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**Biological control of the snail intermediate hosts
of human *Schistosoma* spp.:
a review of its present status and future prospects**

F. S. McCULLOUGH

Summary

The biological control of freshwater snail hosts of schistosome parasites has attracted much attention in recent years, but the efficiency of such bio-control agents has rarely been tested outside laboratory conditions. The present paper attempts to summarize the present status of biological control of snail intermediate hosts, to indicate some major gaps in our knowledge of this subject, especially those of a practical kind and, not least, to identify studies and activities which apparently merit priority for further sponsorship and support.

Key words: snail intermediate hosts; schistosomiasis; biological control.

Present status

During the last decade increasing concern with some chemical pesticides, in particular, their possible adverse environmental impact and not least their escalating costs, has stimulated search for alternative intervention procedures, including wide-ranging studies on biological control (Huffaker, 1974).

It is clear that success or failure of any bio-control scheme will depend on ecological, extrinsic parameters such as the carrying capacity of the habitat as well as intrinsic characteristics of the target species, together with those of the biological control organism, at both individual and population levels. De Bach (1974) has listed the qualities exhibited by effective biological control agents, and these apply equally to any organism which may be utilized in the bio-control of the snail hosts of *Schistosoma* spp. or other trematode parasites.

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Regarding bio-control of snail intermediate hosts, several hundred species, ranging from fish to fungi, have been considered as potential competitors or predators (including parasites and pathogens), but their efficiency has rarely been tested outside laboratory model systems.

Papers by Michelson (1957), Ferguson (1972, 1978) and Hairston et al. (1975) deal comprehensively with biological control of aquatic snail hosts; a synopsis of these publications would be inadequate, and they should be referred to in the original. For present purposes, the subject may be succinctly described under the following headings, with special reference to control potential and environmental impact.

Predators/parasites/pathogens

Of the many species of predator listed, only two groups, fish and insects, have been studied in enough detail to merit serious consideration. Several fish species are malacophagous (*Serranochromis* sp., *Astatoreochromis alluaudi*, *Tilapia melanopleura*, *Clarias* sp., etc.) but rigorous observations on their efficiency in field situations are still lacking. Further studies should be encouraged as fish ponds often provide suitable habitats for snail hosts, and they may also act as potential transmission sites in which molluscicides cannot be applied; additionally, some predator fish may be useful as a source of scarce protein.

The use, in combination, of certain species of perch, which are malacophagous and voraciously vegetarian, could well be further explored, but the efficacy of any fish species in the bio-control of snail host populations depends entirely on ecological characteristics and/or management regimes which govern the population dynamics of the biota of all freshwater systems.

To date, almost all observations on fish/snail host interactions have been carried out in East and Central Africa, but none can be regarded as conclusive and the need for much more rigorous investigations is evident.

Among snail-eating insects, most interest has focused on sciomyzid flies, which are obligatory feeders on mollusc larvae, mainly gastropods (see review by Berg, 1964). Several hundred species exist with a wide range of predator-prey systems, which may eventually lead to more efficient control. Hairston et al. (1975) cite 26 references dealing with the potential role of sciomyzid flies, but the subject is still embryonic, and further investigations deserve encouragement.

While Michelson (1957) and Ferguson (1972) list many species of insect, other than sciomyzids, as predators of snails, the only noteworthy study remains that of Voelker (1966, 1968) in Egypt on the aquatic hemipteran (*Limnogeton fieberi*), an obligatory, but non-specific, feeder on snails. In Egypt the impact of this voracious insect on schistosome transmission is probably seldom significant. Outside its natural range it could perhaps prove efficient, but the cautions concerning liberation of any exotic organism beyond its normal range would need to be strictly observed.

The use of other trematode parasites (e.g. *Ribeiroia marini guadeloupensis*) capable of sterilising the snail hosts (*Biomphalaria glabrata*), as well as being antagonistic to concomitant schistosome sporocysts, has been studied in detail by French scientists (Drs Combes, Nassi, Pointier, Théron, Golvan et al.) in Guadeloupe. The experimental seeding of *R. guadeloupensis* in a small, permanent pond resulted in the “disparition quasi-totale” of the snail host population. Apart from some important limitations this approach has several attractive aspects (target specific, competitively economical) and deserves to be explored further as advocated below.

In Guadeloupe, recent detailed field studies undertaken by Pointier (1979) on the natural enemies of *B. glabrata* in diverse habitats should be noted. From Pointier's careful observations it may be concluded that, in nature, co-existing predators (leeches, insects, crustaceans, etc.) *do* play a marked role in governing snail host population densities especially in small, mature, static waterbodies and also where natural enemies occur in combination. However, their role in significantly reducing or eliminating transmission of *Schistosoma* is likely to be far from absolute which detracts from their broad exploitation as effective biological control agents.

There is a considerable literature dealing with micropathogens (protozoans, microsporidia, bacteria) of snail hosts and/or their trematode parasites (see Ferguson, 1978); however, virtually all such studies are laboratory based. While no successful field demonstration of the efficacy of micropathogens in the control of snail host populations or their parasites has yet been made, the ultimate aim of searching for and isolating an efficient micropathogen should be encouraged. At the present time most work on micropathogens is concentrated on microsporidian hyperparasites of schistosome larvae. Although such studies are still at a basic, exploratory stage (i.e., their practical potential can not yet be adequately evaluated) this should not detract from giving them any support possible.

Interlarval trematode antagonism/predation

Apart from the studies mentioned above, the antagonistic and/or predacious interactions, per se, of the larval stages of certain trematodes infecting the same snail, have been studied intensively in the last decade, with the long-term goal of utilizing such antagonism for purposes of biological control. Lim and Heyneman (1972) and Lie (1973) have reviewed the subject comprehensively, and Hairston et al. (1975) have provided a useful synopsis.

In brief, observations have shown that schistosome larvae (sporocysts) can seldom survive the antagonism exhibited by redia-producing trematodes, especially the echinostomes. Some small scale field trials have been successful, others not. According to Hairston et al. (loc. cit.) serious practical problems are likely to arise as a result of the necessity of “achieving a very abnormal infection rate of the antagonistic species in snails (70% or more)”. Such high rates are

virtually unattainable under natural conditions. In any event, much additional research will be needed to discover suitably efficient antagonistic trematodes, if they exist and to develop cost-effective methods of mass culture.

In the Sudan relatively low prevalence rates and perhaps also the peculiarly uneven distribution of *S. haematobium* in the vast, seemingly homogeneous Gezira irrigation scheme has been attributed, at least in part, to the effects of antagonism/sterilization caused by larval echinostomes, which have been noted to be highly prevalent in local *Bulinus truncatus* populations (Amin, personal communication). This hypothesis deserves to be tested by carefully designed quantitative studies, if funding and staff can be found.

Intramolluscan competition

The attraction of this approach is based on the principle of competitive exclusion/displacement, whereby it is believed that if two species are sufficiently similar in their biological profile, then one (the stronger and hopefully, the introduced species) will inevitably eliminate the other weaker, and hopefully, the target species. Even if elimination is not achieved, competition per se can play a significant role in controlling population size. Thus, if a competing species is successfully introduced the abundance of the target species will be reduced, perhaps substantially. Unfortunately, however, at the present time, little is exactly known about the role of snail host population density in transmission dynamics. Moreover, as Hairston et al. (loc. cit.) have aptly pointed out, "despite the theoretical difficulties and the paucity of examples of intentional introductions of competitors, the number of successful introductions for other reasons (mainly to do with agriculture) is impressive, particularly on oceanic islands. The fact that many of these have had undesirable consequences may have contributed to a hesitancy in attempting introductions of competitors. Given careful preliminary research ..., however, such introductions are to be encouraged."

The introduction of possible competitive species of snails (*Marisa cornuaretis*, *Helisoma duryi*, *Pomacea haustru*, *Potamopyrgus jenkinsi*, *Bulinus tropicus*, *Tarebia granifera* and *Physa* spp.) has received most attention to date. Of these species *M. cornuaretis* has been most exhaustively studied (Ferguson, 1978), and it can be argued that its effectiveness in Puerto Rico has been demonstrated in certain types of habitat, especially ponds, as a competitive feeder and incidental predator on the eggs and young of *Biomphalaria glabrata*. As with mollusciciding, persistence of effort was needed to maintain *Marisa* in transmission sites, but costs were estimated to be about a third of that of application of the best molluscicide. The introduction of *Marisa* had no evident adverse environmental effects. A review of this latter topic has recently been prepared by Christie and McCullough (in press).

In addition to *Marisa*, *Helisoma duryi* appears to have some possibilities as an effective competitor in certain types of habitat. There is some evidence that

H. duryi can not aestivate or withstand flowing conditions as well as most planorbid snail hosts can do. The main parameters, at least under laboratory controlled conditions, favouring *H. duryi* as a potential bio-control agent appear to be food competition, growth inhibiting factors, mechanical effects on egg masses, superior reproductive and relatively low mortality rate, vis-à-vis certain snail host species. Further well designed laboratory studies and carefully controlled field testing of the efficacy of this species in a range of simulated habitats, preferably against several snail hosts, are needed. A review of *H. duryi*, with relevance to biological control, has recently been prepared by Frandsen and Madsen (1979).

Doby et al. (1965) noted that *B. truncatus* was apparently displaced from habitats in Corsica by the tiny hydrobiid snail, *Potamopyrgus jenkinsi* which, in recent years, has spread dramatically over much of Europe. The island of Corsica, however, is located at the geographical limits of the distribution of *B. truncatus*. In such a zone the effects of competitive displacement may well be accentuated in comparison with those in areas offering optimal conditions for reproduction and survival of snail hosts. Unfortunately, the observations of Doby et al. (1965) have not been followed-up; they might well be relevant to control of schistosomiasis transmission in some foci in such countries as Morocco, Algeria and Mauritius.

In the neotropics, some recent observations have indicated that populations of *Biomphalaria glabrata*, which is mostly highly compatible with local strains of *S. mansoni*, can be drastically reduced, if not eliminated, by *B. straminea* (Barbosa, 1973; Michelson and Dubois, 1979), and by *B. tenagophila* (Kawazoe et al., 1980); the latter two species are, in general, poorly compatible with *S. mansoni*. Such displacement could therefore probably reduce significantly schistosome transmission in many endemic foci in Brazil. This phenomenon also may apply presently in Martinique (Guyard and Pointier, 1979), where further investigations on this subject are now being pursued.

Screening and evaluation of bio-control organisms

Recently, a scheme for rational screening and evaluation of the most promising organisms for biological control (see Table 1) has been proposed by Arata (1975) and WHO (1975). For obvious reasons this scheme stresses that due attention must be paid to safety of the agents affecting man in particular, and non-target organisms in general, under a wide range of environmental conditions.

While the scheme was devised with bio-control of insect vectors in mind, its relevance to control of snail intermediate hosts is evident. Clearly, with regard to the latter, most studies have not progressed beyond Stages I and II (laboratory findings), very few have reached Stage III (preliminary field trials), fewer still have advanced to Stage IV (non-target impact studies) and none has, as yet, achieved Stage V (large scale field trials).

Table 1. Preliminary scheme for screening and evaluating the efficacy and safety of biological agents for control of disease vectors*

| Stage I Laboratory | Stage II Laboratory | Stage III Preliminary field trials | Stage IV Laboratory | Stage V Large scale field trials |
|----------------------------------------------------------|------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| A. Identification and characterization ^a | A. Mammalian infectivity tests to ensure safety to laboratory and field personnel ^b | Strictly regulated pond tests under WHO supervision ^c to determine efficacy against disease vectors under natural conditions | More detailed tests on mammalian infectivity, using appropriate techniques | Review of Stages I, II, III and IV by informal consultation group |
| B. Assessment against selected target vectors | | | | To be conducted under WHO auspices. Not presently defined, and will vary according to target vector, habitat(s), mode of application, etc. |
| C. Preliminary evaluation of ease of rearing in quantity | B. Preliminary assessment against certain non-target species | | <i>Laboratory and field trials</i> Detailed studies on non-target range – especially other fauna in habitats where Stage V trials may be conducted | |

^a This study may vary from routine taxonomic determination (fish, nematodes, predatory insects) to the detailed serotyping necessary for microorganisms, especially viruses.

^b Not required in predator-prey situations, but more detailed tests on effects on non-target organisms could be substituted in trials of voracious fish, predatory insects, etc.

^c Especially where the biological control agent is not indigenous.

* From WHO (1975). Technical Report Series, No. 561, p. 35.

Future action

As already indicated, biological agents for control of snail hosts must pass a complex battery of tests capable of being quantitatively evaluated. Their efficacy in reducing the population of the target species to a threshold, below which transmission of the parasite will no longer represent a public health problem, must be unequivocally demonstrated under carefully simulated field conditions. Similarly, their safety to man and other non-target biota must be proven. Not least, their cost-effectiveness must not exceed local resources and they must be competitive when evaluated against other interventions. Finally, their availability, when needed, must not be in doubt.

Unfortunately, none of the biological agents, which have been seriously proposed for control of snail intermediate hosts, has so far satisfactorily met *all* of these criteria. Indeed, the criteria are perhaps too ambitious and it is for this reason that the usefulness of biological control agents can probably best be exploited if they are combined with classic methods of schistosomiasis control such as chemotherapy, health education, etc.

There can now be little doubt that the efficacy of biological control for schistosomiasis reduction/elimination will be restricted to specific habitat situations and will rarely, if ever, be universal. Moreover, it is likely that its role will almost always be supportive rather than dominant. Future action must, therefore, be linked to problem analysis, habitat/transmission definition and the continuous elucidation of gaps in our knowledge, taking account of an ecological situation always diverse and dynamic. Nevertheless, support of carefully designed research programmes, especially those concerned with preliminary field testing (Stage III) and non-target impact studies (Stage IV) can be strongly advocated, and the following activities appear to have priority:

- Support for quantitative, cost-effective studies aimed at evaluating reduction of transmission indices, following intervention by trematodes, which bring about sterilization of the snail hosts as well as exhibiting antagonistic interaction with schistosome sporocysts. This work might well be undertaken in selected endemic sites in Guadeloupe and/or Africa.
- Sponsorship of research on the efficacy of snail-eating fish, either alone or in combination with herbivorous species, in permanent impoundments, whether fish ponds or not. This work should obviously be undertaken in close collaboration with freshwater fisheries' authorities. Potential sites for such studies may possibly be found in the Sudan, Kenya, Malawi and Cameroon.
- Support for research on such promising competitors as *Marisa*, *Helisoma* and *Potamopyrgus*, particularly at Stages III and IV (see Table 1) evaluation levels, in a variety of habitats including those in which focal mollusciciding is prohibited, and not least in zones where the target species is near the limits of its distribution. The effect of competitive species in combination, rather than singly, should also be studied.

- Encouragement of projects aimed to identify and study pathogens/predators/competitors which may be attacking snail host populations in their natural habitats.
- Sponsorship of research closely relevant to biological control, e.g. snail host population characteristics, including different density levels, in relation to infectivity patterns and transmission intensity.

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