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TEACHING PARASITOLOGY

ECOLOGY AND CONTROL OF THE SNAIL INTERMEDIATE HOSTS OF TREMATODES IN AN HETEROGENEOUS ENVIRONMENT: THE *BIOMPHALARIA GLABRATA* MODEL IN THE INSULAR FOCUS OF GUADELOUPE

J.P. POINTIER[1] & A. THÉRON[2]

[1]*Laboratoire de Biologie Marine et Malacologie (EPHE)*
Centre de Biologie et d'Ecologie Tropicale and Méditerranéenne, Université de Perpignan,
Avenue de Villeneuve 52, 66860 Perpignan, France
[2]*Laboratoire de Biologie Animale (URA CNRS 698),*
Centre de Biologie et d'Ecologie Tropicale and Méditerranéenne, Université de Perpignan,
Avenue de Villeneuve 52, 66860 Perpignan, France

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STUDY PLAN: Introduction. - Environmental heterogeneity and malacological communities.– Lotic waters: canals, streams and rivers. - Lentic waters: pools, ponds and marshes. - Environments and population dynamics of *Biomphalaria glabrata*.- Spatial variations. - Role of aquatic vegetation.– Role of organic pollution.– Temporal variations.– Abiotic factors.– Biotic factors. - Environments and snail control. - Environmental methods.- Biological control. - Sterilizing trematodes. - Competitor snails. - Conclusions.

CHARACTERISTICS OF THE COURSE: **A) General teaching context**: graduate/specialization course; **B) Directed to**: multidisciplinary (bio-medicine students); **C) Suggested level**: mainly for graduates but also for advanced undergraduates who have sufficient knowledge of Malacology, Ecology and Parasitology; **D) Type of course**: theoretical; **E) Teaching material needed**: slides/transparences.

KEY WORDS: Medical malacology, ecology, population dynamics, snail hosts, Schistosomiasis, biological control, Antilles, Guadeloupe.

INTRODUCTION

The control of the snail intermediate hosts of trematodes of medical and veterinary interest has been considered until recently as an important element in the reduction or elimination of some of these parasites. Control programmes, for example, against human schistosomiasis, have shown that the use of molluscicides in support of other methods such as chemotherapy, sanitary education, water supply, etc., contributed to a significant reduction of parasite transmission. In Venezuela the control programme, in which molluscicides played a major role, resulted in a strong decrease of the prevalence of the intestinal schistosomiasis from 15% between 1943 and 1960 to 0,6% in 1988 (BALZAN, 1988).

At the present time, however, the increasing use of effective new drugs has in most endemic areas modified control strategies by limiting the importance given to the destruction of the snail hosts. The curative but not preventive, characteristic of medical treatment, in particular the continuing high cost of treatment campaigns, show that snail control still deserves to be in the strategy of some control programmes. Thus in certain well defined foci snail destruction by chemical, physical or biological methods, often supported by improved water supply, sanitation or health education, has demonstrated its efficacy.

Nevertheless the facets determining the most cost effective control strategy are extremely complex in their interactions. For example, the snail hosts of trematodes include a great variety of species living in very diversified habitats. Such biological and environmental heterogeneity may explain in part the difficulty of determining a good control strategy. It is therefore evident that a particular snail control programme will be most likely to succeed if it is based on a detailed biology of the snail host and the local biotic and abiotic environment.

The aim of the present paper is to illustrate, using a pedagogic and synthetic approach and with reference to published literature, some key aspects of the population biology of *Biomphalaria glabrata*, snail host of *Schistosoma mansoni* in Guadeloupe. In this respect, the *B. glabrata* model in the schistosomiasis focus of Guadeloupe seems to be exemplary, as it encompasses in a small-scale insular system, a great variety of freshwater habitats and eco-epidemiological situations.

Firstly, the general characteristics of the freshwater malacological communities of Guadeloupe will be described and secondly, the population dynamics of *B. glabrata* will be detailed. All collected data have been used in a control programme of which the results, achieved over a relatively long period, are given below.

ENVIRONMENTAL HETEROGENEITY AND MALACOLOGICAL COMMUNITIES

The freshwater malacological fauna of the tropics is relatively poor in comparison with either marine or land snails. For example, only fewer than 400 freshwater species in such a great continent as Africa have been identified (BROWN, 1994). The same phenomenon is observed in the Caribbean region. The Guadeloupean archipelago harbours only 22 species, including 6 prosobranchs, 14 pulmonates, and two bivalves (POINTIER, 1974). There is no endemic species for the archipelago and only one, *Neritillia succinea*, is restricted to the Antillean region. All the other species have a widespread distribution from the northern to the southern hemisphere of the New World (POINTIER, 1976; JELNES & POINTIER, 1985).

The freshwater habitats of Guadeloupe fall into six main types: canals, streams, rivers, ponds, marshes and forest pools (GOLVAN *et al.*, 1981). This diversity is due to the differing geomorphological characteristics of the two main islands of the Guadeloupean archipelago. Basse Terre is a volcanic mountainous island with numerous rivers, streams and canals, whereas Grande Terre is flat and calcareous, offering numerous lentic habitats such as natural or artificial ponds and marshes.

The richness and diversity of the malacological fauna in the habitats of each island are always low or very low. *B. glabrata*, which is the sole intermediate host of *S. mansoni*, is a common species and is often present in high densities (POINTIER, THÉRON & DE VATHAIRE, 1985). The malacological communities show great variety in their spatial distribution, and temporal variation is also significant. In recent years it is not unusual to record the appearance of «foreign» species with the apparently unassisted introductions of *Melanoides tuberculata* and *Biomphalaria straminea* into the archipelago (POINTIER & MC CULLOUGH, 1989; POINTIER, PARAENSE & MAZILLE, 1993). The first species has successfully colonized the whole hydrographic system and deeply modified the characteristics of the malacological communities. These observations were made in the development of a biological control programme of *B. glabrata* in several types of habitats. The results of this programme are presented at the end of this paper. The second introduced species, *B. straminea*, transmit *S. mansoni* in north-eastern Brazil. Its extension in Guadeloupe is currently limited to some ponds of Grande Terre and at present it is of no epidemiological importance.

Lotic waters: canals, streams and rivers

Artificial canals are numerous in Basse Terre island and may be divided into two main types: a) canals of sugar producers; b) small irrigation canals.

The canals of sugar producers are usually large, permanent, well maintained, and are fed from a river. The canal water returns to the river downstream of the sugar refinery or flows into the creole gardens. The more important region for this type of canal is in the north-eastern part of the island, comprising the Grosse Montagne/Lamentin area (Fig. 1).

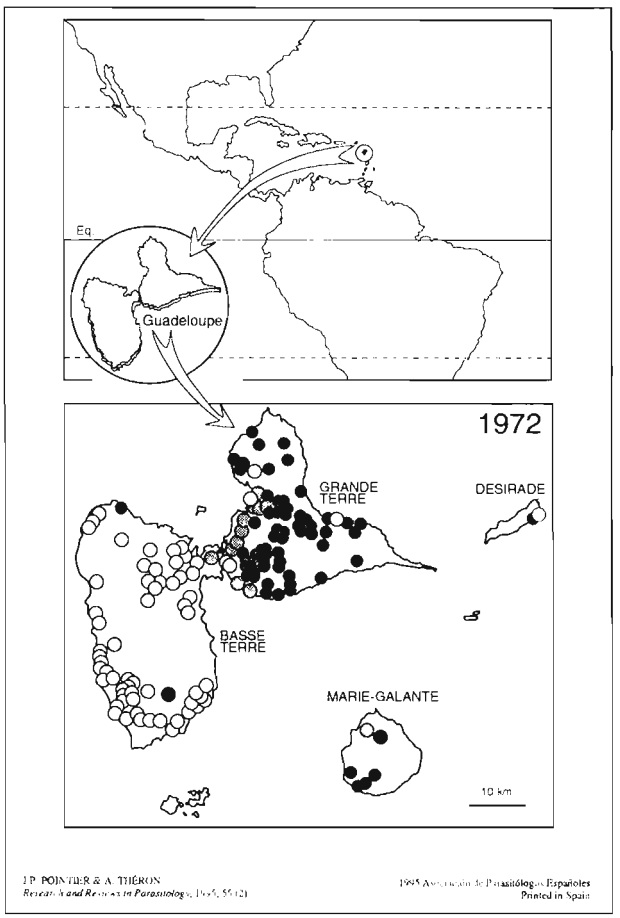

Fig. 1.– Distribution of *Biomphalaria glabrata* in the Guadeloupean archipelago in 1972. White circles: rivers, streams and canals; grey circles: marshes; black circles: ponds and lakes.

The small irrigation canals are particularly numerous in the lower part of the valleys of Capesterre, Trois-Rivières, Basse-Terre and along the leeward coast. Usually these canals are about 50 cm wide and fed from water points located on the upper part of the rivers. They irrigate banana fields or creole gardens.

The malacological communities of the sugar producing and irrigation canals are generally poor and seldom include more than four or five species. The more common snails are *B. glabrata, Physa cubensis, Pomacea glauca, Potamopyrgus parvulus* and since the beginning of the eighties, *M. tuberculata*. This thiarid snail is now the dominant species in this type of habitat (POINTIER, 1974; POINTIER & DELAY, 1995).

Streams are ubiquitous in Basse Terre island and are characterized by an irregular flow and irregular periods of drying. *B. glabrata* is the usual snail of this habitat, together with *P. cubensis, P. glauca and P. parvulus*. During the eighties, *M. tuberculata* invaded some of

these streams, displacing the majority of the *B. glabrata* populations.

Rivers are the most important hydrological element and are characterized by an irregular, but permanent flow. They harbour three species of Neritidae: *Neritina virginea* live in the mouths of the rivers, while *N. punctulata* and *N. succinea* occur in the upper parts. *B. glabrata* is absent from this type of habitat because of several unfavourable factors such as high current velocities, absence of aquatic vegetation and presence of predators. However, it can occur sporadically in some branches of rivers protected from the main course. Some of the rivers now harbour *M. tuberculata* but it is generally present at low densities and thus does not seem to affect the local, original snail fauna.

Lentic waters: pools, ponds and marshes

The malacological communities of lentic habitats are generally more diversified than those of flowing waters.

All the forest pools are situated in the rain forest at the foot of the Soufrière volcano at an altitude between 400 and 500 metres. Only one pool, Grand Etang, harbours freshwater snails. It is a small lake, formed behind a natural dam, with a total surface area of about 0,03 km^2. Originally the perimeter of the lake was virtually surrounded by aquatic vegetation that could in places spread over several metres. The vegetation belt harbours *B. glabrata, Drepanotrema depressissimum, Aplexa marmorata, Eupera viridans* and since 1976 *P. glauca* (POINTIER *et al.*, 1977, 1988).

The ponds of Grande Terre are extremely variable in size, depth, floristic associations and hydrological regime. Their number reaches more than 700, divided unequally between the more humid region of Grands Fonds, which has approximately 200 ponds and the driest areas of the northern and eastern parts of the island, where 500 ponds exist. The malacological communities living in this type of habitat are usually rich and diversified. The more common species are *B. glabrata, B. schrammi, D. depressissimum, D. lucidum, D. anatinum, A. marmorata* and *P. glauca*. Since 1981, these ponds have been the object of the unassisted introductions of *M. tuberculata* and *B. straminea*. On the other hand, *Marisa cornuarietis* was introduced in some sites for a biological control programme. These various introductions have considerably modified the malacological communities (POINTIER, 1974, 1976; POINTIER & DELAY, 1995).

The littoral part of the Grand Cul-de-Sac of Guadeloupe is characterized by particular types of vegetation including a mangrove swamp, a marshy forest of *Pterocarpus officinalis* and a herbaceous zone liable to flooding. The area extending from the marshy forest to the herbaceous zone is covered by several decimetres of water during the rainy season. It is mainly devoted to the culture of *Colocasia esculenta* and harbours variable densities of *B. glabrata, D. depressissimum, D. cimex, D. lucidum, A. marmorata* and *P. glauca*. The pasture, used for cattle grazing, is also suitable for *B. glabrata* and *D. aeruginosum*; they tend to be sporadic. Additionally, permanent ponds fed by groundwater can be found in the two preceeding environments. They are used for watering cattle or for growing water-cress and provide favourable habitats for *B. glabrata* (POINTIER, 1974, 1976; POINTIER & THÉRON, 1979).

ENVIRONMENTS AND POPULATION DYNAMICS OF *BIOMPHALARIA GLABRATA*

The population dynamics of *B. glabrata* will deal with spatio-temporal variations and the ecological factors responsible for them. The first factor influencing the distribution of the freshwater snails is linked to the chemical composition of water. Usually, very soft or very hard waters are unfavourable to the presence of snails (WILLIAMS, 1970). However, in Guadeloupe, the chemical composition of waters does not constitute a limiting factor for the distribution of *B. glabrata* (LÉVEQUE & POINTIER, 1978). Other factors also intervene, such as climatic or anthropic factors, aquatic vegetation, predators, competitors and parasites. Additionally, as already mentioned, the great variety of the environments has given prominence to the role of other ecological factors in the spatio-temporal variations of the snail host.

Spatial variations within the habitat

In a given habitat snail distribution may be very irregular and in Guadeloupe, two main factors (aquatic vegetation and organic pollution) seem to be important.

Role of aquatic vegetation: Emerged, submerged or floating plants play a role determining the density and distribution of snail populations. The aquatic vegetation provides a substrate for the growth of algae, fungi and bacteria which constitute the main source of food for the pulmonates. Such plants can also provide suitable egg-laying sites. In addition, they may provide protection against predators.

Several habitats in Guadeloupe may illustrate the importance of plants for the density and distribution of *B. glabrata*. For example, Grand Etang pool is characterized by the presence of a belt of aquatic vegetation several metres wide in places, including *Polygonum punctatum*, and the floating plant, *Pistia stratiotes*. This latter is the preferred habitat of *B. glabrata* in the pool (Fig. 2). The highest densities of the planorbid snail are observed in the central part of the *P. stratiotes* area and none was found elsewhere (POINTIER *et al.*, 1977).

In the ponds of Grande Terre, the snail populations are also strongly associated with different types of vegetation (POINTIER *et al.*, 1985). Observations in a pond located in the Grands Fonds region showed the respective influence of *Nymphaea ampla, Paspalum conjugatum* and *Hymenachne amplexicaulis* on the density of the snail host (Fig. 3) (POINTIER, 1979).

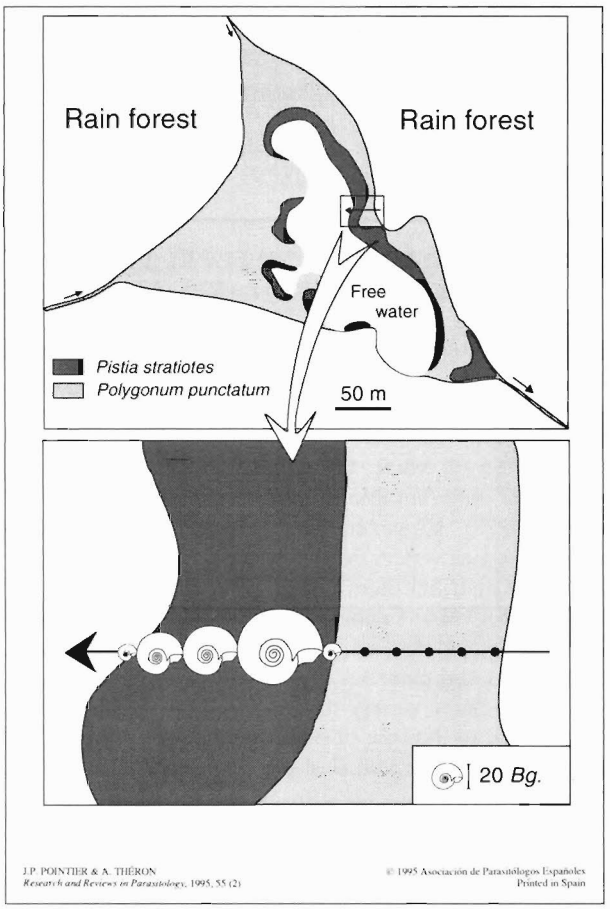

Fig. 2. Density variations of *Biomphalaria glabrata* along a transect crossing the vegetation belt surrounding Grand Etang lake, Guadeloupe.

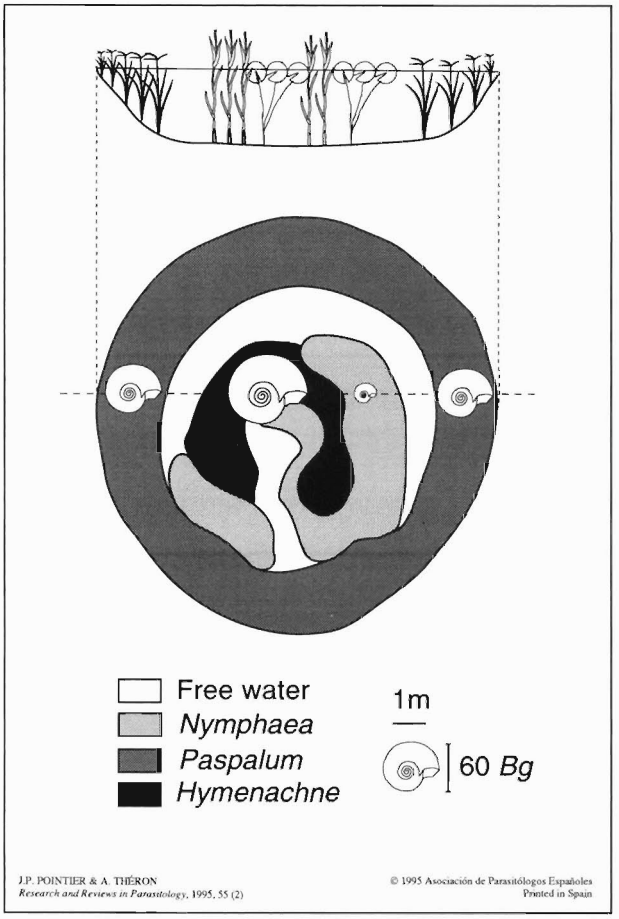

Fig. 3. Density variations of *Biomphalaria glabrata* in a pond of Grande Terre.

Role of organic pollution: Organic pollution from human activities may contribute importantly to the life style of *B. glabrata* along streams and canals. Highest densities of snails have been observed at sites where there was regular discharge of household refuse and faecal material. These materials constitute additional sources of food favouring the growth and reproduction of snails (Fig. 4). Observations on snail host distribution and bionomics and of the factors which influence them are fundamental for a better understanding of the transmission and control of the schistosome parasites (THÉRON *et al.*, 1977, 1978).

Temporal variations

Abiotic factors such as drying periods, floods, etc. influencing the temporal fluctuations of the snail host will be distinguished from biotic factors such as aquatic vegetation, predators, parasites and competitors.

Abiotic factors: Two main seasons may be considered in the Little Antilles: the dry season extending from December to April, and the rainy season from August to November. Between April and August lies an intermediate period which is very variable according to the year. In fact, only two seasons can be considered for the aquatic environments, the dry season that begins around February and the rainy season that begins in August/September. This seasonal cycle has important consequences for almost all of the aquatic habitats (POINTIER & COMBES, 1976). This is the case, among others, of the Grande Terre ponds, where the development of the *B. glabrata* populations is strongly linked to the seasonal alternation shown in Fig. 5. Similarly, in some streams the snail numbers may be reduced after a period of drying or even more drastically after a strong flood (Fig. 6 top). On the other hand, in the marshy areas located behind the mangrove, the drying and flood periods are not so sudden as is the case for lotic habitats and have no impact on snail densities because of the aquatic and other vegetation which protects snails against the strong temperature and rainfall variations (Fig. 6 bottom).

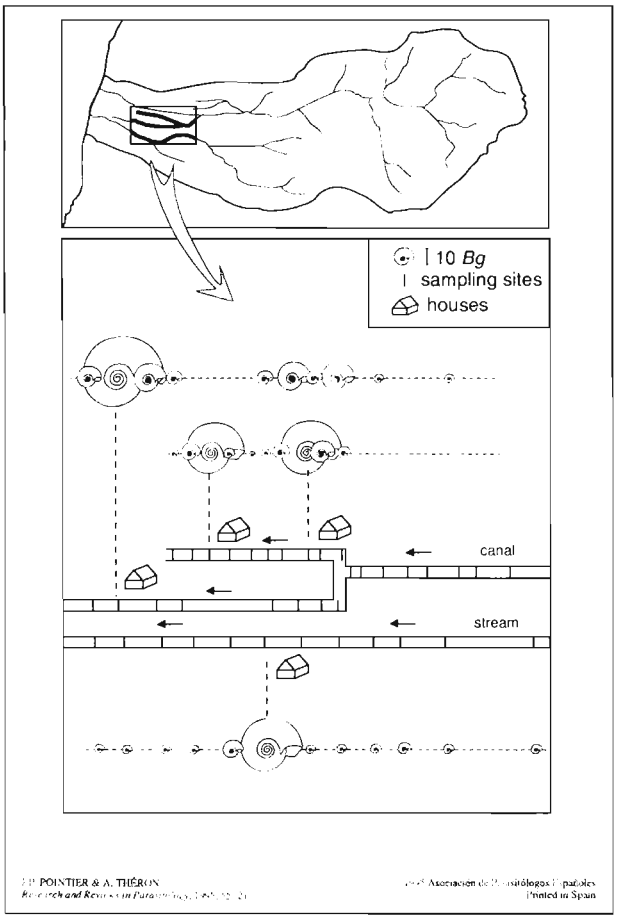

Fig. 4. Density variations of *Biomphalaria glabrata* in canals and streams in the lower part of a valley from the leeward coast of Basse Terre. Sites with high snail densities correspond to regular discharge of household refuse and faecal material.

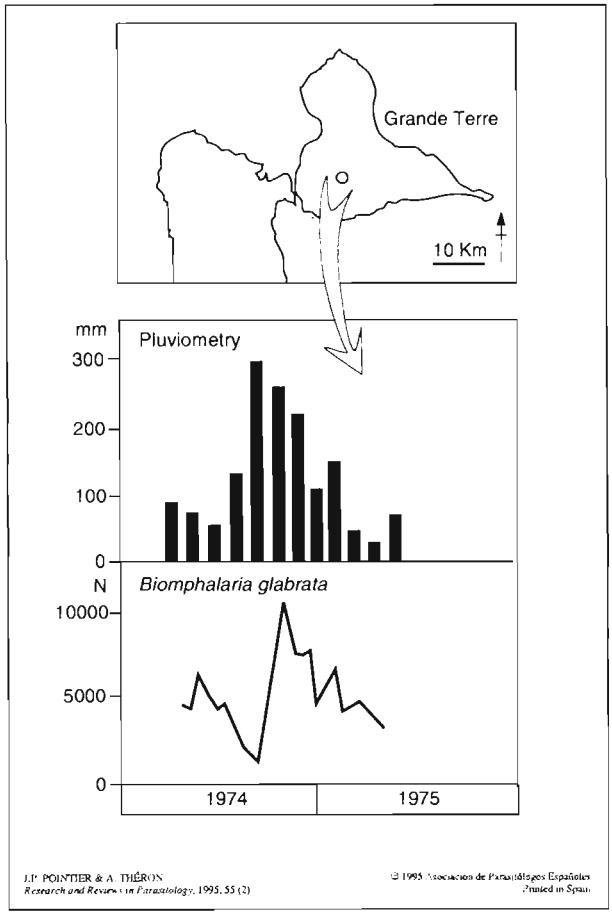

Fig. 5. Influence of the rainy season on temporal variations of *Biomphalaria glabrata* densities in a pond of Grande Terre.

Biotic factors: Several biotic factors affect the temporal variations of *B. glabrata* in Guadeloupe. As for spatial distribution, the aquatic plants can play a significant role in the temporal fluctuations of snails. In ponds the leaves of water lilies are prefered egg-laying sites, but they do not allow the full development of the young, which must rapidly migrate to other microhabitats (POINTIER, 1979).

Predators are also an important component of the density fluctuations of snails. In Guadeloupe they belong to several zoological groups: a) insects such as *Belostoma boscii* and *Hydrophilus insularis*; b) leeches: *Helobdella punctato-lineata*; c) crustaceans: *Chlamydotheca unispinosa* and *Macrobrachium faustinum*; d) fishes: *Tilapia mossambica*; e) birds: *Butorydes striatus* and *Tringa flavipes*; f) mammals: *Rattus rattus* and *Rattus norvegicus* (POINTIER & DELPLANQUE, 1976, 1978). Their role in the regulation of malacological populations is difficult to evaluate but may be illustrated by the observations that have been carried out in a pond of Grande Terre (Fig. 7 bottom). In that pond, the malacophagous leech *H. punctato-lineata* feeds exclusively upon the newly hatched snails under the water lily leaves. Its density peak is moved forward a month with that of the snails. The recruitment of young snails is important at the beginning of the rainy season when the predator density is weak, and becomes nil when the density of leeches is maximal. It starts again briefly before the dry season, when the number of leeches has disminished (Fig. 7 centre).

Parasites, especially trematodes, can also play a role in the regulation of malacological populations. Undoubtedly parasites having a sterilizing action upon their host have an influence on the dynamics of its populations. In Guadeloupe besides *S. mansoni*, eight trematodes parasitizing birds or mammals have *B. glabrata* as their intermediate host for their life cycle and several species have a partial or complete sterilizing action upon their host (NASSI, 1978, 1980, 1987; NASSI & BAYSSADE-DUFOUR, 1980; NASSI & DUPOUY, 1988; POINTIER *et al.*, 1985). This is the case, among others, of *Ribeiroia marini guadeloupensis*, a trematode living as an adult in

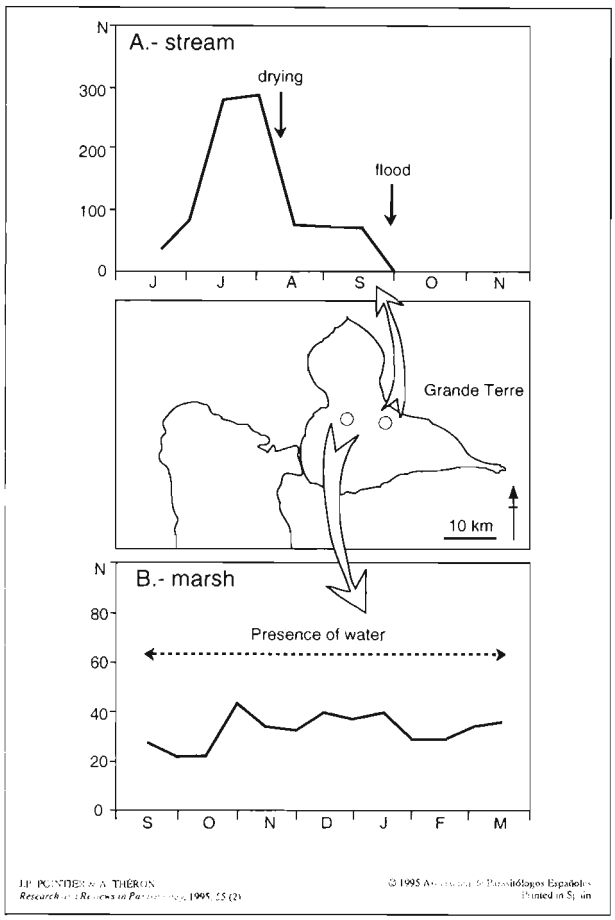

Fig. 6. Influence of climatic factors on temporal variations of *Biomphalaria glabrata* densities. Role of drying periods and floods according to the type of habitat: example of a stream and a marsh in Grande Terre.

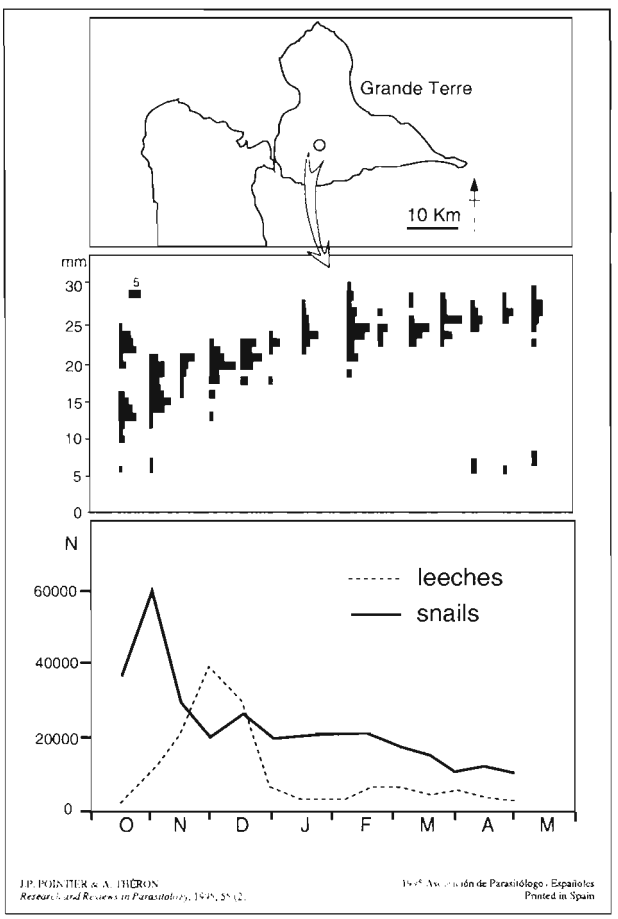

Fig. 7. Influence of the malacophagous leech *Helobdella punctato-lineata* on the population dynamics of *Biomphalaria glabrata* in a pond in Grande Terre.

the rat and using *B. glabrata* as its first intermediate host, and *Tilapia mossambica* as its second host. An experiment has been carried out in a pond of Grande terre harbouring a snail population of which the dynamics was known . The details of this experiment are given in the section on snail control.

Interspecific competition is also an important factor to be taken into account. The different snail species living in the Guadeloupean freshwater environments have neighbouring ecological niches and competition phenomena between *B. glabrata* and the recently introduced *M. tuberculata* and *M. cornuarietis* have been conspicuous in some habitats. These two species have been the object of numerous observations and experiments in the Caribbean area within biological control programmes of the snail intermediate host of *S. mansoni* (PALMER *et al.*, 1969; JOBIN *et al.*, 1978; JOBIN & LARACUENTE, 1979; PRENTICE, 1983). The results achieved in Guadeloupe are a good example of competition phenomena and variable overlapping of alimentary or spatial niches.

ENVIRONMENTS AND SNAIL CONTROL

The current control programmes of the snail hosts of trematodes and especially of schistosomes imply three main types of methods that are used separately or in association: physical, chemical or biological methods. The diversity of the environments reflect the characteristics of the transmission sites and will determine in the main the choice of one or another method.

The studies which have been carried out between 1972 and 1978 in Guadeloupe defined the main types of *S. mansoni* foci and characterized the transmission sites. A good knowledge of the population dynamics of *B. glabrata* was also recorded in these sites. All these data were used to establish an integrated control programme of the parasitosis from 1978 and applied by the Service Parasitoses of the Direction Départementale des Actions Sanitaires et Sociales (D.D.A.S.S.). This programme initiated a set of interventions at different levels: systematic detection and treatment of patients with Oxamniquine,

sanitary education, sanitation, water supply, destruction of useless canals and biological control of snails. The use of molluscicide was not judged to be necessary because of their high cost and their negative impact on the environment. Snail control has been consequently restricted to environmental methods and biological control.

Environmental methods

These methods included such engineering measures as the destruction of concrete fords and building of footbridges, straightening of banks, regular cleaning, etc. They also included the elimination of useless canals. In the urban area of Pointe-à-Pitre, the whole canal system, which was responsible for very active transmission in 1972, was eliminated by being joined to the subterranean sewerage system in 1974.

Biological control

In the past, control of the snail intermediate hosts of schistosomes has been carried out through almost exclusive and extensive use of chemical molluscicides. However, molluscicides are expensive and harmful for the environment and the organization needed to apply them is complex. Biological control was proposed as an alternative approach, but its efficiency was often questioned because in spite of numerous empirical field or laboratory observations, few concrete results were available under field conditions (MICHELSON, 1957; FERGUSON, 1977; COMBES & MCCULLOUGH, 1982; POINTIER, 1983; COMBES & CHENG, 1986; POINTIER & MCCULLOUGH 1989). Some ecological situations are however highly favourable to this type of control, as demonstrated by several field experiments carried out in Guadeloupe. On that island, two types of biological agents have been tested, sterilizing trematodes and competitor snails.

Sterilizing trematodes: It has been shown that in Guadeloupe, *B. glabrata* plays the role of intermediate host for eight trematode species. One of them, *R. marini guadeloupensis*, has a strong sterilizing action upon its host (NASSI, 1978). Eggs of this trematode have been produced by laboratory rats and introduced each week into a pond. Preceeding studies on snail population dynamics were taken as reference. A total of seven to nine million of eggs was introduced in this way between September 1976 and December 1977. Despite the low yield of these introductions, due particularly to the high turbidity of the water, this trial demonstrated that the parasite was capable of causing the disappearance of the snail population in 15 months (NASSI *et al.*, 1979). Sampling carried out during the following years showed a reappearance of the snails a year after the end of the experiment (Fig. 8). The recolonization of the pond then occurred normally and malacological populations reached their original level three years after the end of the parasite introductions (POINTIER *et al.*, 1981). This trial demonstrated the initial efficacy of this method in a closed and restricted habitat. However, in the laboratory the raising of a great number of parasite eggs is difficult because this trematode species has a low reproductive rate and its culture needs the passage of two distinct intermediate hosts, a fish and a snail, a somewhat complicated life cycle. Other biological agents were therefore investigated.

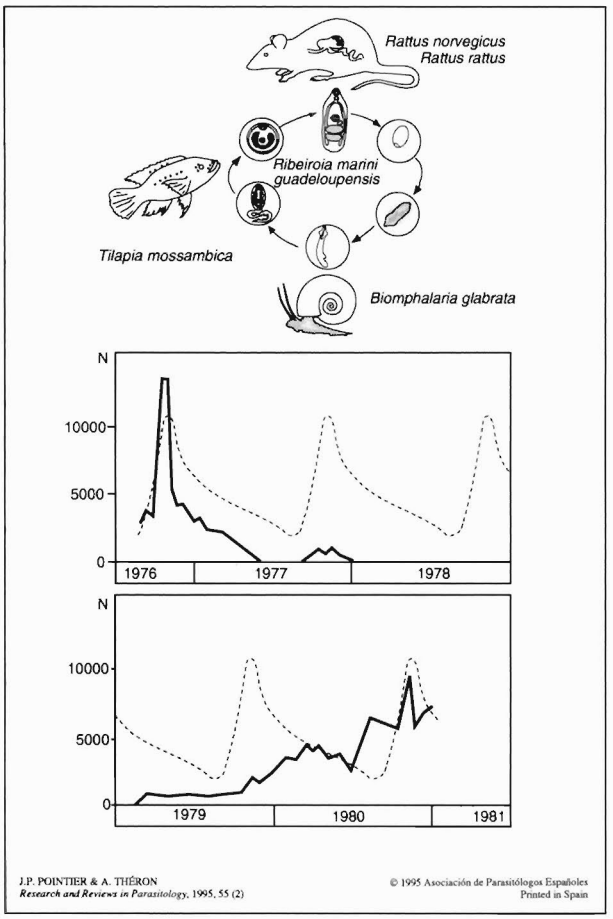

Fig. 8.– Consequences of the introduction of the sterilizing trematode *Ribeiroia marini guadeloupensis* upon temporal variations of *Biomphalaria glabrata* densities in a pond of Grande Terre. A total of 7 to 9 million parasite eggs were introduced into the pond from September 1976 to December 1977. The unassisted recolonisation has been followed from 1978 to 1981. Dotted line: density fluctuations observed during the year of reference 1975/1976.

Competitor snails: Displacement of intermediate snail hosts, imputed to the presence of one or several other concurrent species, has often been observed in the field. It is difficult however to assert that this phenomenon was the result of interspecific competition, because other factors such as predation, parasitism or particular microenvironmental conditions may have intervened. The choice of reference situations where the suspected competitor is absent makes the hypothesis of competitive exclusion highly probable; it is therefore an essential pre-

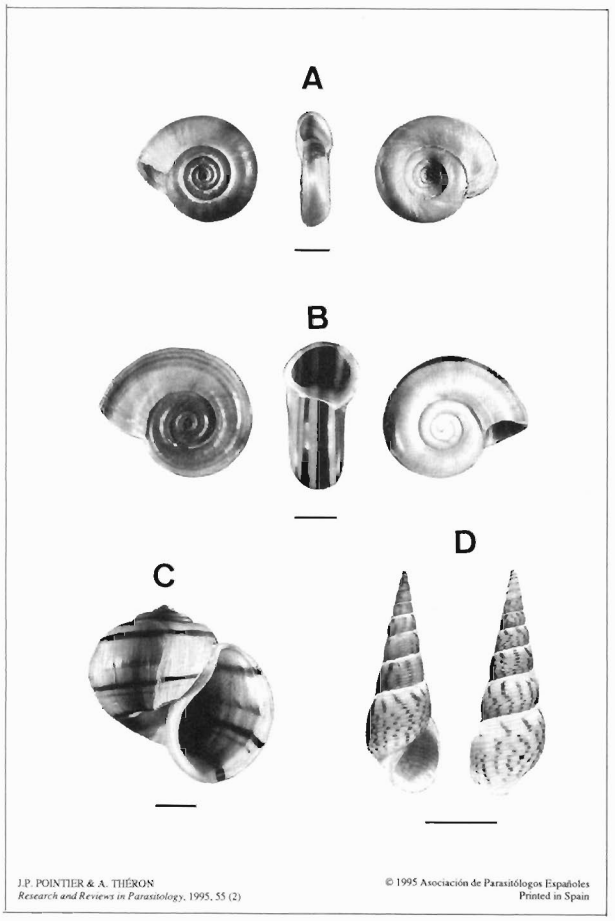

Fig. 9. - The snail intermediate host of *Schistosoma mansoni* in Guadeloupe, *Biomphalaria glabrata* (A), and the snails used as competitors in the biological control programmes in Guadeloupe: B) *Marisa cornuarietis*; C) *Pomacea glauca*; D) *Melanoides tuberculata*. Scale bar = 1 cm.

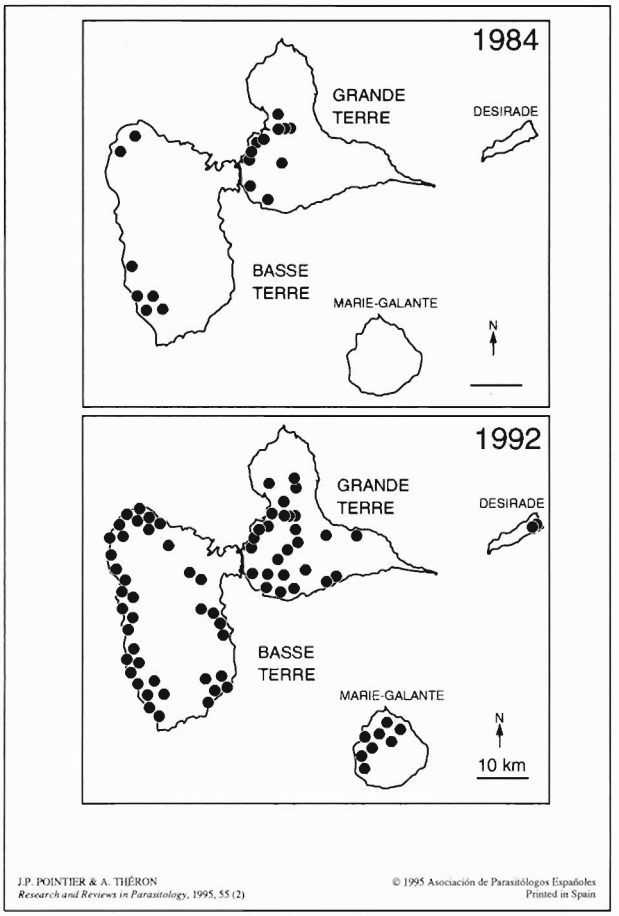

Fig. 10.- Introduction sites of the competitor snail *Melanoides tuberculata* in 1984 and its distribution in 1992.

condition for every field experiment. Two types of reference situations may be considered: a) control sites having similar environmental conditions and where the competitor will not be introduced; b) population dynamics studies in the experiment site during a certain time before the beginning of the trial. Both types of reference situations have been employed in Guadeloupe during the biological control programmes using competitor snails.

The former studied species (Fig. 9 D), *M. tuberculata*, was accidentally introduced into Guadeloupe, probably with aquatic plants used in aquaria. It originates in the Middle East and East Africa. From 1979 the snail invaded several urban canals of the Pointe-à-Pitre and Abymes areas (POINTIER & MCCULLOUGH, 1989; CORNÉLY, personal communication). In 1984 it was introduced into several streams and canals of the Basse Terre island as well as to eight sites of the marshy forest of Grande Terre.(Fig. 10). During the following years, its unassisted invasion of the whole hydrographic system was very rapid. Concomitantly, a marked reduction of the *B. glabrata* populations was observed. In 1985, following the discovery of an autochthonous case of schistosomiasis on the island of Désirade, *M. tuberculata* was introduced to several springs and to a small stream, that had harboured the snail host for many years. In 1990, the competitor snail was well established and the snail host has completely disappeared (POINTIER *et al.*, 1991).

The introduction of *M. tuberculata* in the mangrove focus was, however, a failure (Fig. 11). At first, it was planned to introduce the competitor into several plots harbouring *B. glabrata* in the northern part of the focus and to keep other plots in the southern part free. These latter would serve as a control of the dynamics of *B. glabrata* in the absence of *M. tuberculata*. Unfortunately, a few weeks after the beginning of the programme, unassisted introductions of the thiarid snail were observed at the control plots and also at two other places. It was thus decided to introduce the competitor into the whole focus. The colonization by the competitor was effective in all types of habitats, but the consequences upon *B. glabrata* varied according to the type of site. In permanent habitats such as water-cress cultures, the populations of the

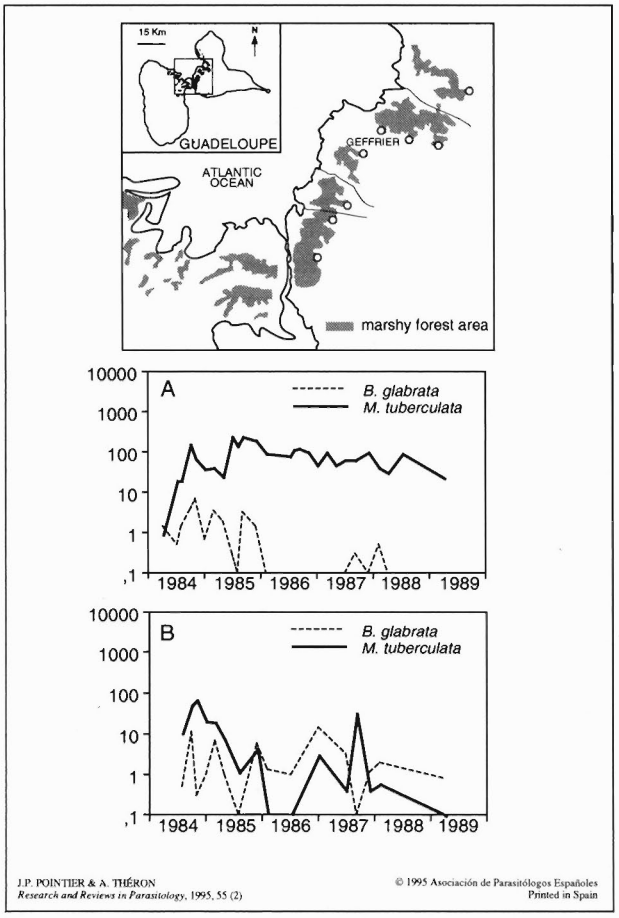

Fig. 11.– Introduction of *Melanoides tuberculata* in different habitats of the marshes of Grande Terre and its colonization dynamics: A) water-cress beds with permanent water; B) *Colocasia esculenta* cultures drying periodically.

snail host have considerably decreased. In the cultivated areas subject to periods of drying and where parasite transmission occurs, *M. tuberculata* densities remained much lower and its impact on the *B. glabrata* populations was nil. The consequences upon the infection of the reservoir host, *Rattus rattus*, were also nil, confirming the failure of the control programme in this type of focus (POINTIER *et al.*, 1993).

This last example illustrates the limits of this competitor snail. The best results have been achieved in relatively stable and homogenous environments such as springs, water-cress beds, small canals and streams. In contrast, in more heterogeneous habitats or those submitted to more or less prolonged periods of drying, *M. tuberculata* and *B. glabrata* may coexist without apparent exclusion (POINTIER *et al.*, 1991). The thiarid snail is today a common species in the whole Caribbean area and it does not seem to have deleterious effects upon the associated fauna and flora, apart from some planorbid species.

The second studied species, *M. cornuarietis* (Fig. 9 B), is endemic to Venezuela and has been present in Guadeloupe for more than twenty years. Its efficacy as a competitor of *B. glabrata* has been tested only in stagnant waters such as Grand Etang pool and some ponds of Grande Terre.

Grand Etang pool is a sylvatic focus for *S. mansoni*, characterized by populations of heavily infected *R. rattus* populations. In 1976, the prosobranch snail *Pomacea glauca* (Fig. 9 C) was accidentally introduced into the pool and caused a strong reduction of the floating plant, *P. stratiotes*, which is the preferred habitat of *B. glabrata* in the pool (Fig. 12). Concomitantly, a rapid decline of the rodent schistosome prevalences was observed from 61,3% in 1980 to 34,8% in 1981, 6,5% in 1982, 2,8% in 1983, 11,6% in 1984 and 0% in 1985 and 1986 (POINTIER *et al.*, 1988). However, in 1987, a resurgence of the parasite was noted following an exceptional dry period occurring in the southern part of Basse Terre (MORELL, 1988). *M. cornuarietis* was then introduced into four sites around the pool (Fig. 13). Colonization by that snail was rapid, and by 1989, the remaining associated *P. stratiotes/B. glabrata* colonies were eliminated, as

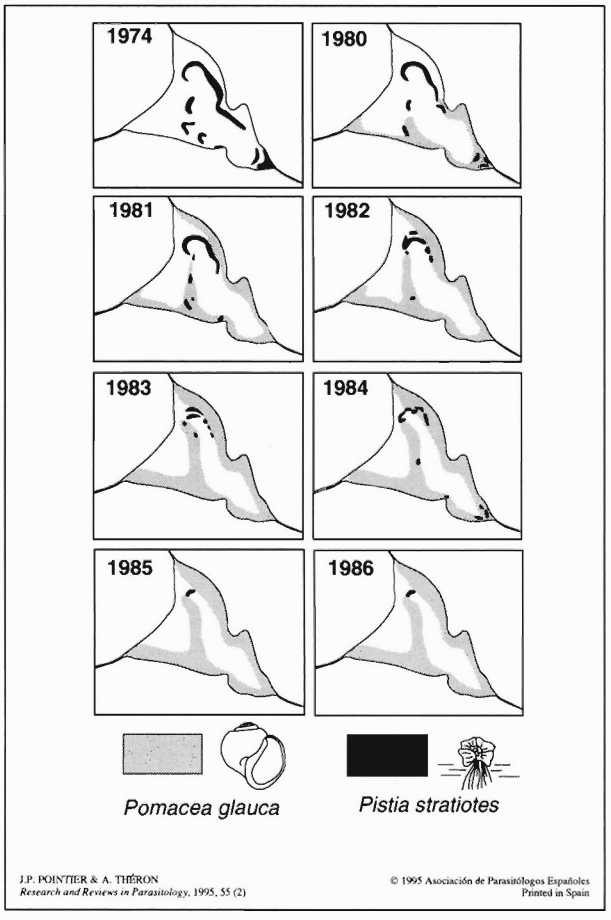

Fig. 12.– Biological control of *Biomphalaria glabrata* by *Pomacea glauca* in Grand Etang lake. The *Pistia stratiotes* zone in black is the habitat of *B. glabrata*.

was the *S. mansoni* infection in rats. Sampling carried out in 1990 and 1991 confirmed the eradication of both the snail host and its parasite (POINTIER *et al.*, 1991).

In some regions where schistosomiasis is endemic, some potential habitats do not work as active transmission sites, despite a favourable environment. The ponds of Grande Terre give a good example of this type of situation. These ponds are indeed excellent habitats for *B. glabrata* and the human water contacts are frequent for domestic purposes or watering cattle. A study of the ecological factors responsible for this situation was carried out between 1980 and 1981. This study showed that environmental conditions seemed to be favourable for the transmission of *S. mansoni*. However, no faecal pollution of the waterbodies was observed and the life cycle of the parasite was not established (POINTIER *et al.*, 1985; THÉRON & POINTIER, 1985). The protection of the ponds and of the two recently man-made lakes, Gardel and Gaschet, from schistosome infection, will depend as a matter of urgency on the measures taken to avoid fecal contamination of these sites and the detection and prompt treatment of any infected individuals. Moreover, in order to minimize this risk, a control programme of *B. glabrata* has recently been undertaken using *M. cornuarietis*.

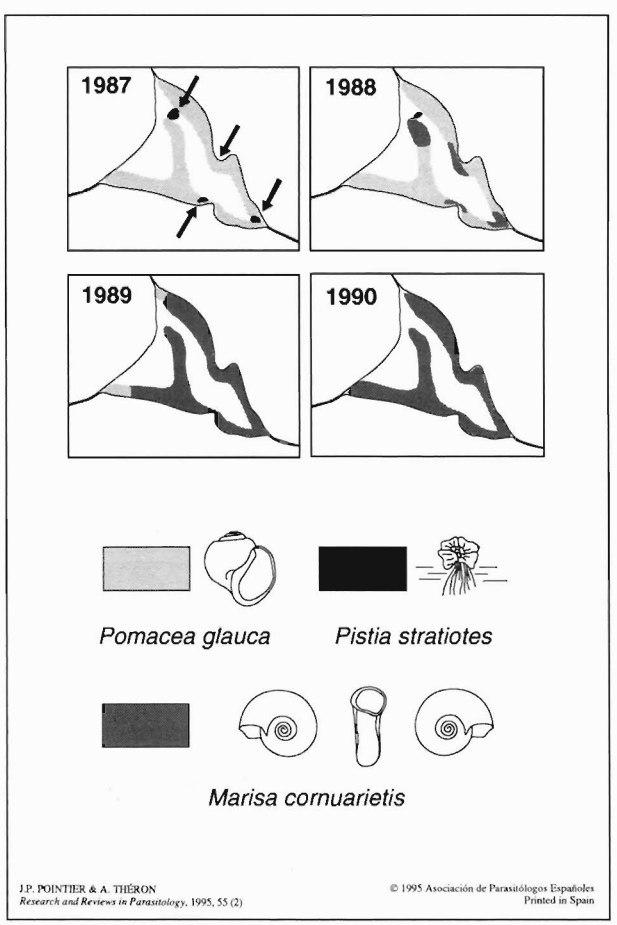

Fig. 13.– Eradication of *Biomphalaria glabrata* by *Marisa cornuarietis* in Grand Etang lake. The *Pistia stratiotes* zone in black is the habitat of *B. glabrata*.

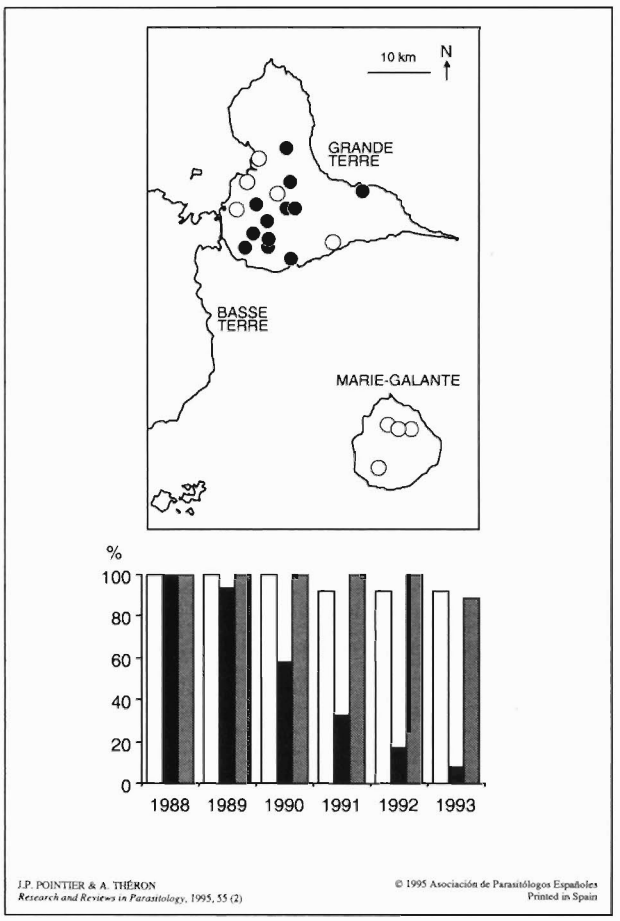

Fig. 14.– Ponds in Grande Terre harbouring *Biomphalaria glabrata* (black histograms) and its competitor *Marisa cornuarietis* (white histograms). *M. cornuarietis* was introduced into 12 ponds in 1988 (black circles). Nine other ponds harbouring *B. glabrata* (white circles), where the competitor was not introduced, were taken as control sites.

This species was first introduced in 1988 into 12 ponds harbouring *B. glabrata* populations. Five other ponds of Grande Terre and four ponds of Marie-Galante island where *M. cornuarietis* was not introduced have served as control (Fig. 14). By 1993, the results were very promising: only 8% of the ponds (i.e. one pond out of 12) still harboured *B. glabrata*, whereas 89% of the control ponds (i.e. 8 ponds out 9) contained the snail host (Fig. 14). During this study an unassisted colonization by *M. tuberculata* was also observed in 5 out 12 experimental ponds and in 3 out 9 control ponds. This unexpected invasion by another competitor snail has perhaps also played a role in the disappearance of the planorbid snail from these sites (POINTIER, 1989).

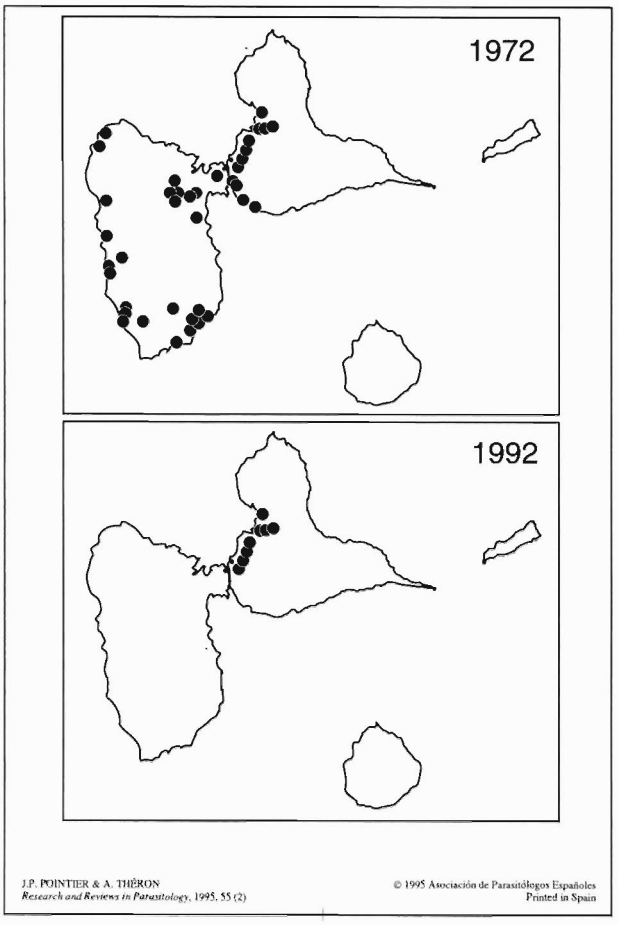

Fig. 15.– Distribution of active transmission sites for *Schistosoma mansoni* in Guadeloupe in 1972 and 1992.

CONCLUSIONS

In 1972 the island of Basse Terre was an important focus of schistosomiasis; streams and canals were the transmission sites. The biggest rivers were of minor importance because of the absence of the snail host. In all sites several associated control measures were initiated: systematic detection and treatment of patients, health education, improved sanitation and water supply, destruction of useless canals and biological control of snails. These measures proved very successful, as shown in Fig. 15.

In Grande Terre, the situation was quite different. In 1972, the marshes located behind the mangrove swamps were the sole focus, apart from canal systems in the urban focus of Pointe-à-Pitre. The urban focus was controlled quickly in 1974-1975 following the introduction of engineering measures. However, the mangrove focus remains a problem due to the presence of the reservoir host, *R. rattus*. The role of humans at this focus has considerably diminished following the systematic detection and treatment of patients and sanitary education. Biological control of the snail host has been less than sucessful and the use of molluscicides for diverse reasons cannot be seriously considered. This focus continues to be under investigation and with better knowledge of this complex habitat and its reservoir hosts it is hoped that elimination of transmission will be achieved.

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BIBLIOGRAPHY

Cited references

BALZAN (C.), 1988.– Programa de lucha contra la esquistosomiasis en Venezuela. *Ministerio de Sanidad y Asistencia Social, Direccion general Sectorial de Malariologia y Saneamiento Ambiental*: 1-18.

BROWN (D.), 1994.– *Freshwater snails of Africa and their medical importance*. Second edition. Taylor & Francis Ed., 608 pp.

COMBES (C.) & CHENG (T.C.), 1986.– Control of biomedically important mollusks. *Archives de l'Institut Pasteur d'Algérie*, 55: 153-193.

COMBES (C.) & MCCULLOUGH (F.), 1982.– Le contrôle des mollusques vecteurs de schistosomes: résultats récents et perspectives. *Revista Ibérica de Parasitología*, Vol Extra: 5-14.

FERGUSON (F.F.), 1977.– The role of biological agents in the control of schistosome-bearing snails. *U.S. Department of Health, Education and Welfare, Public Health Service, Center for Disease Control*, Atlanta, Georgia, 30333: 1-107.

GOLVAN (Y.J.), COMBES (C.), EUZEBY (J.) & SALVAT (B.), 1981.– Enquête d'épidémiologie écologique sur la schistosomose à *Schistosoma mansoni* en Guadeloupe (Antilles françaises). *Mémoires du Muséum National d'Histoire Naturelle*, 119: 1-229.

JELNES (J.E.) & POINTIER (J.P.), 1985.– Taxonomie expérimentale de *Biomphalaria* (Gastropoda: Planorbidae). III. Mobilités enzymatiques considérées comme éléments de diagnostic pour les *Biomphalaria* antillais. Etude de sept systèmes enzymatiques. *Malacologia*, 26 (1/2): 137-143.

JOBIN (W.R.), BROWN (R.A.), VELEZ (S.P.) & FERGUSON (F.F.), 1977.– Biological control of *Biomphalaria glabrata* in major reservoirs in Puerto-Rico. *American Journal of Tropical Medicine and Hygiene*, 26: 1018-1024.

JOBIN (W.R.) & LARACUENTE (A.), 1979.– Biological control of schistosome transmission in flowing water habitats. *American Journal of Tropical Medicine and Hygiene*, 28: 916-917.

JOURDANE (J.) & KULO (S.D.), 1982.– Perspectives d'utilisation de *Echinostoma togoensis* Jourdane et Kulo, 1981, dans le contrôle biologique de la bilharziose intestinale en Afrique. *Annales de Parasitologie Humaine et Comparée*, 57: 443-451.

LÉVÊQUE (C.) & POINTIER (J.P.), 1976.– Study of the growth of *Biomphalaria glabrata* (Say) and other Planorbidae in Guadalupe (West Indies). *Annals of Tropical Medicine and Parasitology*, 70: 199-204.

LÉVÊQUE (C.), POINTIER (J.P.) & TOFFART (J.L.), 1978.– Influence de quelques facteurs du milieu sur la fécondité de *Biomphalaria glabrata* (Say, 1818) (Mollusca, Pulmonata) dans les conditions du laboratoire. *Annales de Parasitologie Humaine et Comparée*, 53: 393-402.

MICHELSON (E.H.), 1957.– Studies on the biological control of schistosome-bearing snails. Predators and parasites of freshwater mollusca: a review of the literature. *Parasitology*, 47: 413-426.

MOREL (M.), 1988.– Le carême de l'année 1987 dans le sud de la Basse Terre. Conseil *Régional de la Guadeloupe, Centre ORSTOM de la Guadeloupe*: 1-45.

NASSI (H.), 1978.– Données sur le cycle biologique de *Ribeiroia marini guadeloupensis* n. ssp., Trématode stérilisant *Biomphalaria glabrata* en Guadeloupe. Entretien du cycle en vue d'un contrôle éventuel des populations de mollusques. *Acta Tropica*, 35: 41-56.

NASSI (H.), 1980.– Données expérimentales sur le cycle biologique de *Petasiger caribensis* n. sp. (Trematoda: Echinostomatidae), parasite larvaire de *Biomphalaria glabrata* en Guadeloupe. *Annales de Parasitologie Humaine et Comparée*, 55: 41-55.

NASSI (H.), 1987.– Sur quatre furcocercaires émises par *Biomphalaria glabrata* en Guadeloupe. *Annales de Parasitologie Humaine et Comparée*, 62: 17-35.

NASSI (H.) & BAYSSADE-DUFOUR (C.), 1980.– Cycle biologique de *Clinostomum golvani* n. sp. (Trematoda: Clinostomatidae) parasite larvaire de *Biomphalaria glabrata*, mollusque vecteur de *Schistosoma mansoni* en Guadeloupe. *Annales de Parasitologie Humaine et Comparée*, 55: 527-540.

NASSI (H.) & DUPOUY (J.), 1988.– Etude expérimentale du cycle biologique d'*Echinostoma parvocirrus* n. sp. (Trematoda: Echinostomatidae) parasite larvaire de *Biomphalaria glabrata* en Guadeloupe. *Annales de Parasitologie Humaine et Comparée*, 63: 103-118.

NASSI (H.), POINTIER (J.P.) & GOLVAN (Y.J.), 1979.– Bilan d'un essai de contrôle de *Biomphalaria glabrata* en Guadeloupe à l'aide d'un Trématode stérilisant. *Annales de Parasitologie Humaine et Comparée*, 54: 185-192.

PALMER (J.R.), COLON (A.Z.), FERGUSON (F.F.) & JOBIN (W.R.), 1969.– The control of schistosomiasis in Patillas, Puerto-Rico. *Public Health Reports*, 84: 1003-1008.

POINTIER (J.P.), 1974.– Faune malacologique dulçaquicole de l'île de la Guadeloupe (Antilles françaises). *Bulletin du Muséum National d'Histoire Naturelle de Paris*, 3 (159): 905-933.

POINTIER (J.P.), 1976.– Répartition locale et biogéographie des mollusques dulçaquicoles de la Guadeloupe (Antilles françaises). *Malacological Review*, 9: 85-103.

POINTIER (J.P.), 1979.– *Mollusque vecteur et schistosomose en Guadeloupe. Inventaire faunistique, études systématiques et écologiques des mollusques dulçaquicoles et du vecteur Biomphalaria glabrata. Analyse des deux principaux systèmes épidémiologiques guadeloupéens*. Thèse de Doctorat d'Etat, Université de Perpignan, Perpignan, 168 pp.

POINTIER (J.P.), 1982.– Etude de la croissance de *Biomphalaria glabrata*, mollusque hôte intermédiaire de la schistosomose intestinale dans les forêts marécageuses à *Pterocarpus* de Guadeloupe (Antilles françaises). *Malacologia*, 22 (1-2): 395-398.

POINTIER (J.P.), 1983.– La lutte biologique contre les mollusques hôtes intermédiaires des bilharzioses à l'aide de mollusques compétiteurs. *Symbioses*, 15 (2): 85-91.

POINTIER (J.P.), 1989.– Comparison between two biological control trials of *Biomphalaria glabrata* in a pond in Guadeloupe, French West Indies. *Journal of Medical and Applied Malacology*, 1: 83-95.

POINTIER (J.P.), BOREL (G.), INCANI (R.N.), BALZAN (C.), CHROSCIECHOWSKI (P.), PERERA (G.), YONG (M.) & FERRER (J.), 1991.– La lutte biologique contre les mollusques vecteurs de la schistosomiase intestinale dans la région Caraïbe. In: *Rencontres Caraïbes en Lutte Biologique* (5-7 novembre 1990), Ed. INRA, Paris (Les Colloques No. 58): 225-233.

POINTIER (J.P.) & COMBES (C.), 1976.– La saison sèche en Guadeloupe et ses conséquences sur la démographie des mollusques dans les biotopes à *Biomphalaria glabrata* (Say, 1818), vecteur de la bilharziose intestinale. *La Terre et la Vie*, 30: 121-147.

POINTIER (J.P.) & DELAY (B.), 1995.– Spread of the introduced freshwater snail *Melanoides tuberculata* (Müller, 1774) on the island of Guadeloupe, French West Indies (Prosobranchia: Thiaridae). *Haliotis*, 24: 109-116.

POINTIER (J.P.) & DELPLANQUE (A.), 1976.– Les prédateurs de *Biomphalaria glabrata* (Say, 1818), mollusque vecteur de la schistosomose en Guadeloupe (Antilles françaises). *Bulletin de la Société des Sciences Vétérinaires et Médicales Comparées de Lyon*, 78 (6): 319-331.

POINTIER (J.P.) & DELPLANQUE (A.), 1978.– Some predators of *Biomphalaria glabrata*, intermediate host of *Schistosoma mansoni* in Guadeloupe, French West Indies. In: *Proceedings of the International Conference on Schistosomiasis* (Cairo, 18-25 October 1975), 2: 727-729.

POINTIER (J.P.), FRÉDÉRIC (M.), & MAZILLE (V.), 1991.– Biological control of *Biomphalaria glabrata* by *Melanoides tuberculata* in the small island of Désirade, French West Indies. *Journal of Medical and Applied Malacology*, 3: 49-52.

POINTIER (J.P.) & MCCULLOUGH (F.), 1989.– Biological control of the snail hosts of *Schistosoma mansoni* in the Caribbean area using *Thiara* spp. *Acta Tropica*, 46: 147-155.

POINTIER (J.P.), PARAENSE (W.L.) & MAZILLE (V.), 1993.– Introduction and spreading of *Biomphalaria straminea* (Dunker, 1848) (Mollusca: Pulmonata: Planorbidae) in Guadeloupe, French West Indies. *Memórias do Instituto Oswaldo Cruz*, 88: 449-455.

POINTIER (J.P.), SALVAT (B.) DELPLANQUE (A.) & GOLVAN (Y.J.), 1977.– Principaux facteurs régissant la densité des populations de *Biomphalaria glabrata* (Say, 1818), mollusque vecteur de la schistosomose en Guadeloupe. *Annales de Parasitologie Humaine et Comparée*, 52: 277-323.

POINTIER (J.P.) & THÉRON (A.), 1979.– La schistosomose intestinale dans les forêts marécageuses à *Pterocarpus* de Guadeloupe (Antilles françaises). Ecologie du mollusque vecteur *Biomphalaria glabrata* et de son parasite *Schistosoma mansoni*. *Annales de Parasitologie Humaine et Comparée*, 54: 43-56.

POINTIER (J.P.), THÉRON (A.) & BOREL (G.), 1993.– Ecology of the introduced snail *Melanoides tuberculata* (Gastropoda: Thiaridae) in relation to *Biomphalaria glabrata* in the marshy forest zone of Guadeloupe, French West Indies. *Journal of Molluscan Studies*, 59: 421-428.

POINTIER (J.P.), THÉRON (A.) & IMBERT-ESTABLET (D.), 1988.– Decline of a sylvatic focus of *Schistosoma mansoni* in Guadeloupe (French West Indies) following the competitive displacement of the snail host *Biomphalaria glabrata* by *Ampullaria glauca*. *Oecologia*, 75: 38-43.

POINTIER (J.P.), THÉRON (A.), IMBERT-ESTABLET (D.) & BOREL (G.), 1991.– Eradication of a sylvatic focus of *Schistosoma mansoni* using biological control by competitor snails. *Biological Control*, 1: 244-247.

POINTIER (J.P.), THÉRON (A.) & VATHAIRE (F. de), 1985.– Corrélations entre la présence du mollusque *Biomphalaria glabrata* et quelques paramètres du milieu dans les mares de la Grande Terre de Guadeloupe (Antilles françaises). *Malacological Review*, 18: 37-49.

POINTIER (J.P.), TOFFART (J.L.) & LEFEVRE (M.), 1991.– Life tables of freshwater snails of the genus *Biomphalaria* (*B. gla-*

brata, B. alexandrina, B. straminea) and of one of its competitor *Melanoides tuberculata* under laboratory conditions. *Malacologia*, 33 (1-2): 43-54.

POINTIER (J.P.), TOFFART (J.L.) & NASSI (H.), 1981.- Recolonisation d'une mare de Guadeloupe (Antilles françaises) par une population de *Biomphalaria glabrata* à la suite d'un essai de contrôle biologique. *Haliotis*, 11: 197-200

PRENTICE (M.A.), 1983.- Displacement of *Biomphalaria glabrata* by the snail *Thiara granifera* in field habitats in St Lucia, West Indies. *Annals of Tropical Medicine and Parasitology*, 77: 51-59.

THÉRON (A.) & POINTIER (J.P.), 1985.- Recherches des facteurs susceptibles d'empêcher la réalisation du cycle de *Schistosoma mansoni* dans les mares de la Grande Terre de Guadeloupe (Antilles françaises). *Annales de Parasitologie Humaine et Comparée*, 60: 155-164.

THÉRON (A.), POINTIER (J.P.) & COMBES (C.), 1977.- Recherches sur les facteurs responsables des densités de cercaires de *Schistosoma mansoni* en Guadeloupe. *Annales de Parasitologie Humaine et Comparée*, 52: 421-433.

THÉRON (A.), POINTIER (J.P.) & COMBES (C.), 1978.- Approche écologique du problème de la responsabilité de l'homme et du rat dans le fonctionnement d'un site de transmission à *Schistosoma mansoni* en Guadeloupe. *Annales de Parasitologie Humaine et Comparée*, 53: 223-234.

WILLIAMS (N.V.), 1970.- Studies on aquatic pulmonate snails in Central Africa. I.- Field distribution in relation to water chemistry. *Malacologia*, 10: 153-164.

Suggested Textbooks and Monographs

BARBAULT (R.), 1981.- *Ecologie des populations et des peuplements*. Biologie Maitrises. Masson Edit. (General Ecology.)

BARBAULT (R.), 1993.- *Ecologie générale. Structure et fonctionnement de la biosphère*. Masson Edit. 2nd edition. (General Ecology.)

MALEK (E.A.), 1985.- *Snail hosts of Schistosomiasis and other snail-transmitted diseases in tropical America: a manual*. Pan American Health Organization Edit., Scientific Publication N° 478. (An outstanding volume on snail hosts taxonomy in tropical America.)

WEISER (J.), 1991.- *Biological control of vectors*. UNDP/World Bank/WHO. John Wiley & Sons Edit. (This manual is to help field workers with different aspects of the field handling of interesting new pathogens and parasites.)

Further Readings

Journal of Medical and Applied Malacology, 1989.- (see all recent issues of this Journal for references on Medical Malacology).

Journal of Molluscan Studies, 1980.- (see all recent issues of this Journal for references on snail ecology).

Malacologia, 1980.- (see all recent issues of this Journal for references on snail ecology).