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Danish Bilharziasis Laboratory, Charlottenlund, Denmark

A review of *Helisoma duryi* in biological control

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Summary

Biological control of schistosomiasis by means of introduction of the north American planorbid snail, *Helisoma duryi*, as a competitor of the intermediate host snails has been proposed. The systematics of the genus *Helisoma* and the geographic distribution of the different species is described. Papers dealing with laboratory experiments or field observations on the competition between *H. duryi* and different intermediate host snails have been reviewed. The status of *H. duryi* as intermediate host of trematodes has been evaluated by searching the literature for all the trematode species that are recorded from the genus *Helisoma*. The list does not include trematodes of medical or veterinary importance and despite many attempts it has not been possible to infect *H. duryi* with *Schistosoma mansoni* and *S. haematobium*. Finally this paper makes a few comments on the experiments that should be performed in the laboratory, under semi-field conditions and field conditions before *H. duryi* should be actively dispersed in Africa. The aspects to be considered include the nature of the competitive interactions, the relation between *H. duryi* and different medical and veterinary important trematodes and the effect of *H. duryi* on the biotope.

Key words: schistosomiasis, biological control, competition, *Helisoma, Biomphalaria, Bulinus*, 1. intermediate host, 2. intermediate host.

Snail control is an essential part of the control of snail-borne diseases and a lot of work has been done in developing new methods for controlling the intermediate snail hosts, especially in regard to the most important of the snail-borne diseases, schistosomiasis.

Until now molluscicides have proved to be the only effective agent in reducing snail numbers, but an increasing concern for the environment (espe-

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cially the general biocid effect of molluscicides), the cost of chemical products and finally, the long-term aspects of controlling schistosomiasis by this method (i.e. the evolution of molluscicide resistant snails and the accumulation of toxins through food chains) have had a stimulating effect on the development of more specific molluscicides, on biological control methods and new drugs.

In the last few years new and very effective schistosomicides, unfortunately very expensive ones, have been developed and it seems possible to control the load of schistosome worms in the final hosts, human beings, by mass-chemotherapy campaigns in certain areas.

Although advances have been made, a much greater effort should be concentrated on non-chemical methods for combatting the intermediate hosts, and on other ways of reducing the incidence of the disease such as sanitary installations, environmental control and education.

Methods for the biological control of the intermediate hosts of schistosomes have been reviewed by Michelson (1957b), Berg (1973), Hairston et al. (1975) and Ferguson (1977).

A lot of effort has been concentrated on the possible use of predators of freshwater snails such as leeches, Ampullariidae, Sciomyzidae and other insects, certain fishes and ducks, but none of these have proved satisfactory in the control of snails. Experiments have dealt with hyperparasitism of the schistosomes (i.e. microsporidians) and predators of the free-living larval stages of the schistosomes. These include oligochaetes (*Chaetogaster*), water fleas (*Daphnia*) and certain fishes (*Lebistes*). Furthermore, attempts to control schistosomes have been tried during the intramolluscan stages using the antagonistic effect between rediae of different echinostomes and the sporocysts of the schistosomes.

From a biological point of view the ideal method for controlling disease vectors should be based upon competitive displacement by the introduction of a non-vector species with ecological requirements similar to the vector species (i.e. an ecological homologue) but with higher biological potential and adaptability. Competitive displacement has not yet appeared because of geographical barriers which have prevented the foreign species from spreading into the area.

A snail species with a higher intrinsic rate of natural increase due to a higher growth rate, better utilization of food resources, longer life span, etc. could supersede and eventually eliminate the schistosome vector snails.

The introduced competitor must be refractory to schistosomes and other important trematodes such as *Fasciola, Paramphistomum,* etc. and at the same time harmless to crops such as rice and other water plants.

The following deals with a member of the family Planorbidae, *Helisoma duryi,* a species which seems to possess the ability to replace and take over the role of *Biomphalaria* and *Bulinus* but not as transmitter of schistosomes.

Systematic position and distribution of Helisoma

The genus *Helisoma* belongs to the subfamily Planorbinae and is endemic to America. It consists of 36 species (Table 1) which can be separated into four subgenera: 1. *Helisoma s.s.*, two species, one of which *H. anceps*, is very common, with geographic distribution from Hudson Bay southward to Louisiana and Alabama and westward to the Rocky Mountains; 2. *Seminolina*, three species, including the proposed control agent, *H. duryi*, which is endemic to Florida; 3. *Pierosoma*, 29 species, among which the most important are *H. trivolvis* and *H. tenue*, both divided into many subspecies. The species of this subgenus cover the area from Alaska to Georgia, Louisiana, Texas and California, the whole of Mexico and southward down the west coast of South America to Peru. It is also known in the West Indies. The last subgenus, 4. *Planorbella*, includes two species and is distributed from Labrador to New York, Ohio and Illinois and westward to North Dakota.

The centre of the genus *Helisoma* is in North America, principally in the southern part of Canada and the northern part of the United States where the largest number of species and races are found. Southward the number of species decreases rapidly and only two are known from South America and the West

Table 1. Species of the genus *Helisoma* Swainson, 1840 according to Baker (1945)

Subgenus *Helisoma* (s. str.) Swainson, 1840
- H. anceps (Menke)
- H. eucosmium (Bartsch)

Subgenus *Seminolina* Pilsbry, 1934
- H. scalare (Jay)
- H. duryi (Wetherby)
- H. preglabratum (Marshall)

Subgenus *Pierosoma* Dall, 1905
- H. ammon (Gould)
- H. binneyi (Tryon)
- H. calodermum (Pilsbry)
- H. caribaeum (d'Orbigny)
- H. chatauquense Baker
- H. columbiense Baker
- H. contrerasi (Pilsbry)
- H. corpulentum (Say)
- H. costaricense (Preston)
- H. equatorium (Cousin)
- H. eyerdami Clench and Aguayo
- H. foveale (Menke)
- H. horni (Tryon)
- H. kennicotti Baker
- H. kolymense Lindholm (fossil?)
- H. magnificum (Pilsbry)
- H. multicostatum Baker
- H. occidentale (Cooper)
- H. oregonense (Tryon)
- H. peruvianum (Brod.)
- H. pilsbryi (Baker)
- H. plexatum (Ingersall)
- H. salvini (Clessin)
- H. subcrenatum (Carpenter)
- H. tenue (Philippi)
- H. traskii (Lea)
- H. trivolvis (Say)
- H. truncatum (Miles)
- H. tumens (Carpenter)
- H. winslowi (Baker)
- H. wyldii (Tristoun)

Subgenus *Planorbella* Haldeman, 1842
- H. campanulatum (Say)
- H. multivolvis (Case)

Table 2. Records of *Helisoma duryi* from Africa, The Middle East, and South America

Africa		
Congo	Brazzaville, Pinare Stream	McCullough, 1962*
Kenya	Mombasa, Alana Farm	Highton, 1970*
	Mombasa, Bamburi	Haller, 1975*
	Mombasa, Botanical Garden	Highton, 1970*
	Nairobi	Jelnes, 1976*
Mauritius	Trianon	Courtois, 1973*
Namibia	Spitzkoppe, Sandamap Farm	Van Bruggen (1974)
Republic of South Africa	Tugela River, Mandini Paper Mill	Brown, 1964 (according to Van Bruggen, 1974)
	Cape Point	Appleton (according to Van Bruggen, 1974)
Reunion		Picot, 1975*
Rhodesia	Lake Kariba	Jewsbury, 1976*
Tanzania	Tanga	McMahon, 1976 (pers. comm.)
Uganda	Entebbe	Dbko, 1974*
	West Uganda	Thomas, 1977*
Zambia	Lusaka	Hira, 1969*
Tenerife		Mandahl-Barth, 1965*
Middle East		
Israel	Tel Aviv	Gold, 1966*
Saudi Arabia	Qaisunah	Ghanma, 1969*
	Refha	Alio, 1966*
South America		
Brazil		Paraense (1976a)
St. Vincent Kingston		Sturrock, 1968*
Puerto Rico		Ferguson, 1968*
St. Croix		Ferguson (1977)

* Samples at the Danish Bilharziasis Laboratory

Indies. The taxonomy of the genus has been treated by Pilsbry (1934) and Baker (1945). A critical revision would probably reduce the number of species considerable. Paraense (1976b) considers that *H. foveale* and *H. equatorium* are synonymous to *H. trivolvis* and Harry (according to Hubendick, 1961) claims that *H. wyldii* is a synonym of *H. foveale.*

The proposed control agent *H. duryi* is a very common snail in freshwater aquaria and seems well adapted to these aquaria. It has spread all over the world largely through the transportation of aquatic plants which are cultivated in "nursing gardens" for the use in freshwater aquaria.

In the last few years samples of *H. duryi* have been received at the Danish Bilharziasis Laboratory from many areas of Africa (Table 2), and recently *H. duryi* has been located in the central part of Brazil (Paraense 1976a).

The shells of *H. duryi* populations outside North America, i.e. St. Vincent (Prentice et al., 1977) may resemble very much the genus *Biomphalaria;* similar

observations have been registered for samples of *H. duryi* from Africa received at the Danish Bilharziasis Laboratory.

Observations on the different species of Helisoma

The different species of *Helisoma* have been widely used in physiological studies but rather few studies have been done on the bionomics of natural *Helisoma* populations (Boerger 1975a, b; Hermann and Harman 1975). However, it is not our ambition to include these aspects in the present discussion. References to these studies can be found in a list of publications on the genus *Helisoma* which has been compiled at the Danish Bilharziasis Laboratory and can be obtained upon request.

Observations on Helisoma against Biomphalaria and Bulinus under laboratory conditions

During 1941–42 Dr. G. Mandahl-Barth observed that *H. duryi* was multiplying in the exhibition tanks at the Danish Aquarium and was superseding *Biomphalaria taenagophila.* Later, in 1964, when the Danish Bilharziasis Laboratory was established, he started experiments on *H. duryi* and species of *Biomphalaria* and *Bulinus.* The observations showed (personal communications) that after 7 months the following species were eliminated: *Biomphalaria pfeifferi, B. angulosa, B. alexandrina, Bulinus truncatus, B. globosus, B. africanus* and *B. nasutus.* There was no suppression of *Biomphalaria glabrata.* These observations were presented at the first African Symposium of Bilharziasis in Cairo in 1969 and later in Addis Abeba in 1970. The results and further observations on the effect of *Helisoma*-conditioned water indicated that *H. duryi* excrete a substance which impedes the hatching of egg masses from the vector snails and further inhibits the growth of juvenile *Biomphalaria* and *Bulinus.*

Only a very few laboratory control experiments with *H. duryi* have been published and the following is a short presentation of the experimental designs and results, with a few comments.

Ayad et al. (1970) tested *H. duryi* in controlling *Bulinus truncatus. H. duryi* had a very high reproductive rate and a low mortality among the offspring and adults under laboratory conditions.

A pilot experiment was carried out with 50 three-month-old snails in 8 l of dechlorinated tap water which was changed weekly, and fresh lettuce was supplied in excess of requirements. The mortality among *B. truncatus* in mixed species aquaria was 100% after 6 weeks in comparison to 52% in the control group. Similar mortality for the groups of *H. duryi* was 10% and 8% respectively. In another experiment of the same experimental design all dead snails were replaced by snails of the same age and kept under similar conditions in order to "stabilize the biological space". *B. truncatus* in the mixed species aquaria were

replaced 2.76 times the initial number during a 16-week period of observation in comparison with 1.36 times in the control group.

These studies confirm that *H. duryi* is very well adapted to laboratory conditions, while the extremely high mortality in the *B. truncatus* control group indicates that this snail species has been kept under very "stressed" conditions. *Helisoma* appears thus to accelerate the mortality rate among *B. truncatus.*

Abdallah and Nasr (1973) conducted competition experiments between *H. duryi* and *B. alexandrina* and *B. truncatus.* Three 10-litre aquaria were started with 10 young snails of each species, one aquarium with *Helisoma* and *Biomphalaria,* one with *Helisoma* and *Bulinus* and the third with *Biomphalaria* and *Bulinus.* During the first months the vector snails multiplied and later on *Helisoma* started reproducing rapidly. A few weeks later egg masses of *Biomphalaria* and *Bulinus* failed to hatch and the young snails began to die. After five months all small specimens of vector snails had disappeared. A month later only *Helisoma* remained. All vector snails in the third aquarium were alive with an increase in their numbers.

Furthermore they observed that egg masses of the vector snails would not hatch when placed in one litre of water containing three or more *Helisoma* individuals. Some eggs developed when two *Helisoma* were present and all developed if there was only one *Helisoma.* Egg masses did not develop in water conditioned by *Helisoma* for more than one month. Unfortunately the number and size of the conditioning snails are not given, and furthermore control experiments on the effect of conditioning by the vector snails on their own egg masses are not described. Abdallah and Nasr do not mean that *Helisoma* devours the egg masses of the vector snails.

El-Hassan (1947) was rearing *B. truncatus, B. alexandrina, Physa acuta* and *H. tenue* alone and together in dechlorinated tap water, and found that growth, survival and egg production of the intermediate hosts were reduced more by the presence of *Physa* than by *Helisoma. Physa* was more reproductive and dominated *Helisoma.* Experiments with vector snails in tap water or *Helisoma*-conditioned water treated in various ways indicated that *Helisoma* removed essential ions from the water.

Two papers on the influence of *H. duryi* on cercarial production from infected *Biomphalaria* species have been published (Frandsen, 1976; Frandsen and Christensen, 1977). The results indicated that *H. duryi* behaves as a decoy snail in removing a number of miracidia, as has earlier been shown by Chernin (1968). If *H. duryi* and *B. pfeifferi* were kept together during the exposure and in the same aquarium after the exposure in equal numbers, a 95.9% reduction in cercarial production compared to the control group was found. When *H. duryi* was introduced 12 h after exposing the vector snails, the production of cercariae was about 77,000 per 100 exposed snails compared to 487,000 in the control group.

The experimental series with *B. glabrata* producing cercariae and *H. duryi*

confirm the earlier observations for *B. pfeifferi.* The reduction in the cercarial production from *B. glabrata* was smaller than that obtained when the two snail species were kept together during the exposure, prepatent period and then later on in the same aquarium.

The growth rate of the experimental group of *B. pfeifferi* was markedly reduced in comparison with the control group. The same conclusions could not be made for *B. glabrata* but the presence of *Helisoma* seems to suppress the reproduction of *B. glabrata.*

Recently Malek and Malek (1978) found that the growth of *B. glabrata* was not affected by the competition with either *H. duryi* or *H. trivolvis* but reproduction was strongly inhibited. *B. glabrata* eggs failed to hatch and mortality among hatched embryos was high. Furthermore they found that the infection rate of *B. glabrata* was inversely related to the abundance of *Helisoma.*

A series of experiments on the interspecific competition between *H. duryi* and *Biomphalaria camerunensis* have been carried out at the Danish Bilharziasis Laboratory (Madsen and Frandsen, 1978; Madsen, 1978a, b). The following is a short résumé of the results.

Four 25-litre aquaria were started with a total snail population of 40 individuals. Two were experimentals with equal numbers of the two species while the other two were controls for *B. camerunensis.* In one of the experimentals the biomass of the *Helisoma* increased to 2100% of the original biomass during six months and in the other to 2150% during five months. This increase was due to rapid reproduction and growth. Similar values for the two *B. camerunensis* populations in the experimental aquaria were 95% and 20%, respectively. Only few juvenile *B. camerunensis* were observed in the experimental aquaria, while reproduction was still going on in the control aquaria at termination of the experiment. The biomass of the control populations were 530% and 265% of the original biomass after six and five months respectively.

Series of 4-litre aquaria were started with 20 snails and juveniles were removed. The numerical fraction between the two species was varied and in some of the experimental aquaria the two species were separated by a nylon mesh. Food was weighed to give the same amount per snail in all aquaria and the amount given was very close to the maximum 24-h consumption. From the growth data of experimental groups from aquaria with or without partitioning it appeared that competition for food (perhaps due to mechanical interference between the snails) was involved when snails were not separated. Competitive interactions based mainly on food competition might limit the success of *H. duryi* as a competitor of the intermediate hosts in the field. However, there is some evidence that food in certain cases could be a limiting factor of snail population (Madsen, 1978a).

The growth of *B. camerunensis* control groups exceeded the growth of the different *B. camerunensis* experimental groups from aquaria with partitioning. This could be explained by growth inhibiting factors secreted by *H. duryi* or by

the presence of specific growth promoting factors for *B. camerunensis.* Such substances have been demonstrated for *B. glabrata* (Thomas, 1973).

Growth and reproduction of *B. camerunensis* individuals isolated in 200 ml of either *Helisoma, Biomphalaria* or non-conditioned water indicated that both growth inhibiting and promoting substances could be involved, although there was no significant differences in mean size between the three groups after six weeks.

Another factor that might be important for the outcome of competition in the laboratory is mechanical interference with egg masses. Juvenile and adult *H. duryi* destroyed a large number of *B. camerunensis* egg masses while the effect on egg masses of its own species was negligible. *B. camerunensis* adults also damaged their own egg masses but only few *Helisoma* egg masses. Even juvenile *B. camerunensis* had some damaging effect on egg masses belonging to their own species. It seems as if *H. duryi* egg masses are better protected against the radula teeth of the snails.

In summary the following factors might be involved in the outcome of competition under laboratory conditions: food competition, growth-inhibiting factors and possibly mechanical effect on egg masses.

Observations from field experiments on the interactions between Helisoma and Biomphalaria and Bulinus

Only few experiments under field or semi-field conditions with *Helisoma* have been carried out.

1. Ferguson et al. (1958) observed a population of *Helisoma duryi eudiscus* in one pond in Puerto Rico reaching very high densities and *B. glabrata* was absent. (These observations are described later in Ferguson, 1977, but the species is here referred to as "probably *caribaeum*".) *H. duryi* was transplanted to four similar ponds and in two of these *H. duryi* thrived well and *B. glabrata* disappeared. In the third pond both snail species declined and disappeared while in the last pond *H. duryi* did not become strongly established and the resident *B. glabrata* population remained unaffected. It was found that the ponds with *H. duryi* were all well supplied with filamentous algae.

H. duryi can be eliminated by other snails thus the waterbodies with the reported presence of *H. duryi* were reinvestigated in 1975 and all were found to contain dense populations of introduced control snails, *Marisa cornuarietis* and *Terebia* (Ferguson, 1977).

Ferguson et al. (1958) did not succeed in starting *H. duryi* populations in small streams, but later it occurred spontaneously in Rio Caguitas, reducing the formerly abundant *B. glabrata.* On St. Croix *H. duryi* was introduced into four waterbodies, and after one year the snail was dominating.

2. Abdallah and Nasr (1973) introduced *H. duryi* into an outdoor concrete pond in which both *B. alexandrina* and *B. truncatus* had been numerous and

breeding well for many years. One year later *H. duryi* was thriving well but the vector snails had completely disappeared. Five ditches were started with mixed populations: one with *Helisoma* and *B. alexandrina*, one with *H. duryi* and *Bulinus truncatus*, one with *Helisoma*, *Biomphalaria* and *Bulinus*, one with *Helisoma* and one with the vector snail species. The vector snails were eliminated in all the test ditches after eight months but were reproducing well in the ditch with no *H. duryi*. According to personal communications the number of *Physa*, *Melanoides*, *Cleopatra* and *Bellamya* seemed to be unaffected. This series thus gave the same results as previously observed in aquaria, but added no new knowledge about the control effect, i.e. in comparison with control groups.

3. Other field trials have been carried out by Rasmussen (1974, and personal communication). The first experiment was performed in temporary ponds around Mwanza, Tanzania, but these ponds dried up for a long period and both *B. pfeifferi* and *H. duryi* disappeared.

The next experiment was conducted in some experimental furrows on a sugar estate near Moshi, Tanzania. Five furrows, irrigated with water from a nearby river, were used.

The experimental design was as follows: 1. *B. pfeifferi* was seeded in one furrow, control; 2. *H. duryi* was introduced into the second furrow, control; 3. ten times as many *B. pfeifferi* as *H. duryi* were introduced in the third furrow; 4. breeding place for *H. duryi;* 5. control furrow for a natural population of local snails.

Because of many factors, such as the inflow of *B. pfeifferi* from the surroundings, overflow caused by heavy rains, accidental molluscicide, the drying up of the furrows in different lengths, etc., the original design was destroyed. The furrows were very close to each other and the banks between quite low. The flow of water during the rainy season was also a possibility as well as the spreading of snails by birds, etc.

The furrows were populated by native snails, including *B. pfeifferi*, before the introduction of control and test snails, and further the furrows were left for six months with water before the experiments were started which may also have affected the results.

Instead of looking at five separated furrows, it may perhaps be the most correct to consider the experiments as having been carried out on one large furrow.

A routine procedure of snail collection was used and the results were recorded monthly for one year for each furrow. The observations varied, but in general *H. duryi* exceeded *B. pfeifferi* and constituted about 95% of the total number of these two species. In one furrow (3) *B. pfeifferi* was the dominating species after nine months, but a new introduction of *H. duryi* changed the situation and after eight months the "control snail" constituted about 70–80% of the total number of the two species.

Hairston et al. (1975) had many objections to the experimental design and

the interpretation of the results, along the same lines as mentioned above, but they concluded that both species increase in abundance. In this case it is necessary to keep in mind that the actual number of *H. duryi* was up to 100 times that of *B. pfeifferi.*

The most valuable conclusion to be drawn from these experiments is that *H. duryi* reduced the number of *B. pfeifferi* and can thrive well in the tropics, given the same biophysical and chemical conditions as the intermediate host.

Helisoma duryi as vector for flukes and other agents of diseases

In Tables 3 and 4 all the known species of flukes using the genus *Helisoma* as first or second intermediate host in North America are given. The list is based on literature from 1927 and up to date.

The *Cercaria* sp. have not been identified. Most of the trematodes listed are parasites from fishes, amphibians and birds, and only very few of these flukes occur in mammals. In spite of the high number of trematodes using the genus *Helisoma* as intermediate host only few are reported from *H. duryi.*

Several laboratory experiments have been done on the susceptibility of *H. duryi* to infection with species of *Schistosoma.* Cram et al. (1944) failed to infect several species of *Helisoma* with *S. mansoni.* Chernin (1968) exposed *H. duryi* to *S. mansoni* miracidia but found that the miracidia were making an abortive penetration. Richards (1963) sectioned *H. duryi* exposed to *S. mansoni* and could not find any sporocysts. Nawal Haroun (personal communication) exposed *H. duryi* to hundreds of *S. haematobium* miracidia and sectioned the snails after 24 h without finding any sign of mother sporocysts.

Aboul-Ela (1973) exposed *H. duryi* at different ages to five miracidia each of *S. mansoni* and *S. haematobium* but no infections were established. Ayad et al. (1970) obtained similar results. Observations at the Danish Bilharziasis Laboratory support that *H. duryi* is refractory to *S. mansoni* and *S. haematobium.*

It has been shown by Yousif and Lämmler (1975) that *H. duryi* acts as intermediate host for *Angiostrongylus cantonensis,* the rat-lung worm causing eosinophilic meningitis of man. But all fresh water snails examined are acting as intermediate hosts for this nematode, and the "capacity index", calculated for showing the suitability of the mollusc as intermediate host, was very low for *H. duryi* and very high for the genera *Biomphalaria, Bulinus, Lymnaea* and *Physa.*

The experiments that should be carried out with Helisoma

The following deals with some aspects which must be taken into consideration in future research: why *Helisoma* supersede some snail species under laboratory conditions; under which conditions/biotopes the competition may act;

Table 3. Trematodes using the genus *Helisoma* as intermediate host

Species	1. intermediate host	2. intermediate host	Final host	Authors
Strigeidae				
Cotylurus erraticus	H. trivolvis	snails	birds	Olson (1970)
Cotylurus flabelliformis	Helisoma sp.	snails	birds	Van Haitsma (1931), Cort et al. (1944)
Apatemon gracilis	H. anceps, H. trivolvis	leeches	birds	Szidat (1931), Stunkard et al. (1941)
Diplostomatidae				
Crassiphiala bulboglossa	H. anceps, H. trivolvis	fish	birds	Hoffman (1955, 1956)
Bolbophorus confusus	H. trivolvis	fish	birds	Fox and Olson (1965), Fox (1966)
Diplostomulum scheuringi	H. anceps	fish, amphibians	birds	Etges (1961b)
Uvulifer ambloplitis	H. trivolvis	fish	birds	Wendell (1932), Hoffman and Potz (1965)
Alaria canis	H. duryi, H. trivolvis, H. campanulatum	amphibians	carnivores	Pearson (1956)
Alaria marcianae	H. duryi, H. trivolvis, H. campanulatum	amphibians	carnivores	Odlaug (1940), Johnson (1968)
Spirorchiidae				
Spirochis parvus	H. anceps, H. trivolvis, H. campanulatum		reptiles	Wall (1940), Holliman et al. (1971)
Spirorchis neurophilus	H. anceps		reptiles	Fischer (1968)
Spirorchis scripta	H. anceps		reptiles	Fischer (1968)
Spirorchis elephantis	H. trivolvis, H. campanulatum		reptiles	Wall (1941b)
Spirorchis elegans	H. anceps		reptiles	Goodchild and Kirk (1960)
Clinostomatidae				
Clinostomum marginatum	H. anceps, H. trivolvis	fish	birds	Krull (1934a), Edney (1959)

Table 3 (continued)

Species	1. intermediate host	2. intermediate host	Final host	Authors
Cyclocoelidae				
Tracheophilus cymbius	H. trivolvis		birds	Stunkard (1934)
Cyclocoelum oculeum	H. trivolvis		birds	Taft (1972)
Cyclocoelum vanelli	H. trivolvis		birds	Taft (1974)
Cyclocoelum mutabile	H. trivolvis		birds	McLaughlin (1976)
Cyclocoelum brasilianum	Helisoma sp.		birds	Taft (1975)
Echinostomatidae				
Echinostoma revolutum	Lymnaea	H. trivolvis, clams	birds	Fallis (1934), Beaver (1937)
Petasiger nitidus	H. anceps	fish	birds	Beaver (1939a)
Echinoparyphium flexum	Lymnaea sp.	Helisoma sp., amphibians	birds	McCoy (1927), Cheng (1962
Psilostomatidae				
Pseudopsilostomum ondatrae	H. anceps	fish	birds, rodents	Beaver (1939b)
Paramphistomatidae				
Wardius zibethicus	H. anceps		rodents	Murrell (1963, 1965)
Zygocotyle lunata	H. anceps		birds	Willey (1936, 1941)
Allassostomoides parvum	H. anceps, H. trivolvis	amphibians	reptiles	Beaver (1929), Krull (1933)
Megalodiscus temperatus	H. anceps, H. trivolvis, H. campanulatum	amphibians	amphibians	Krull and Price (1932), Herber (1939)
Macroderoididae				
Glypthelmins pennsylvaniensis	H. trivolvis	amphibians	amphibians	Cheng (1961)
Alloglossidium corti	H. trivolvis, H. campanulatum	insects	amphibians	McMullen (1935), Crawford (1937), Cort et al. (1939)
Alloglossidium macrobdellensis	H. trivolvis		leeches	Beckerdite (1974), Corkum and Beckerdite (1974)
Macroderoides typica	H. trivolvis, H. campanulatum	amphibians	fish	Cort et al. (1939)
Macroderoides spinifera	H. duryi	fish, amphibians	amphibians	Leigh (1956, 1958)
Paramacroderoides echinus	H. duryi	fish, amphibians	fish	Leigh and Holliman (1956)
Paramacroderoides pseudoechinus	H. duryi	fish, amphibians	fish	Leigh (1975)

Table 3 (continued)

Species	1. intermediate host	2. intermediate host	Final host	Authors
Cephalogonimidae				
Cephalogonimus americanus	H. anceps, H. trivolvis	amphibians	amphibians	Lang (1968)
Cephalogonimus salamandrus	H. trivolvis	amphibians	amphibians	Lang (1968), Dronen and Lang (1974)
Cephalogonimus brevicirrus	H. trivolvis	amphibians	amphibians	Brooks and Welch (1976)
Plagiorchiidae				
Plagitura parva	H. anceps	insects	amphibians	Mead and Corderoo (1967)
Plagitura salamandra	H. anceps	insects	amphibians	Owens (1946)
Eustomus chelydrae	H. anceps, H. trivolvis	insects	reptiles	Krull (1934a, 1937), McMullen (1935)
Haplometrana intestinalis	H. trivolvis	amphibians	amphibians	Olsen (1937), Current and Lang (1975)
Auridistomatidae				
Auridistomum chelydrae	H. trivolvis	amphibians	reptiles	Ralph (1938)
Lissorchiidae				
Lissorchis mutabilis	H. trivolvis, H. campanulatum	planarians	fish	Wallace (1941)
Lissorchis fairporti	H. trivolvis	insects	fish	Magath (1917)
Halipegidae				
Halipegus occidualis	H. trivolvis	copepods	amphibians	Thomas and Johnson (1934), Krull (1935), Macy et al. (1960)
Halipegus eccentricus	H. trivolvis	copepods	amphibians	Thomas (1939)
Gorgoderidae				
Gorgodera amplicava	clams	H. anceps, H. trivolvis	amphibians	Krull (1934b, 1936a), Goodchild (1948)

Table 4. Cercariae of unknown trematodes reported from the genus *Helisoma*

Cercaria sp.	Group	Snail species	Author
C. cortii	amphistome	H. trivolvis	Byrd and Reiber (1940)
C. compacta	echinostome	H. trivolvis	Byrd and Reiber (1940)
C. oedomatocauda	echinostome	H. trivolvis	Byrd and Reiber (1940)
C. rebstocki	echinostome	H. trivolvis	Byrd and Reiber (1940)
C. acanthocoela	xiphidiostome	Helisoma sp.	Miller (1935)
C. tricystica	xiphidiostome	H. trivolvis	Miller (1935)
C. welleri	xiphidiostome	H. anceps	McMullen (1938)
C. brachystyla	xiphidiostome	H. trivolvis	Byrd and Reiber (1940)
C. brevicauda	xiphidiostome	H. trivolvis	Byrd and Reiber (1940)
C. instigata	xiphidiostome	H. trivolvis	Byrd and Reiber (1940)
C. macrotrema	xiphidiostome	H. trivolvis	Byrd and Reiber (1940)
C. simulata	xiphidiostome	H. trivolvis	Byrd and Reiber (1940)
C. sphaerula	hemiuridae	H. trivolvis	Lyell (1932), Thomas (1934)
C. dorsata	distome	H. trivolvis	Byrd and Reiber (1940)
C. reelfooti	distome	H. trivolvis	Byrd and Reiber (1940)
C. projecta	distome	H. anceps	Willey (1930)
C. whitentoni	distome	H. trivolvis	Croft (1933)
C. pteractinota	distome	Helisoma sp.	Miller (1935)
C. tetradena	distome	H. trivolvis	Miller (1935)
C. flexicorpa	distome	H. trivolvis	Collins (1935), Hobgood (1938)
C. chandleri	distome	H. corpulentum	Abdel-Malek (1952a)
C. reynoldsi	distome	H. anceps	Etges (1961a)

the kind of health and environmental risks rising from the introduction of a new species into a new area.

a) Laboratory experiments

Controlled experimental designs for minimizing the effects of factors that might interfere with the evaluation of the results (i.e. general waste products and elimination of essential factors as calcium) should be developed. These designs would give more conclusive results on the nature of the competitive interactions.

The interactions between *H. duryi* and other snail genera than *Bulinus* and *Biomphalaria,* as for example *Lymnaea, Gyraulus, Physa,* etc. should be examined. Such experiments are essential in the interpretation of the factors involved between *H. duryi* and the intermediate hosts for schistosomes.

Experiments should be carried out to describe the "ecological niche" of the species involved, especially in relation to such factors as food, other organisms, vegetation, water velocity, water depth, temperature, calcium concentration, other ions and pH. These experiments should give some indication of the nature of the habitats in which *Helisoma* could be expected to displace the intermediate host species.

Further studies on the effect of *H. duryi* on the cercariae production from the intermediate host snails and the decoy effect of *H. duryi* should be performed.

Table 5. Trematodes that should be tested in relation to *H. duryi*

Schistosoma species
All experimental infections of *H. duryi* with *S. haematobium* and *S. mansoni* have been unsuccessful; but very small *H. duryi* and the human pathogen schistosomes should be examined more carefully.

Fasciola species
All known species of *Fasciola* have species of *Lymnaea* as intermediate hosts, but it is necessary to examine the relationship between *F. gigantica* and *H. duryi.*

Members of Paramphistomidae
In North America *Helisoma* acts as intermediate host for different species of this family, mainly parasites occurring in amphibians, reptiles, and birds (Table 3).

A high number of Paramphistomes are known from Africa, all occurring in cattle and relatives. Parasites of this family are of some economical importance.

The relationship between following parasites and *H. duryi* must be examined:
- *Paramphistomum.* For example *P. microbothrium* and *P. phillerouxi,* using different species of *Bulinus* and *Biomphalaria* as intermediate hosts;
- *Ceylonocotyle,* using *Ceratophallus natalensis* as intermediate host;
- *Stephanopharynx,* using *B. forskalii* as intermediate host;
- *Carmyerius,* using *Ceratophallus natalensis* and *B. globosus* as intermediate hosts;
- and following genera with unknown intermediate hosts: *Bothriophoron, Calicophoron,* and *Cotylophoron.*

Members of Echinostomatidae
should be examined, but no species of this family are of economically or public health importance.

Before any introduction of *H. duryi* to Africa is made on a larger scale very intensive and careful investigations on the relationship of *H. duryi* to various African parasites, especially flukes, should be carried out. The trematodes requiring investigation include members of Paramphistomidae and other important species (Table 5) and possibly some foreign species that might be introduced together with *H. duryi.*

b) A survey of the known African populations of H. duryi for parasites

c) Seminatural conditions

To evaluate the ability of *H. duryi* to compete and replace vector species in very complex systems, with alternative and abundant food sources, abundant and varied vegetation, other species of fresh water animals among these predators of fresh water snails and fluctuating temperatures, etc. to simulate natural conditions should be carried out under laboratory and semi-field conditions.

The possible effect of *H. duryi* on different crop plants (for example, rice), aquatic plants and the general effect on the biotope should be carefully evaluated under both laboratory and semi-field conditions before any active introduction of *H. duryi* into Africa.

d) Field experiments

The first field experiments to be performed should be carried out under very controlled conditions to avoid any inadvertent escape of snails. These experiments should be performed in specially constructed canals with both running and stagnant water and remote from other water sources. The final step would be control experiments under natural irrigation conditions.

The experimental design of projects under field conditions should be planned to the least detail and as many data, physical, chemical and biological, as possible be collected.

From such experiments it must be possible to examine the influence of *H. duryi* on the biotope and the interference with other snail species.

References on the trematodes using *Helisoma* as intermediate host (Tables 3 and 4) have been omitted but these can be found in a bibliography on the genus *Helisoma* which on requisition can be obtained from the Danish Bilharziasis Laboratory.

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