selected parthenogenetic mollusc rapidly colonizes the habitats to which it is introduced, often at the expense of indigenous mollusc species (Murray, 1970). The snail was introduced into Florida in the 1940s (Abbott, 1952) and has subsequently spread, in chronological sequence, to Puerto Rico, Vieques, the Dominican Republic, Grenada (Ferguson, 1977); Antigua, Dominica, St Lucia (Prentice, 1980) and Jamaica (C. M. Crawford, University of the West Indies, Jamaica: personal communication). Field trials of its efficiency as a competitor for *B. glabrata* are currently in progress (Prentice, 1983).

The concept of biological control is not only appropriate to countries which have achieved maintenance control status but also wherever transmission is hypoenemic. Antigua, Montserrat and Martinique would find it difficult to justify economically the initiation of elaborate control programmes to eliminate their relatively trivial levels of schistosomiasis-induced morbidity. The low cost and minimal maintenance involved in mounting a biological control programme, however, would seem a justifiable investment against the possibility of recrudescence.

While it seems natural to consider control only in relation to those areas with endemic schistosomiasis it is important to remember that the cheapest control option, prevention, is still available to the majority of Caribbean countries. The introduction of infection requires four factors: infected human hosts, susceptible snail hosts, low standards of sanitation and human contact with snail habitats. The latter two factors are typical of most Caribbean countries and hence the
persistence of schistosomiasis anywhere in the Caribbean poses a potential threat to the Public Health of the whole region. The degree and quality of this threat will vary between countries, being not least dependent upon the susceptibility of indigenous snail species.

In the discussion of intermediate host distribution it was indicated that *B. glabrata* has been reported from 10 island localities in which schistosomiasis does not occur (see above). In 8 of these the absence of transmission could be attributed to deliberate control or an absence of suitable transmission sites. The remaining 2, Haiti and Dominica, have recently established vector snail populations and are at potential risk of introduction of infection.

Haiti is geographically contiguous with a schistosomiasis endemic country, the Dominican Republic. The Haitian strain of *B. glabrata* is susceptible to Brazilian (Tauros-strain), Puerto Rican and Dominican Republican strains of *S. mansoni* (Raccurt, Sodeman, Bartlett, Rodrick & Vargas de Gomez, 1981). The country is one of the poorest in the region with accordingly poor standards of sanitation and intensive domestic use of natural water systems. This combination of factors suggests that Haiti only requires infected humans for schistosomiasis transmission to be initiated, and it is very probable that this last factor will be provided (Raccurt *et al.* 1982). Every year the Dominican Republic recruits 12-15000 Haitian workers to cut sugar-cane, and an appreciable proportion of this work-force is employed in the schistosomiasis endemic region. It seems inevitable that a returning worker will eventually carry the infection to the north-Haitian foci of *B. glabrata*.

The situation of the other new island focus of *B. glabrata*, Dominica, is only marginally less perilous. Dominica has snail habitats and sufficient water contact for at least moderate risk of transmission (Prentice, 1978, 1980). The Dominican strain of *B. glabrata* is susceptible to the St Lucian strain of *S. mansoni* (Sturrock & Sturrock, 1970). Human infections could be introduced from St Lucia, a Caribbean Economic Community trading partner, or more probably from Guadeloupe or Martinique which are its nearest neighbours to north and south. A more-or-less illegal trade with the latter two countries ensures frequent visits of Dominicans to the schistosomiasis endemic French-Antilles. One factor that may ameliorate the threat of introduction to Dominica is that *Thiara granifera* has become established in the significant *B. glabrata* habitats and may slow down the rate of spread (Prentice, 1980).

It is difficult to envisage any enforceable method of preventing infected individuals from entering Haiti and Dominica. In both cases there is considerable illicit human movement into neighbouring endemic countries so that any kind of border control would have only superficial significance. The ineffectuality of such legislative attempts to restrict the dissemination of disease was clearly demonstrated recently by the speed with which African Swine Fever swept across a supposedly closed border between the Dominican Republic and Haiti.

The risk of introduction to French Guyane has yet to be adequately quantified. This is the only mainland Caribbean territory with endemic *B. glabrata* but no transmission of schistosomiasis. The vector appears to be somewhat resistant to the St Lucian strains of *S. mansoni* (Sturrock & Sturrock, 1970), but may be more susceptible to strains from its geographical neighbour, Suriname. The location of
dense snail populations in roadside drains in the crowded suburbs of Cayenne may provide suitable conditions for transmission (Sturrock & Sturrock, 1970).

The significance to transmission of the existence of poorly susceptible *B. straminea* or *B. havanensis* in some islands is enigmatic. There are no records of these snails establishing an infection cycle in the islands although this has occurred in Brazil under somewhat different epidemiological conditions. It is possible that these intermediate hosts may become actively involved in transmission if human and snail host density were to increase.

A much more imminent threat is the introduction of *B. glabrata* to new environments. Prentice (1978, 1980) identified St Vincent and Grenada as islands with a high transmission potential if the vector snail became established. The risk of subsequent disease transmission is considered higher for St Vincent than Grenada because of the competitive effects of autochthonous *B. straminea* and introduced *T. granifera*. The risk of introduction to Jamaica has yet to be assessed but the ‘land of wood and water’ provides numerous potential snail habitats, currently occupied by *B. pallida* (Malek, 1969), and appropriate domestic water contact, particularly in rural areas. Jamaica’s location at the extreme west of the Greater Antilles may, however, provide a certain degree of geographical isolation.

Measures to prevent the introduction of *B. glabrata* to non-endemic countries are obviously required. Prentice (1978) urged a complete ban on the movement of aquatic plants between islands, since the most likely method of introduction is as snail egg masses on water lilies or water weeds for ornamental or piscicultural use. This appears to have been the route of introduction of *B. glabrata* into Martinique and Dominica, and *B. tenagophila* into St Vincent. There are, of course, a variety of other routes by which snails may be spread and Prentice suggested that periodic malacological surveillance of ornamental ponds and similar habitats would allow for their early detection. Development of such surveillance programmes would require greatly improved awareness, on the part of non-endemic countries, of the threat of introduction of schistosomiasis.

**CONCLUSIONS**

This article has shown that the regional status of schistosomiasis has remained fluid over the last 80 years of observation. Many of the changes in national prevalence and regional occurrence are attributable to the deliberate or incidental effects of human actions. Some of the advantageous changes resulted from conscious attempts to reduce the incidence of infection. This category of change would include the successful control programmes in Puerto Rico and St Lucia, the promising control activities in Suriname, and the eradication of infection from the island of Vieques. Other advantageous changes, such as the abatement of transmission in St Kitts and St Martin, were the incidental product of human actions which could as readily have had negative effects.

Human agency has also had a disadvantageous influence on national and regional occurrence of infection. At the most basic level, the disease could not have been introduced into the region without the movement of its human host; the presence of schistosomiasis in the Americas at all is the result of the forced migration of enslaved Africans during the 17th to 19th centuries. The late
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recognition of occurrence, and apparent expansion from single foci of infection, in the Dominican Republic, Montserrat and St Lucia may indicate recent introduction to these countries. More indirect human actions have resulted in the spread of infection within and between countries. The development of irrigation and drainage systems for the culture of bananas, rice and sugarcane provided acres of new habitats for the intermediate host in the Dominican Republic, Guadeloupe, Puerto Rico, St Lucia and Suriname. The importation of aquatic plants served to introduce potential intermediate hosts to Dominica, Martinique and St Vincent.

The challenge that now faces the Caribbean region is to ensure that future human actions achieve advantageous changes, thus reducing the incidence and restricting the occurrence of schistosomiasis. This could be achieved by avoiding past mistakes and by planning control programmes at two levels. Firstly, control at the national level to reduce the incidence of infection and minimize the risk of introduction to other parts of the region. Secondly, preventative measures at the regional level to reduce the probability of introduction of both intermediate hosts and infection into non-endemic areas.

Traditional attitudes to control have been concerned only with the national level and the substantial advances already achieved have to be consolidated and extended. The implementation of comprehensive programmes in some new areas will require preliminary research to obtain pre-control data on the prevalence, incidence and distribution of infection in the Dominican Republic, the epidemiological and control implications of murine schistosomiasis in Guadeloupe and the role of \textit{B. straminea} in transmission in Martinique.

The most pressing requirement at the national level, and one that is ultimately relevant to all endemic regions, is for the development of low-cost methods of maintenance control. Comprehensive control has been successful in Puerto Rico and St Lucia, and is showing promising results in Suriname. Puerto Rico, largely through its favourable level of socio-economic development, has consolidated its control gains but the other two countries are likely to be committed to active maintenance control for the foreseeable future. A similar fate awaits the successful outcome of control in the Dominican Republic. Present methods of maintenance control have expensive man-power and material requirements. Furthermore, governments are reluctant to commit a substantial proportion of their health budgets to long-term maintenance of the status quo, rather than more immediate, and politically visible, alternative health goals. Similar considerations may also discourage countries with naturally low levels of transmission from implementing control. The persistence of hypoendemic schistosomiasis transmission in Antigua, Martinique and Montserrat may act as a potential reservoir of infection for neighbouring countries but probably does not represent a national health priority to the endemic countries themselves. It is unrealistic to expect these countries to implement control for altruistic reasons unless the cost is readily supportable.

For all the endemic countries of the region, therefore, there is a need for economically appropriate methods for controlling low levels of transmission, whether such levels are a natural consequence of the local epidemiology or a consequence of successful comprehensive control measures. Biological control of intermediate hosts offers a low cost and low maintenance alternative to traditional maintenance control by mollusciciding. The mollusces \textit{Thiara} and \textit{Marisa} have been
shown to interact competitively with *B. glabrata*, but further operational research is required to incorporate biological methods into a rational control strategy.

Regional level control is concerned with preventing the spread of infection to currently non-endemic countries. There are three components to preventative control. Firstly, elimination of regional reservoirs of infection through control at the national level, as described above. Secondly, recognition by non-endemic countries of the threat posed by schistosomiasis, and of the need to prevent introduction. Thirdly, development of mechanisms to prevent introduction to non-endemic countries. Such mechanisms would include restriction on the importation of aquatic vegetation from *B. glabrata* enzootic countries, and surveillance of probable introduction sites.

The infra-structure for national control already exists within the governmental health agencies, but no specific mechanism for regional level cooperation has been developed. In an attempt to encourage regional collaboration in research and control, locally based health personnel have established a special interest group based in the regional University of the West Indies. The Caribbean Schistosomiasis Group, which includes representatives from the English, Dutch, French and Spanish speaking countries of the region, is intended to maximize the availability of locally scarce skills and facilities, and to encourage perception of schistosomiasis as a Caribbean problem.

From the conclusions presented here it is apparent that the attack on Caribbean schistosomiasis has progressed from a first stage of problem recognition at the beginning of the century, through a second stage of major comprehensive control development. If the control gains achieved over the last eighty years are to be consolidated and expanded there must be a progression to a third stage in which schistosomiasis is recognized as a problem requiring indigenous, regional solution.

I would like to thank the other members of the Caribbean Schistosomiasis Group, particularly its leader Dr Ellen Caldeira-Comvalius, for providing access to information on their own countries. The continuing assistance of WHO and PAHO in the development of the Group is gratefully acknowledged. The perspectives are my own.

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