A Multidisciplinary Approach to Schistosomiasis Control in Northern Cameroon

With special reference to the role of fish in snail control

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Voor mijn vader

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PREFACE

The research project described in this thesis originates from the research group Ecological Morphology of Fishes at the Department of Organismal Zoology of Leiden University, where in June 1984 I started with a research project on the possible use of molluscivorous cichlids in the control of snail intermediate hosts of schistosomiasis. The research group was already involved in field and laboratory studies on the biology of Lake Victoria cichlid fishes. The cichlids of Lake Victoria form a species flock that, before the proliferation of the Nile perch, consisted of over 300 closely resembling species (Witte, 1987), with a wide variety in morphological and ecological adaptations to different niche-requirements. This group of fishes constituted an ideal object for comparative research on functional and ecological morphology (Barel, 1985). In more than ten years of field research the ecology of different groups of cichlids was studied (e.g. zooplanktivores by Goldschmidt, 1989, and molluscivores by Hoogerhoud, 1986). Descriptive and experimental laboratory research further elucidated the complex interactions between morphological adaptations and ecological requirements (e.g. the description of the head muscles in cichlids by Anker, 1978; the relation between morphology and feeding behaviour of an insectivorous fish by Galis, 1991, and ecological significance of photoreception for different fish species by Van der Meer, 1991).

Some of the specialized molluscivorous cichlid species from shallow waters were transported from the Mwanza Gulf of Lake Victoria (Tanzania) to the Zoologisch Laboratorium in Leiden. In an early phase of my research it became evident that the knowledge of the morphology of these fishes surpassed that of their foraging behaviour. Especially the group of pharyngeal crushing species, named that way because they usually crush shells between their pharyngeal jaws, were well described by Hoogerhoud (1986) and Greenwood (1974). Furthermore, several so-called oral shelling species, i.e. fish that pull snails from their shells with their oral jaws, were described in some detail by Greenwood (1974). From stomach content analyses of Lake Victoria individuals that were caught wild, it was obvious that both groups of cichlids specialized in feeding on snails, but the mechanisms of prey selection were not yet understood. The rapid development of foraging models in ecology in the seventies and eighties, that were successful in explaining the food choice of a wide range of animals, appeared to be a good starting-point for my research. Laboratory observations of four species of snail eating cichlids proved the applicability of a simple foraging model that explained the prey choice of fish observed in tanks, expressed as the maximum benefit in prey mass obtained per second of handling time (Slootweg, 1987; Van der Klaauw, 1986; Rhijn 1987; Zoetemeyer, 1988; Mommers; 1989). Unfortunately, many questions concerning the prey choice of molluscivorous fish remained unsolved because aquarium observations were seriously hampered by building activities in and around the laboratory.

In 1987, I was invited by the consultancy firm Haskoning in Nijmegen to join a fishculture project in Cameroon in order to study possibilities to control schistosomiasis snail hosts in aquaculture ponds. The logical and necessary step from laboratory research to field trial could thus be made, and in the remaining period of laboratory research the activities were directed towards this coming field trial. The pharyngeal crushing cichlid species Astatoreochromis alluaudi was chosen for field trials and had to be reproduced in order to be able to supply an initial stock for the fish culture station in Cameroon. Meanwhile, the ability of this species to survive the high temperature and low oxygen levels normally encountered in the trial area, was assessed by See (1989). A possible problem that might arise with fish reared under artificial conditions was the reduction of the pharyngeal jaws, occurring during the ontogeny when the fish are not able to feed on their natural prey from Lake Victoria, the hard-shelled Melanoides tuberculata. A study of laboratory reared (Overbeek, 1986; later continued by J.D. Smits) and wild-caught fish (Hoogerhoud, 1986) served as a baseline study for comparison with fish to be reared in Cameroon. In August 1988, the Projet Pisciculture Lagdo started near the village of Gounougou in the North Province of Cameroon. At that moment the outline of this thesis started taking shape.

The Dutch Directorate General for Development Cooperation (DGIS) which, together with the Cameroonian Mission d'Etude et d'Aménagement de la Vallée Supérieure de la Bénoué (MEAVSB) gave financial and logistical support to the field research, favoured a more integrated schistosomiasis control strategy in which the experimental biological control of snails constituted only a part of the activities. Therefore, the approach of the project became much wider with research activities as diverse as the biology of snails, aquacultural aspects of A. alluaudi, human behaviour in relation to the use of water, primary health care, and water management. It became obvious that the operational research increasingly deviated from studies on ecological morphology and it seemed logical to look for a more suitable research institute to accommodate this project. In August 1989, the project was put within the framework of the Programme Environment and Development (PM&O) of the Centre of Environmental Science (CML) at Leiden University. CML was already deeply involved in field research in the North of Cameroon and since 1989 it has a field station at its disposition, jointly staffed by researchers from CML and the agricultural university of Dschang, Cameroon. The problem-oriented and interdisciplinary approach of PM&O, together with its presence in North Cameroon made the inclusion of the Lagdo project virtually self-evident.

The information contained in this thesis is based on field data obtained between April 1987 and July 1991. During these years the project has accommodated ten Dutch biology students who made significant contributions to the collection of data. In 1991, when it became clear that the experiments on biological control of snails by fish did not lead to satisfying results, DGIS decided to separate the fish-culture and health components, and thus the cooperation between the two implementing institutions, Haskoning and CML respectively, ended in 1991. After a positive evaluation, the schistosomiasis research programme received further funding. In January 1992 the project continued under the name Contrôle Intégré de la Bilharziose et du Paludisme (CIBP), staffed by former project student Piet Vroeg and Margot Reijnhoudt. The control of malaria was added to the project objectives, and the intensified cooperation with the University of Yaoundé, and with the malaria unit of OCEAC (Yaoundé), resulted in Cameroonian biology students participating in the project. In September 1993 the financing of the project will terminate, due to a shift in funding policy at DGIS. By then we hope that the transmission dynamics of schistosomiasis and malaria in the Benue valley of North Cameroon have been fully clarified, and that a basis has been created which will enable local authorities to implement effective control measures. The data presented in this thesis on the effectiveness of the health facilities in dealing with schistosomiasis, and the effect of integrated water management on populations of snail intermediate hosts give some reason for optimism in the control of schistosomiasis; on the other hand, the ongoing expansion of irrigated agriculture in the Benue valley gives much reason for caution, especially where it concerns the proliferation of malaria (Slootweg & Schooten, 1991; Robert et al., 1992). Continued monitoring of the health situation and where necessary the application of mitigating measures remain a necessity for the local authorities.

References

Anker, G. C. (1978). The morphology of the head muscles of a generalized Haplochromis species: H. elegans Trewavas 1933 (Pisces, Cichlidae). *Netherlands Journal of Zoology* 28: 234-271.

Barel, C.D.N. (1985). *A matter of space. Constructional morphology of cichlid fishes*. Thesis. Rijksuniversiteit Leiden.

Galis, F. (1991). *Interactions between the pharyngeal jaw apparatus, feeding behaviour and ontogeny in the cichlid fish, Haplochromis piceatus.* Thesis. Rijksuniversiteit Leiden.

Goldschmidt, P.-T. (1989). *An ecological and morphological fieldstudy on the haplochromine cichlid fishes (Pisces, Cichlidae) of Lake Victoria*. Thesis. Rijksuniversiteit Leiden.

Greenwood, P.H. (1974). The cichlid fishes of Lake Victoria, East Africa: the biology and evolution of a species flock. *Bull. Br. Mus. nat. Hist. (Zool.) suppl.* 6: 1-134.

Hoogerhoud, R.J.C. (1986). *Ecological morphology of some cichlid fishes*. Thesis. Rijksuniversiteit Leiden.

Klaauw, S. van der (1986). *Prooiselectie, prooigrootte en prooibehandeling door Haplochromis ishmaeli en Macropleurodus bicolor met de slak Bulinus truncatus, een bilhariza vector.* Student Report. Department of Organismal Zoology, Rijksuniversiteit Leiden.

Meer, H.J. van der (1991). *Ecomorphology of photoreception in Haplochromine cichlid fishes*. Thesis. Rijksuniversiteit Leiden.

Mommers, P. (1989). *Energie-opname door drie soorten cichliden bij verschillend prooi aanbod.* Student report. Department of Organismal Zoology, Rijksuniversiteit Leiden.

Overbeek, M. van (1986). *Vormplasticiteit van het pharyngeale kaakapparaat van twee molluscivore cichliden soorten Astatoreochromis alluaudi en Haplochromis ishmaeli, onder invloed van een voedselfaktor*. Student report. Department of Organismal Zoology, Rijksuniversiteit Leiden.

Rhijn, E.R. van (1988). *De prooikeuze van Haplochromis ishmaeli bij aanbod van verschillende prooitypen (Biomphalaria glabrata, Chaoborus sp. en Chironomidae).* Student report. Department of Organismal Zoology, Rijksuniversiteit Leiden.

Robert, V., A. van den Broek, P. Stevens, R. Slootweg, V. Petrarca, M. Coluzzi, G. LeGoff, M.A. Di Deco & P. Carnevale (1992). Mosquitoes and malaria transmission in irrigated rice-fields in the Benoue valley of northern Cameroon. *Acta Tropica* 52: 201-204.

See, D. (1988). *Hypoxia tolerance of Astatoreochromis alluaudi and Haplochromis sauvagei at high temperatures*. Student report. Department of Organismal Zoology, Rijksuniversiteit Leiden.

Slootweg, R. (1987). Prey selection of molluscivorous cichlids foraging on a schistosomiasis vector snail, Biomphalaria glabrata. *Oecologia* 74: 193-202.

Slootweg, R. & M.L.F. van Schooten (1991). Paludisme et irrigation. Augmentation du paludisme à cause de l'introduction des cultures irriguées à Gounougou, et une estimation de la perte au niveau du ménage. *Rapports du Projet Pisciculture* 36. MEAVSB, B.P. 17, Garoua, Cameroun.

Witte, F. (1987). *From form to fishery. An ecological and taxonomical contribution to morphology and fishery of Lake Victoria cichlids.* Thesis. Rijksuniversiteit Leiden.

Zoetemeyer, R.B. (1988). *Prooiselectie van Haplochromis ishmaeli bij aanbod van verschillende prooitypen (Biomphalaria glabrata & Chaoborus spp.).* Student report. Department of Organismal Zoology, Rijksuniversiteit Leiden.

Chapter 1

INTRODUCTION

In the arid and semi-arid areas of Africa, the floodplains of large rivers are among the richest resources in terms of biodiversity as well as economic productivity. The seasonal flooding of these areas guarantees the livelihood of fishermen, pastoralists and peasants. In order to cope with the increasing demand for food and energy, the natural flooding patterns of these rivers are increasingly altered by men; irrigation works have to guarantee yearly double cropping, and dams and artificial reservoirs are created in order to produce hydro-electricity. Due to the reduction in seasonal floods, many of the traditional production functions of floodplains are lost. The intensified use of land in areas where irrigation systems have been constructed does not allow uncontrolled flooding, necessitating the construction of flood control devices to protect the farmlands. After the damming of a floodplain river fish yields for fishermen decline dramatically. The formerly seasonally flooded plains served as breeding grounds for many riverine fish species. After recession of the floodwater, remaining pools on the plains were rich in fish which could easily be harvested by local inhabitants. After the construction of dams and irrigations systems the remaining pools and lakes only fill up with rainwater, and the yearly restocking of fish from the rivers ceases, leaving unproductive reservoirs.

Another problem that is associated with flood control and subsequent irrigation development is the proliferation of vector-borne diseases; schistosomiasis and malaria are notorious examples. The organisms responsible for transmission of these diseases (freshwater snails and mosquitoes) find suitable breeding grounds in or around an irrigation system where water is permanently present. It is generally recognized that irrigation development itself is not necessarily responsible for the creation of a vector-borne disease problem, but rather bad water management and insufficient maintenance of the irrigation system. Faulty operation and insufficient maintenance of the irrigation schemes often lead to obstruction of the drainage canals, to waterlogging and spills. This creates habitats which are favourable breeding sites for vector organisms. While the creation of breeding sites of vectors of these parasitic diseases cannot always be avoided in view of the need to extend food production through irrigated agriculture, the risks can be reduced by establishing a well designed, properly operating and carefully maintained system of irrigation.

As the construction of an irrigation scheme guarantees a permanent supply of water, the promotion of small scale fishculture to compensate for the loss of floodplain fisheries was considered a priority in the area of the former Benue floodplains in North Cameroon. Fishculture and control of schistosomiasis are not easily combined. Non-industrial fishculture would imply increased frequency and intensity of man's contact with potentially infested water. At the same time, the available means to reduce the snail populations with the use of chemical molluscicides are not applicable since all commercially available molluscicides are seriously piscitoxic. The implication is that in schistosomiasis endemic regions either the development of small scale fishculture should be disencouraged, or attempts to reduce schistosomiasis transmission should aim at alternative ways of control, not employing molluscicides. The project I am reporting on, i.e. the Lagdo Fishculture Project, had therefore the following, dual objective: (1) the restoration of floodplain fish production through water management and restocking of water bodies in the newly constructed irrigation scheme of Gounougou, and (2) the development of affordable, sustainable and effective methods of snail control and reduction of morbidity due to schistosomiasis.

This thesis concentrates on the second objective of the Lagdo Fishculture Project, i.e. aspects of schistosomiasis transmission and control in and around the Gounougou irrigation scheme, situated immediately downstream of the Lagdo dam on the right bank of the Benue river in Northern Cameroon. The achievements directly related to the first objective, i.e. the enhancement of fish culture, will only be described briefly where necessary for a better understanding of the results.

Schistosomiasis

Although many millions of people are infected with schistosome parasites, comparatively few are suffering from clinical disease. Moreover, the frequency with which manifestations are seen vary by geographical area. In general, serious disease is seen most often in people with high worm loads, excreting many eggs. In a very rough estimate, Warren & Mahmoud (1989) calculated that in 1 in 100 infected patients recognisable illness is noted. (Needles to say that these world-wide estimates cannot be projected on a particular endemic area).

The disease is caused by five species of trematode worm parasites belonging to the genus Schistosoma. The transmission cycle of the parasite involves the final host, i.e. man, the intermediate hosts, i.e. freshwater snails, and freshwater as the transmission medium (Figure 1). Adult worms live in blood vessels of the bladder or the large intestines of man, and produce eggs that actively penetrate the walls of these organs, so that these eggs can leave the human body through urine or faeces. A large number of eggs that do not succeed in passing the walls may cause a wide variety of disease symptoms, ultimately leading to symptoms of chronic disease. Description of the clinical symptoms associated to schistosomiasis infection and the complex relation between morbidity and infection would go beyond the scope of this thesis; relevant is that the worm load, duration of infection, and man's immune response are the most important parameters in explaining the occurrence of illness due to infection.

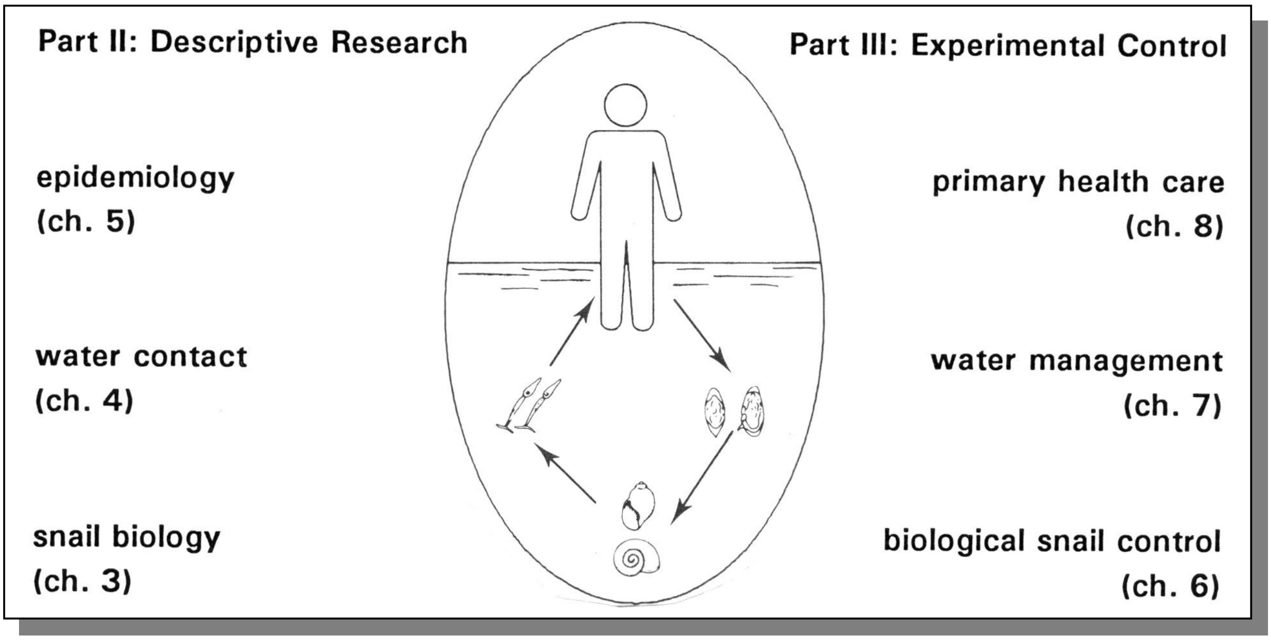


Fig. 1: The contents of this thesis in relation to the transmission cycle of schistosomiasis.

Through human urine and/or faeces the eggs find their way into freshwater habitats, either directly or via rainwater run-off. The eggs hatch, giving birth to miracidia that actively search for their intermediate host snails. Each Schistosoma species has its specific intermediate host snails. After penetration into the snails' body, the miracidia asexually reproduce and the snail starts shedding microscopic worms called cercariae. The cercariae can infect humans that are in direct contact with contaminated water. It is important to note that one infected snail can produce hundreds of male or female cercariae per day and cercarial production may continue for several months. If such a snail lives near a regularly visited site, such as a washing site, it can be responsible for infecting large numbers of persons. The free-swimming cercariae penetrate the skin of persons in contact with water. In the human body they mature and form couples that start producing eggs after some period of time. The production of eggs can continue for more than 20 years. After years of continuous infection people develop some resistance to schistosomiasis infection, which is the principal reason why in endemic areas children between 10 and 15 years of age usually show highest prevalences and intensities of infection.

Control can be directed at interruption of the transmission cycle at various points or at reducing the intensity of infection, and thus reducing morbidity:

(1) **The snail intermediate hosts**. In the days that safe drugs where not available, eradication of the intermediate host snails has long been the core activity in the control of the disease. The application of molluscicides can be a means of snail control, but the rapid reintroduction of snails necessitates repeated treatment. High purchase costs of these chemicals, operational problems in the application and their broad biocidal (piscicidal) properties have resulted in a restricted use, mostly in heavily infested waters of limited surface such as irrigation canals. Yet control of the intermediate host remains a necessity in reducing transmission and research on alternative ways of snail control deserves more attention than it actually gets.

(2) **The water-man interface.** The reduction of contact between man and water can reduce both the risks of contamination of water and infection of persons. The first can be achieved by using reliable latrines which prevent the eggs from entering the environment, the latter by provision of washing and bathing facilities, bridges, etc., that reduce contact with potentially infested water. The use of latrines is often unsystematic and erratic, so the few eggs needed yearly for continued transmission will undoubtedly enter the environment. Latrines can thus only be a useful additional measure. The same applies for the provision of washing facilities, as generally many people are also exposed because of occupational contact with water (fishermen, rice-farmers).

(3) **The adult parasites in man.** All recent control strategies are centred around the use of safe single-dose drugs that kill the adult worms, and also reverse symptoms associated with the early chronic stage of the disease. Reduction of the population of adult worms in man would result in reduced contamination of the environment with eggs. Although most schistosomiasis control programs are nowadays based on large scale use of drugs, the effectiveness of the measures in terms of reduction of transmission remains unclear.

The present day view on schistosomiasis control distinguishes two levels in control: transmission control and morbidity control. The ultimate aim of transmission control is an interruption of the transmission cycle which consequently reduces the risk of people getting infected. Snail-control, sanitary measures, sanitary education, habitat management, and last, but most important, the detection and medication of infected individuals are available instruments. It appeared difficult to protect people against (re-)infection, but given the difference between schistosomiasis infection and disease that usually only develops in heavily infected people, action is nowadays primarily aimed at preventing people from getting ill. This morbidity control is seen as a more realistic and feasible goal in schistosomiasis control. Vertical campaigns with active case-detection and treatment are launched in order to keep prevalence and intensity of infection at a level sufficiently low to prevent people from getting ill. Initially a reduction in morbidity is achieved in such an approach, but reinfection occurs and schistosomiasis indices usually return to pre-treatment levels after 2-5 years. The cost per treated individual is high; as a result follow-up campaigns to maintain or improve upon the positive results are hardly ever launched.

In most endemic regions, however, no system of organized control measures exists and the problem of schistosomiasis is dealt with at the centres of curative health care. People who feel ill are likely to visit a health centre. If the local health centre has the capacity to recognize cases of schistosomiasis, people can be treated locally, and morbidity can be kept to a minimum. The accessibility and diagnostic capacity of the primary health care facility and the availability of drugs at local level, determine to what level this approach can be effective. In contrast to vertical campaigns that concentrate on schistosomiasis control only, the approach through existing health centres has the obvious advantage of being embedded in an existing horizontal structure. Sometimes, vertically and independently organized campaigns can have harmful effects on the health care structure, such as the draining of qualified personnel and financial resources, as well as the loss of interest in schistosomiasis in existing health services if a special schistosomiasis team is operating. One of the disadvantages of the incorporation of schistosomiasis treatment in the existing health services is that morbidity control fully relies on the willingness of people to pay for treatment, but this also applies to most other diseases. There is no special reason to choose for a different approach in dealing with schistosomiasis, as long as irreversible pathology is not a common manifestation of infection in the region.

Morbidity control is a workable approach for the short term, but on the long term the objective in schistosomiasis control should always remain transmission control. In the case of the Benue valley it was obvious that the large scale development of irrigation and fishculture created potential schistosomiasis transmission risks. In order to assess these risks, a descriptive study of the snail hosts, the transmission risks for the people involved, and of the epidemiology of schistosomiasis was carried out. Since an existing health care infrastructure was already present, it was a logical next step to assess the effectiveness of the health centres in the treatment of cases of schistosomiasis. Furthermore, preventive measures were taken to curb possible increased transmission. The measures necessary for the enhancement of fish production, i.e. habitat alteration and water management, were designed in such a way that snail populations and water contacts were reduced as much as possible. In the experimental fishculture programme trials on the use of snail eating fish were carried out.

Structure of this thesis

Part I

The broader context of the Lagdo Fishculture Project and its results after three years are described in Part I of this thesis. In paragraph 2.1 the project in Cameroon is introduced, its objectives are explained, and the general results obtained after three years of participative activities in the village of Gounougou are described. The introduction of fishculture on village level was a failure, but water management for horticulture, fisheries and snail control was a success; problems encountered and lessons learnt in the process of implementation are highlighted.

The next two parts will deal with schistosomiasis, following the three levels of the transmission cycle, i.e. (1) the intermediate host snails, (2) the man-water interface, and (3) man (Figure 1). Part II will give the results of descriptive research on these three levels, while in Part III the results of control activities will be described and discussed.

Part II

Descriptive: snail intermediate hosts

Chapter 3 deals with the biology of the snail intermediate hosts in the Benue valley, where a 36 month sampling programme has provided a wealth of data. The irrigation scheme of Gounougou and its immediate vicinity were most intensively studied, but occasional observations have also been carried out further upstream and downstream of the Lagdo dam. Distribution, succession, and seasonality of six species of snails are presented in paragraph 3.1; the results are discussed with reference to the available scientific literature. Paragraph 3.2 gives the first report of the Sahelian snail intermediate host of vesical schistosomiasis, Bulinus senegalensis, in the Soudanian zone of West Africa.

Descriptive: man-water interface

Chapter 4 describes the results of 8 months of observations on the use of open water by the inhabitants of Gounougou. Water contacts of domestic, occupational and recreational nature, were quantitatively registered during many days of observation. From these data, activities and places with a potentially high risk of schistosomiasis infection were identified. Possible mitigating measures are discussed in relation to the availability of safe water.

Descriptive: man

Chapter 5 gives a description of the demography and epidemiologic features concerning schistosomiasis of two villages in the study area: the village of Gounougou where a 200 ha irrigation scheme is operational since 1987, and the village of Riao where irrigation development has not yet started. Although in some chapters the research area is larger than these two villages only, they constitute the heart of the project area and are most intensively studied. The data presented in this chapter can be considered illustrative for many other villages in this area. These villages are characterized by recent immigration of large numbers of people, and ethnic and religious diversity.

Part III

Control: intermediate host snails

Part III, experimental control, describes control measures taken at the three levels of the schistosomiasis transmission cycle (Figure 1). A rather voluminous chapter 6 is dedicated to snail-control experiments with snail-eating fish. Since 1984 I have been involved in this area of research and in this chapter the experience of eight years of involvement is summarized. Laboratory experiments on the prey choice of molluscivorous cichlid are described in paragraph 6.1. It is shown that in aquarium experiments with a simple choice of prey, the prey choice of four species of molluscivorous cichlid fish could be predicted by a foraging model. This knowledge on fish foraging later appeared to be relevant in explaining the failure of molluscivorous fish in snail control under field conditions.

The fish species proposed to be used in snail control experiments is endemic to the Lake Victoria basin, and must be considered exotic to the Benue-Niger basin. Before any experiments with exotic species could be carried out an assessment of the possible associated risks of introduction should be made. In paragraph 6.2 the introduction of the East African snail-eating cichlid fish Astatoreochromis alluaudi in fishculture ponds in northern Cameroon is assessed, making use of a protocol developed in the U.S.A.

The experiments performed in the fishculture station of Gounougou are described in paragraph 6.3, where it is concluded that the fish are not capable of controlling snails in fish ponds. Paragraphs 6.4 is a review of all experiences in biological snail control with fish, with special reference to A. alluaudi. The reasons of failure of this species are extensively discussed with respect to its foraging behaviour and anatomy. Knowledge on the functional morphology and behavioral ecology of the fish gave important cues to the explanation of its failure.

Control: man-water interface

At the level of the man-water interface schistosomiasis control is directed towards the reduction of the numbers of water contacts and reduction of vector breeding (places). Chapter 7 describes the reconstruction of one of the high-risk areas of transmission near the village of Gounougou. This chapter shows how the two objectives of the Lagdo Fishculture Project, restoration of floodplain production and schistosomiasis control, were intermingled. The reconstruction of a marshy area near the village is described in detail in order to show how technical demands for the management of rain- and drainage-water discharge, the increase of agricultural production and the control of snails can be successfully combined.

Control: man

The role of the existing health care facilities in schistosomiasis control is quantitatively analyzed in chapter 8. The data obtained from schistosomiasis surveys in the area served by the health centres of Lagdo and Gounougou (active case detection), are compared to data obtained from the records of health centres where people report to upon falling ill (passive case detection). In this manner it can be estimated what proportion of the infected population is cured at the health centre. Some methodological difficulties encountered in this relatively new area of research are presented and the importance of health care infrastructure is discussed in relation to the latest opinions on schistosomiasis control.

Finally, chapter 9 evaluates the contributions that this research project has made to the understanding and control of schistosomiasis.

Reference

Warren, K.S. & A.A.F. Mahmoud (1989). *Tropical and geographical medicine*. McGraw-Hill Book Company.

Part I Chapter 2

GENERAL BACKGROUND

2.1 Partial restoration of floodplain functions at local level: the experience of Gounougou, Benue valley, Cameroon

Slootweg, R. & M.L.F. van Schooten (1995). Partial restoration of floodplain functions at the village level: the experience of Gounougou, Benue valley, Cameroon. In: H. Roggeri. *Tropical Freshwater Wetlands: A Guide to Current Knowledge and Sustainable Management*. Development in Hydrobiology 12, Kluwer Academic Publishers (in English and French).

The creation in 1982 of the Lagdo reservoir (700 km2) in the Benue River led to severe ecological and socioeconomic changes, especially downstream of the dam. In the first place, the dam significantly altered the hydrology and the ecology of the downstream floodplain. Priority being given to generation of hydropower, water discharge at the Lagdo dam is kept to a minimum and the river only overflows when heavy rainfall makes water releases from the dam compulsory. Such releases are therefore erratic, and only allow the flooding of a marginal area. In other words, the floodplain of the Benue River no longer exists downstream of the dam.

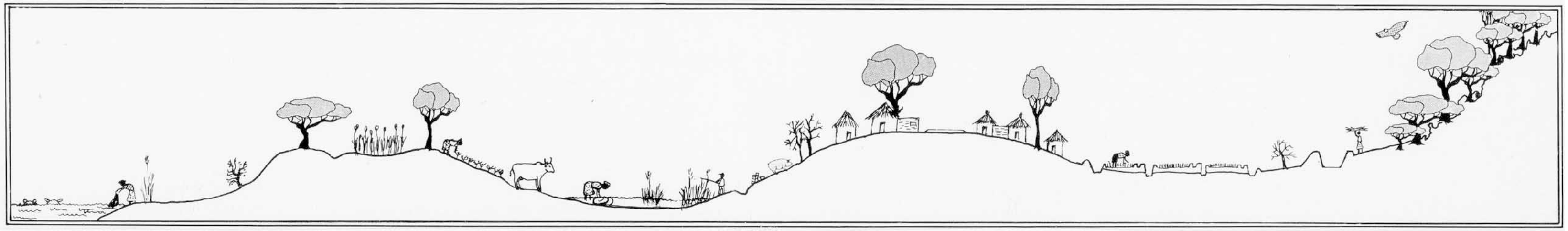
In the second place, subsequent large-scale irrigation schemes have caused environmental damage and massive (partly government-stimulated) immigration in the former floodplain, thereby increasing human pressure on natural resources. Migration from the Sahelian Extreme Northern Province into the project area since 1978 has triggered important social changes. More than 450 families belonging to over 20 ethnic groups now live in Gounougou on the East bank of the Benue River while this village originally consisted of 15 Bata fishermen families. (The floodplain used to be the main source of income for the autochthonous fishermen of the region). Poor management of water supply and faulty drainage resulted in the spread of organisms that transmit malaria (mosquitos) and schistosomiasis (freshwater snails); consequently health risks increase. Finally, local people were excluded from the planning and design of projects (such as irrigation development) that were undertaken after the creation of the reservoir. In summary it can be stated that the situation in the former floodplain is characterized by increasing health risks and threats to natural resources.

A number of activities are being carried out in the region for the purpose of mitigating the adverse effects of the Lagdo Dam and related large-scale construction of irrigation schemes, and for developing sustainable ways to use the new environment. One of these activities is being dealt with in this chapter, i.e. the Lagdo Fishculture Project (LFP).

Project design

The LFP is a pilot project for the East bank of the Benue River between the Lagdo Dam and the confluence of the Benue and Mayo Kebi rivers. Project objectives and actions to be undertaken have been identified on the basis of the actual situation, i.e. the state of the environment and problems resulting from ecological and socioeconomic changes. During the preparation phase of the project (1986), technical and environmental studies have revealed several problems occurring in the six landscape units that can be distinguished in the Gounougou area (Haskoning, 1988; Leeuwerik, 1989). These problems are summarized below (fig. 2).

- **River bed**. Since the closure of the Lagdo Dam, the water level of the river is low in the rainy season. As a result, runoff erodes the (now) steep river bank. Erosion also occurs when water is released from the Lagdo reservoir.
- **Low terrace (river bank).** This area is dominated by rain-fed cultures. In the dry season, herds graze on the remaining millet and maize stems and thus leaving the area barren.
- **Depression (floodplain pools).** During floods these pools are important breeding and spawning grounds for many river fishes; when the water level in the river lowers, fish is plentiful in the remaining shallow water bodies. In years with sufficient flood levels, farmers practise flood-recession agriculture ('mouskouari', a sorghum variety) while cattle graze on the remaining Echinochloa stagnina ('bourgou') fields. The depression of Gounougou is used for the drainage of excess rainwater and waste water from 200 ha of irrigated land, thus minimizing drainage costs (fig. 3). However, by draining the excess water into this area, a permanent swamp is created which favours the reproduction of malaria mosquitos and schistosomiasis snail hosts. The number of malaria cases increased by 400% after the introduction of irrigation (Slootweg & Schooten, 1989) while the prevalence of schistosomiasis has doubled. Land on the pool margins is fertile. However, drainage practices result in unpredictable water levels making the depression unsuitable for agriculture.



	RIVER BED	LOW TERRACE	DEPRESSION	HIGH TERRACE	PLAIN	HILLS
NATURAL DRAINAGE	Infiltration	Infiltration	Stagnation	Infiltration	Stagnation	(Surface) run-off
SOIL	Sand	Sandy	Clayey	Sandy	Clayey	Stony
NATURAL VEGETATI-ON	*Phragmites australis*	*Ziziphus mucronata* *Calotropis procera* *Balanites aegyptiaca*	*Echinochloa stagnina* *Oryza longistaminata*	*Adansonia digitata* *Ficus platyphylla* *Ficus thonningii* *Mangifera indica*	*Anogeissus leiocarpus* *Butyrosperum parkii*	*Pterocarpus erinaceus*
LAND-USE	Fishing Washing Thatching Matting Domain of hippos	Cultivation of ground-nuts, maize, millet. Construction material Grazing Fruits and fodder	Fishing Washing Grazing Brick making Mouskouari culture	Living: . dwellings . main road . water supply . market, school, dispensary	Irrigation canal Cultivation of rice Pharmacy (herbs)	Firewood, timber, fodder Pharmacy Wildlife
PROBLEMS	Erosion of steep river banks	No cultivation in dry season	Decrease in fish production and mineral deposits Increased health risks	Unreliable supply of safe drinking water	No land rights Bad water management and maintenance	Deforestation Erosion Poaching

Fig. 2: Landscape units on a schematic Wets-East transect of the Gounougou area, prior to the iomplementation of the Lagdo Fishculture Project (after Leeuwerik, 1989)

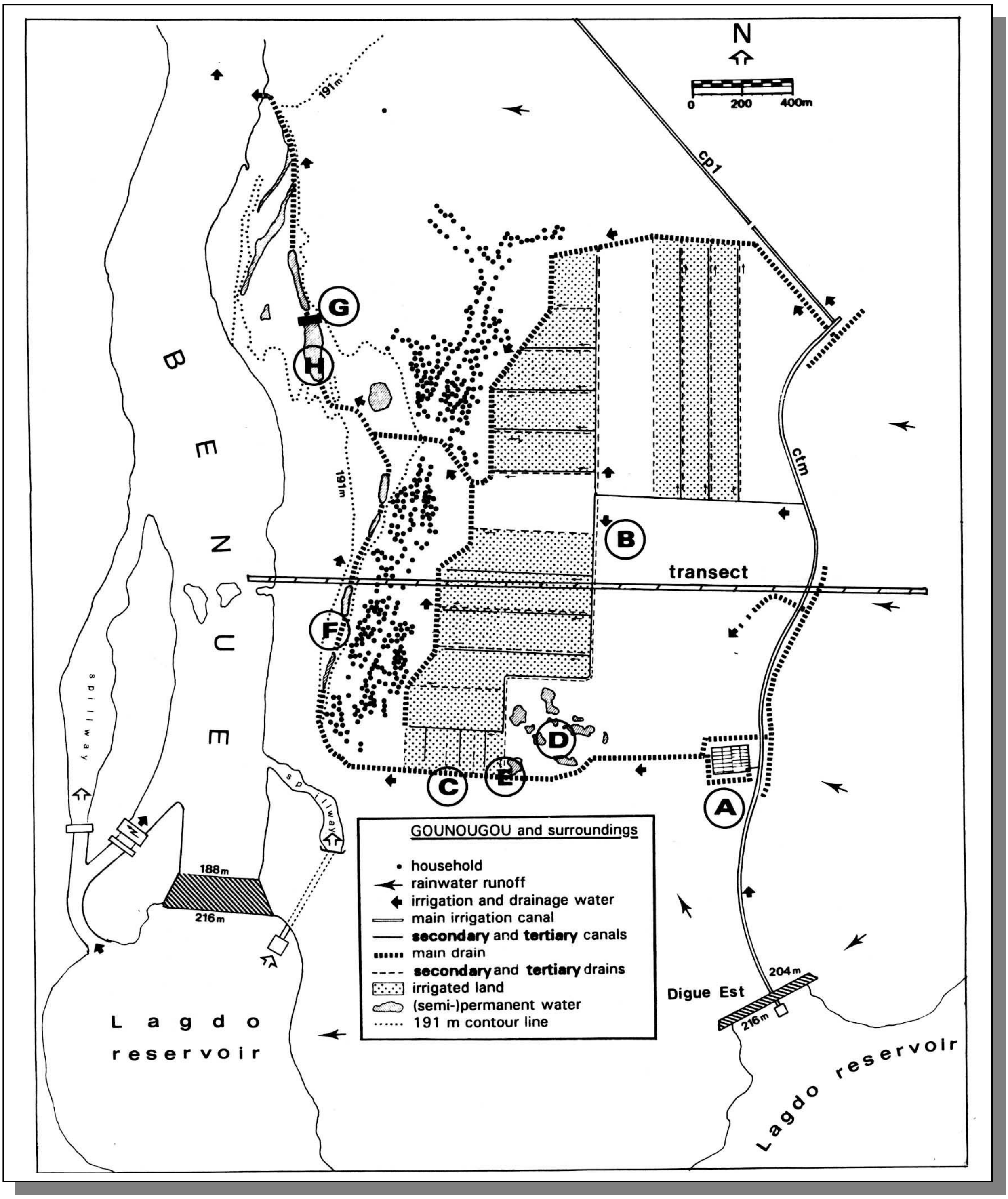


Fig. 3: Changes in the drainage system around the pilot village of Gounougou (circled letter are referred to in the text).

- **High terrace (former river bank).** Most floodplain villages are located on these former river banks as they are well drained and protected against flooding. In the rainy season many crops are grown around the houses. In Gounougou the supply of drinking water is not reliable, and people are forced to use the adjacent pools for washing and bathing; as a result, the risk of infection by schistosomiasis parasites is high.

- **Plain (former floodplain).** Nomadic herds used to graze on the plain during the dry season; yearly floods and clayey soils made the land highly suitable for mouskouari cultivation. The plain will be transformed into a large-scale irrigation development scheme which will eventually extend over thousands of hectares. Mouskouari is no longer cultivated and rice has become the main crop. The land is now state-owned; new irrigated plots are leased to interested farmers.
- **Hills.** Most fuelwood originates from this zone. However, vegetated hill slopes are being threatened by deforestation and erosion as a result of the rapid population growth and increasing demand for firewood. The remaining wildlife of the area (antelopes, porcupine, wart hogs, baboons) is now mainly concentrated in the hills; although this wildlife is legally protected, poaching is widespread.

Socioeconomic studies highlighted the poor social cohesion of a village that hosts more than 20 ethnic groups and where the autochthonous population is outnumbered by immigrants. The need for participation of the local people in the fishculture project is emphasised by these studies and they backed up the participatory approach that had already been adopted. This choice stemmed from two 'principles':

- Once the project is completed, the villagers themselves must be able to carry on with sustainable activities;
- developing sustainable forms of resource use in a new environment may require the introduction of techniques with which villagers are unfamiliar.

The findings of these studies have led to the identification of long-term objectives for LFP:

- to restore and improve the potential of the former floodplain for fisheries through the integration of fish culture into agricultural activities;
- to prevent the spread of schistosomiasis by means of integrated water management.

In accordance with the participatory approach of the project, the long-term objectives have been translated into the following short-term objectives:

- to upgrade fish production in natural and man-made water bodies;
- to integrate water management, fish culture, control of water-related vector organisms and agricultural activities in order to guarantee the optimal and sustainable use of the available natural resources;
- to strengthen the existing village structure and the relationship between the different groups of resource users, especially through the establishment of groups corresponding to specific resource uses —i.e. the so-called 'functional groups';
- to provide education and training on health aspects, fish culture, agriculture and water management;
- to design and develop a sustainable land-use system in cooperation with the local population.

Emphasis was put on pilot activities to be carried out with the local population (fish culture, water management and cultivation of vegetables). Research experiments focused on techniques for the control of waterborne diseases. Their results were translated into concrete actions that can be undertaken with local people (i.e. action-research). In other words, the project is implementing experimental management, which requires flexibility. For example, the knowledge acquired about the population dynamics of schistosomiasis snails has resulted in a water management plan for the depression. This plan aims at maximizing the production potential of the area through vegetable cultivation and fish culture, while minimizing the risk of proliferation of disease transmitting organisms (to this purpose, the effects of water management are continually monitored).

This small project only deals with water-related activities for which the villagers are directly responsible. Operation and management of state-controlled rice schemes and the Lagdo dam and reservoir are beyond its scope.

Project implementation

In 1987, an experimental aquaculture station was built as part of the LFP (A; letters between brackets refer to the map in figure 3). At the same time operation of the first 50 ha of the state-owned irrigation scheme (rice) started. No provisions were made for the drainage of excess rainwater while waste water from the irrigation scheme was discharged into the Gounougou depression, thereby creating a 2 km long swampy area. During the heavy rains of 1988, accumulated rainwater threatened to destroy newly constructed irrigation canals (B), which clearly demonstrated the need for a better drainage system. A canal was dug (C) to drain runoff into the depression, while the ancient clay quarry (D) was reconstructed as a rainwater-storage basin. A monk (E) reduces the flow to 1 m3/sec and, when closed, allows water storage in the clay quarry for dry-season use (fish culture; cattle watering; Echinochloa pastures for cattle and hippopotamuses).

Another canal (F) was dug through the depression in order to connect the different pools and drain the swamps. The depression was dammed at its downstream end (G), which created a larger pool (H), further away from the village. In the rainy season the dam gate is opened and water flows through the depression, thereby preventing the proliferation of mosquitos and snails. In the dry season the gate is closed and the water level rises by 1,5 m, causing the canal alongside the village (F) to fill up. For irrigation purposes, the villagers dig trenches from the canal to the gardens established on adjacent lands. At the end of the dry season, vegetables are harvested and the clay quarry (C) is emptied in order to catch the fish. Finally, gate E is opened and the whole depression drains (for a detailed description see Chapter 7).

The development of a new, sustainable land-use system requires the participation of the whole population. In the case of Gounougou, where immigrants outnumber autochthonous inhabitants, the cohesion of the population has to be stimulated. Village meetings with the 11 chiefs (one per village neighbourhood) and other interested persons are organized to discuss problems, recent developments and planned activities.

The project also stimulates the constitution of groups that correspond to specific activities in order to favour the exchange of experiences and the cooperation between members of the same functional group. For instance, a group of 17 women from the same neighbourhood constituted such a group. They stocked a small pen with fish and decided to integrate fish culture with onion cultivation. The group was coached by a project team member on a very regular basis. It must be stressed that the motivation of group members to persevere in this kind of new activities highly relies on the presence of a coaching person during the early phases. The Gounougou experience shows that it is better to visit the relevant groups several times a week for only half an hour than to organize semimonthly instruction sessions. In other words, the development worker must live and work in the field (not in town). After one season of successful onion culture, the women decided to continue, but the group split up into smaller groups of women living near each other. Making arrangements within a large group did not work very well (e.g. rotation of garden watering among group members). The establishment of functional groups of men appeared to be difficult. Although many men were interested in having a vegetable garden, most of them preferred to have their own garden, and have it cultivated by their family. In the first season of operation 18 gardens were created along the canal with a total surface of about 2 ha (2 groups of women, 2 of men, 2 of children, 10 individual men, 2 individual women).

Fish culture did not succeed, partly because of land-tenure problems between immigrants and the autochthonous population. The management of the depression at village level posed too many problems. Furthermore, people (from surrounding villages but also from Gounougou) continued to fish in the depression even though they knew that aquaculture activities were being introduced. The experiments with pen-culture were hampered by theft of netting material and destruction of fences by grazing hippopotamuses. Moreover, the success of fish culture depends on regular feeding. Many of the villagers have pigs that compete with the fish for household wastes. As long as fish culture has not been shown to be profitable, people prefer to feed their pigs.

Fisheries, however, were successful. After draining the depression at the end of the vegetable growing season, the area is fished by villagers using all traditional techniques. Women fish in groups and use baskets to trap the fish, a very effective technique in shallow waters. The yearly 'fishing day' is a tradition stemming from the once active floodplain fisheries. In the first year, the catch amounted to about 500 kg of fish (species from over 9 genera; many adult fish). In the second year, the catch dropped to 250 kg and consisted mainly of young fish. Obviously the first catch was exceptionally high because the depression had been entirely drained for the first time. The second catch represented the natural production of the depression (estimated at + 50 kg/ha/year). However, the villagers were pleased with the catch which constituted a very welcomed addition to their diet in the difficult last month of the dry season.

Finally, the canalization of the depression has reduced the numbers of mosquitos and snails by more than 90%. If villagers are capable of managing this area for their own benefit, the depression will no longer constitute a major danger to public health.

Project assessment

So far, the project has had the following positive effects:

- Reduction of schistosomiasis health risk, and reduction of the nuisance caused by mosquitos (the rice fields on the other side of the village still produce millions of malaria mosquitos; therefore the problem is only partially solved).
- Increase in dry-season food production.
- Partial restoration of former floodplain fisheries.
- Higher level of self-sufficiency in food and generation of income.
- More efficient use of drainage water from irrigated fields.
- Higher social interaction between different groups of immigrants and autochthones; recognition of problems by the local population and attempts at solving them.
- Increased awareness with respect to water-related health risks.

However, the following problems remain to be solved:

- **Land-tenure**. The evident success of vegetable gardening and the increase in value of the depression land resulted in many land-tenure problems between autochthones and immigrants. Today, these problems continue to stir up discussions. Women are especially vulnerable if landownership is not clear. After it became clear that plots in the depression had increased in value, the 'land chief' allotted another, less fertile plot of land to the group of women who had successfully started to integrate fish culture and vegetable gardening. Even with the help of a local anthropologist the project team was not able to get a good grip on the situation. The villagers could not, or were very reluctant to, explain these problems to outsiders. Obviously, the village needs time to establish a new land-tenure system. We are confident that they will do so, as the benefits of dry-season vegetable growing are very well recognized.
- **Damage caused by hippopotamuses.** In many instances, hippopotamuses have destroyed fences and gardens. An alternative grazing area for hippopotamuses had already been created at the clay quarry, but the animals were difficult to stop. Planting of thorn shrubs is an efficient way of preventing damage, but farmers tend to refuse to do such long-term investments as long as land-ownership issues are not settled.
- **Water management and maintenance of the irrigation and drainage system**. The management of the depression is closely linked to the management of the irrigated land. Since irrigation is new to the inhabitants of the region, much improvement is needed in the field of water management and maintenance of the irrigation and drainage system. However, this problem goes beyond the scope of LFP.

- **Theft of fish**. More intense social interactions in the village and among neighbouring villages hopefully will help tackle this problem. Intensification of the use of land will reduce thefts as many people will be working around the water body.

Lessons

Learning process

In relation to the activities carried out so far, two important facts should be noted. In the first place, solutions to problems cannot be based on a blueprint; they result from the analysis of problems, and the experience acquired on-site through experimental management of the local environment. In the second place, villagers have the opportunity to experience themselves the effects of an activity and the benefits that can be accrued from it. In other words, both the project staff and the local population learn by doing, while activities of the project should be as much as possible towards stimulating the motivation and initiatives of villagers. This learning process is probably the most valuable achievement of LFP so far, as it creates the basis on which a sustainable land-use system can be developed in cooperation with the local population.

From the point of view of the project staff, this learning process generates information not only on the management of ecosystems but also on non-technical issues that are essential to the sustainable use of resources. An incident that occurred in the Gounougou area shows how knowledge is generated by action. The villagers had constructed a small dam in a creek in order to develop fish culture. Women from other villages used to have access to this area and, therefore, went on fishing in the creek after closure of the small dam. The village meetings that followed provided a good insight on existing resource-use regulations, and possible solutions to problems concerning customary rights.

With respect to the participation of the local people in the learning process, and the involvement of villagers in experiments, the use of a video camera turned out to be quite successful. Project activities were recorded and later shown to the villagers. This led to lively discussions and an increased awareness of activities that were carried out.

Activities by the LFP, and participation of the local people were regularly monitored and discussed with the villagers. Thereby, actions can be adapted in accordance with the experience and knowledge acquired. Monitoring and evaluation are key elements in the learning process.

Flexibility

It is not advisable to carry out activities that do not fit the local situation. The 'beneficiaries' of a project actually determine which activities deserve their support —i.e. have a chance to be implemented. This means that some of the planned activities may be fully ignored. In such case, their implementation will be impossible or unsuccessful. Therefore, the project staff must be able to adjust its plan of action.

Activities that are supported by local people may also need to be adapted occasionally. For instance, farmers involved in a rice-fish experiment were supposed to first prepare their fields. However, as time passed the project staff could only conclude that no preparation work was being done. The reason for this 'resistance' soon became clear. Farmers refused to clear their land using traditional means while another project active in the area had provided 'modern tools' that could remove tree stumps from neighbouring fields ten times faster. Farmers and LFP staff jointly reconsidered land preparation works and a bulldozer was provided. Such adaptations require flexibility in terms of objectives, plan of actions and allocation of funds.

Flexibility and the capacity to adjustment also allow the development of new activities to solve new problems that inevitably occur during project implementation. For instance, LFP has tried to direct hippopotamuses towards neighbouring non-agricultural areas in order to prevent them from damaging rice fields.

Project duration

Time is an important factor for projects that are initiated in areas where new (environmental and socioeconomic) conditions prevail. In the case of Gounougou, where important immigration have occurred, lack of social cohesion still constitutes a major problem. Efforts made by the LFP (village meetings, functional groups) have helped improve the situation but tensions between immigrants and autochthonous people still are considerable, especially when it comes to issues such as land ownership. Obviously, much more time is needed before substantial progress can be made.

Short-term financing is unsuitable for projects such as LFP. The need to produce results or to achieve objectives within two years is conflicting with the participatory, long-term approach that is needed. Too often the project staff is tempted to intervene (e.g. with large machinery) to accelerate the transformation of depression lands into gardens, whereas villagers need more time to settle their own problems.

Women

Technical and organizational assistance often is not readily available to women. The presence of female project staff who paid special attention to the needs of local women and helped design women-specific activities undoubtedly has been an asset.

Women are very vulnerable with respect to rights on resource use and landownership as shown by the fact that women were deprived of their lands once their successful integration of fish culture and vegetable gardening had made clear that depression land was valuable. So far no solution to this problem could be worked out. However, this experience has not been without effect as other groups of women have started to organize themselves in order to obtain better access to resources such as irrigated rice plots. The insight and experience gained during the project, and women's increased awareness of their possibilities surely point out the need for more efforts on this issue.

Acknowledgements

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References

Haskoning (1988). Centre d'alévinage Lagdo. Rapport de syntèse. Rapports du Projet Pisciculture, 9. MEAVSB, Garoua, Cameroon.

Leeuwerik, M. (1989). Sugestions pour la mise en valeur des mares de Gounougou et Djanga, Rapports du Projet Pisciculture 20. MEAVSB, Garoua, Cameroon.

Slootweg R. & Schooten M.L.F. van (1989). Paludisme et irrigation. Augmentation du paludisme à cause de l'introduction des cultures irriguées à Gounougou, et une estimation de la perte au niveau du ménage. Rapports du Projet Pisciculture 36. MEAVSB, B.P.17, Garoua, Cameroun

PART II Chapter 3

BIOLOGY OF SNAIL INTERMEDIATE HOSTS OF SCHISTOSOMIASIS

3.1 A longitudinal study of snail intermediate hosts of trematode parasites in the Benue valley of North Cameroon.

Slootweg, R., E. van Rhijn, J.A. van Schijndel, M.J. Dijkstra & A.C. Colenbrander (1993). A longitudinal study of snail intermediate hosts of trematode parasites in the Benue valley of North Cameroon. *Journal of Medical and Applied Malacology* **5**: 45-59.

Throughout the northern Provinces of Cameroon, schistosomiasis is a public health problem. A recent nationwide survey revealed that *Schistosoma haematobium* and *S. mansoni* can reach high prevalences in individual villages in the North province (Ratard et al., 1990). Nation-wide malacological surveys carried out in Cameroon revealed that *Biomphalaria pfeifferi, Bulinus globosus, B. forskalii, B. senegalensis* and *B. truncatus* are possible intermediate hosts of human schistosomes from the Benue Valley (Same Ekobo, 1984; Same Ekobo et al., 1984; Greer et al., 1990; Mimpfoundi & Slootweg, 1991). The studies cited above have contributed significantly to the knowledge of the distribution of possible snail hosts, but the exact population dynamics of snails and the transmission dynamics of schistosomiasis are still in unclear. The construction in 1982 of a hydroelectric dam in the Benue near Lagdo, and the large scale development of irrigated agriculture on the former floodplains of the Benue valley further complicates the assessment of schistosomiasis transmission in the region. The hydrological characteristics of the area were dramatically altered and potential breeding sites for snail hosts have been created. To elucidate the dynamics of snail populations, a longitudinal study in and around the newly constructed irrigation scheme of Gounougou was conducted between April 1988 and March 1991. In 1987, this 200 ha irrigation scheme became operational; at the moment of writing an 800 ha extension is under construction near the villages of Ouro Doukoudjé and Bessoum. In 1986 the prevalence rates in Gounougou were 7% for intestinal and 21% for vesical schistosomiasis (Robert et al., 1989). Since cattle raising is one of the important economic activities in the region and fascioliasis among cattle is common (Cholet, pers. com.), data on the intermediate host snail *Lymnaea natalensis* are also included in this paper.

Snail sampling methods and sites

From April 1988 until March 1991, 13 sites were sampled monthly covering all available aquatic habitats around the village of Gounougou. Sites were sampled with dip-nets, but also hand collections were made. Search-time was taken as the standard measure to quantify the numbers of snails, as described by Olivier & Schneiderman (1956) and thus numbers of snails collected are expressed in numbers per man-hour search-time. Two persons searched for 2 x 15 minutes or one person for 30 minutes. The monthly samples were taken to the laboratory; snails were measured and exposed to sunlight, in order to detect possible cercarial shedding. On two sites with abundant numbers of snails, samples were taken weekly for several months in order to estimate the growth rates for *Bulinus forskalii, B. globosus* and *Lymnaea natalensis*. To avoid sampling errors, weekly sampled snails were measured and immediately replaced. In the aquaculture station, 24 ponds were sampled monthly, starting in May 1989. Here a fixed surface was inspected for snails; the concrete drainage device (monk) was searched with a dipnet. Thus a standard surface was inspected, taking only a few minutes per pond.

The collection sites are indicated in Figure 4; many of these sites are used intensively by inhabitants and may be considered as potential schistosomiasis transmission sites if snail hosts are present. A description of the observed water contact patterns is given in Slootweg et al. (1993a).

- **The Lagdo lake (artificial reservoir)**: the shore of the Lagdo lake at the East Dyke **(A)** is used intensively by fishermen from Gounougou. The lake was created in 1982 and reached its maximum filling level during the rainy season of 1988. The lake fills up between July and October; from November until June the shores recede.
- **The irrigation scheme**: the canals are constructed with laterite which does not allow much vegetation to develop. The primary irrigation canal **(B)** is permanently filled with varying water levels. The secondary **(C)** and tertiary irrigation canals **(D)** contain water only during irrigation and are regulated with valves. The field canals **(E)**, rice fields **(F)** and field drains **(G)** contain water during the entire growing season. Drainage water is disposed of through a tertiary **(H)** and secondary drain **(I)** into the depression of Gounougou. The drains are overgrown with aquatic weeds and are permanently filled with water. Clearing of weeds was done infrequently, and maintenance of the entire irrigation scheme was not optimal. Snail

sampling started less than one year after the scheme became operational. Two cycles of rice are grown per year; a dry season cycle between December and April and a rainy season cycle between June and November. One month after sowing, the rice seedlings are transplanted from sowing beds to the fields.

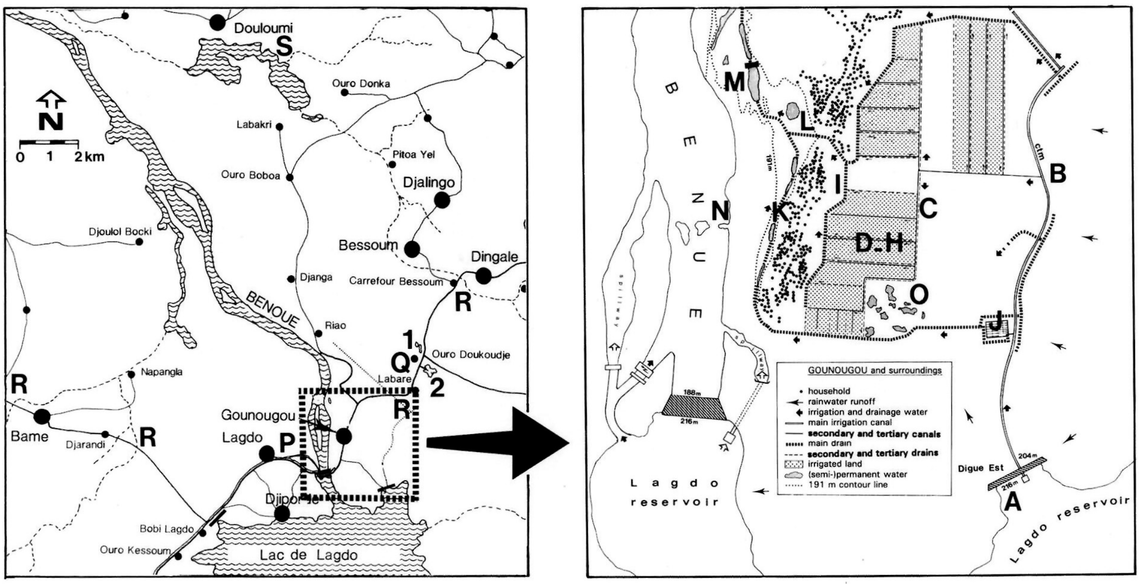


***Fig. 4**:* Location of sampling sites in the Benue valley around the village of Gounougou; sampling sites in alphabetical order explained in the text.

- **The aquaculture station (J)** is located at 500 m from the inlet of the primary irrigation canal, and operational since June 1987. The relation between pond management, fish species and snail populations has been described by Slootweg et al. (1993b).
- **The depression of Gounougou**: this former floodplain depression now serves as primary drainage canal for drainage water of the Gounougou scheme (200 ha), and for the rainwater effluent. The ford in the middle of the depression **(K)**, the entrance of the secondary drain into the depression **(L)**, and a small basin **(M)** in the outlet towards the Benue were sampled.
- **The Benue river**: since 1988 the spillway of the Lagdo dam has been opened every year; during the remaining months the water flow is reduced to 60 m3/s released by the hydroelectric plant. The banks of the Benue have been cleared of vegetation by the spilling. An intensively used washing site was inspected monthly **(N)**.
- **Natural and artificial pools**: several isolated pools have been monitored on a regular or irregular basis. Monthly samples were taken in a clay quarry **(O)** south of the Gounougou scheme. These deep clay pits are used to water cattle in the dry season. Also samples where taken from a semi-natural pool on the left bank of the Benue, near Lagdo **(P)**. This permanent pool collected drainage water from a nearby vegetable garden. After one season of intensive snail sampling the vegetable garden was moved towards the river, and the pool dried completely. Several sites were visited irregularly: laterite quarries in Ouro Doukoudje **(Q)** and temporary streams in the Benue valley **(R)**.

Water temperature was measured weekly in several ponds of the aquaculture station at 8.00 h. and 16.00 h. during the entire research period. On nine sites, also hourly or bi-hourly measurements on water temperature and oxygen contents were carried from 6.00 h. to 18.00 h., with a WTW OXI 91 field kit at 15 cm water depth. Reliable meteorological data were available from 1984 until 1988 in a nearby research station at Karewa (9°10'N, 13°30'E, 200m altitude), located in the Benue valley at 20 km from Lagdo.

Results

Meteorological data and habitat measurements

Weather conditions.

The weather over the five-year period of measurement in the Benue valley is characterized by very high temperatures and evaporation, with lowest temperatures in December and January (Fig. 5) and highest in March and April. Differences between day and night temperatures were less pronounced in the rainy season compared to the dry season. Precipitation reached a mean of 913 mm, with maximal rainfall in August. Evaporation was more than double the precipitation with a mean value of 2327mm yearly, and a maximum in March. A combination of high temperature, low relative humidity and increasing wind speed was responsible for the enormous evaporation of 200mm - 300mm per month from February to May.

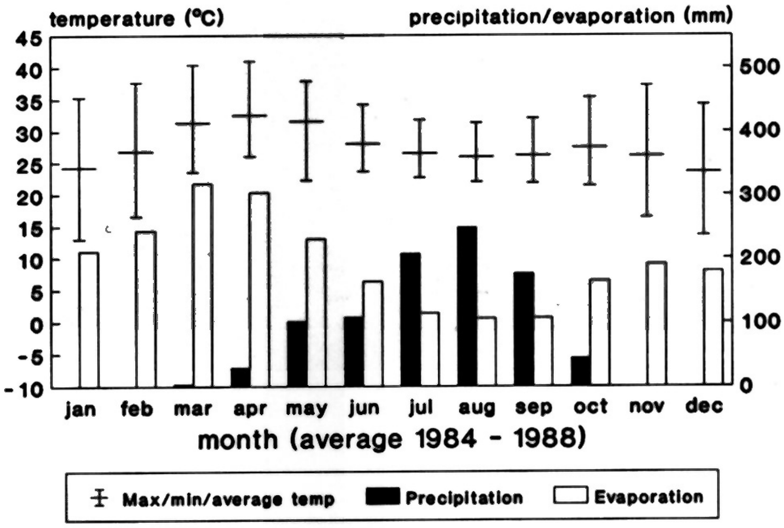


Fig. 5: Mean monthly air temperature, precipitation and evaporation for 1984 to 1988, measured at the experimental farm of Karewa.

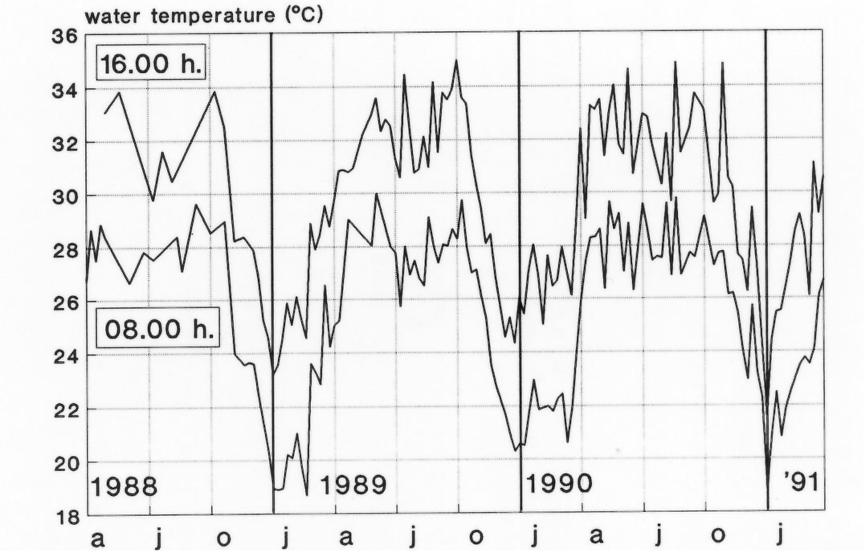


Fig. 6: Water temperatures at 8.00 h a.m. and 16.00 h p.m., measured weekly at the aquaculture station Gounougou between April 1988 and March 1991.

Seasonal water temperatures and snail densities

The water temperatures measured at the aquaculture station (Fig. 6) show remarkably high values in the rainy season between May and October, when the air temperature is relatively low. Morning temperatures (8.00 h.) during these months vary between 26°C and 30°C, and afternoon temperatures (16.00 h.) vary between 30°C and 35°C. Lowest morning water temperatures, measuring 19°C to 22°C, are registered between January and March when the cooling effect of evaporation is maximal. The length of the cool season can vary from one month in 1991 to four months in 1990. The combined effect of air temperature, relative humidity and evaporation results in water temperatures that seem contradictory to air temperatures. Similar results have already been discussed by Betterton (1984) for the Lake Chad region of Nigeria.

All but one of the correlations between water temperature and numbers of snails (Table 1) were negative, indicating that all three species are found in highest numbers when water temperatures are low or have been low in the previous months. Six correlation coefficients were significant; twice for B. forskalii at the fishculture station, and twice for both *B. truncatus* and *L. natalensis* in the drainage canals and clay quarry.

Table 1: Two-tailed test of crosscorrelation of ranks (Spearman) between average monthly water temperature as measured at the aquaculture station Gounougou and the numbers of snails encountered. Correlations were calculated for a time lag between 0 and 4 months; the time lag with highest correlation is given. Site codes refer to Figure 4.
Siginificance level: * $\alpha < 0.05$; ** $\alpha < 0.01$.

Sites (code)	snail species	crosscorrelation of ranks	time lag (months)	N	α
Fishculture station (J)	*B. forskalii*	- 0.52	2	20	*
	B. truncatus	- 0.39	2	20	-
Irrigation canals (B/C/D)	*B. forskalii*	- 0.15	0	35	-
Rice field (F)	*B. forskalii*	- 0.17	1	35	-
Field canal/ drain (E/G)	*B. forskalii*	- 0.46	1	35	**
	B. truncatus	+ 0.30	0	36	-
	L. natalensis	- 0.20	1	35	-
Drainage canals (H/I)	*B. forskalii*	- 0.29	0	36	-
	B. truncatus	- 0.43	0	36	**
	L. natalensis	- 0.44	1	35	**
Depression zone (K/L/M)	*B. forskalii*	- 0.32	0	36	-
	B. truncatus	- 0.23	1	35	-
	L. natalensis	- 0.16	1	35	-
Clay quarry (O)	*B. forskalii*	- 0.07	1	35	-
	B. truncatus	- 0.38	2	34	*
	L. natalensis	- 0.42	2	34	*

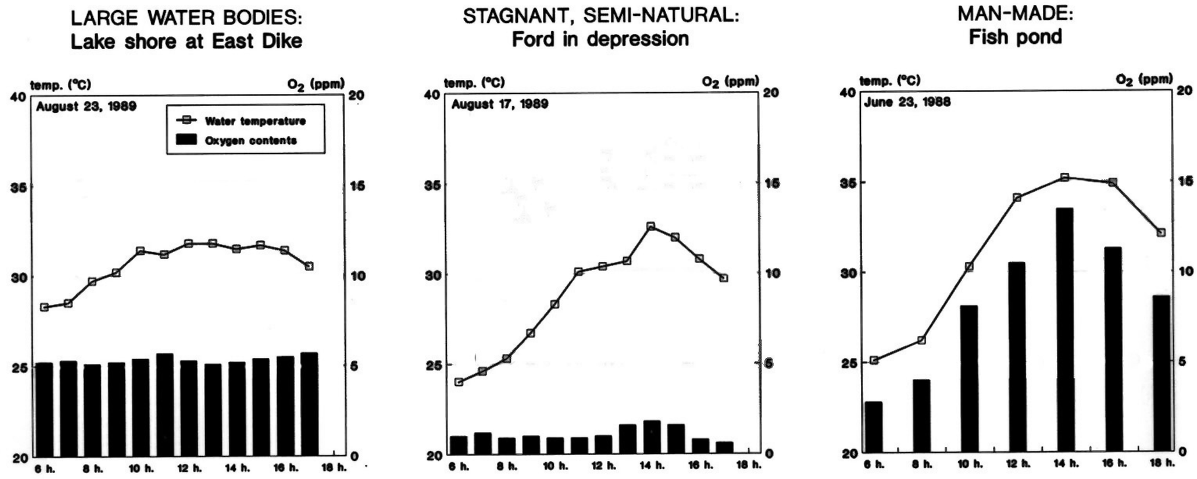
Habitat measurements

Temperature and oxygen measurements made from sunrise to sunset show that habitats can "behave" in a different way. Measurements were taken on sunny days in the rainy season, and thus not influenced by sudden showers. These data are presented to illustrate the variations during the day; data cannot be compared as measurements were taken on different days. Three main types of habitats can be recognized (for each habitat-type one representative figure is given in Figure 7):

1) Large water bodies with constant oxygen content and relatively low variation in water temperature (Fig. 7.1), i.e. the Lagdo reservoir (site A in Figure 4), the Benue river (N) and the primary irrigation canal (B) which receives water almost directly from the lake. These large volumes of water react very slowly to changes in the environment.

2) Stagnant semi-natural medium-sized water bodies. Water temperature rises sharply during the day, but oxygen content stays relatively low during the day (Fig. 7.2): i.e. the clay quarry (O), the ford (K) and drain entrance (L). These reservoirs are rather shallow (< 1.5m) and rapidly warm up. There is little turbulence and the exchange of oxygen with the air is low. The quantity of oxygen producing algae appeared low compared to the next habitat.

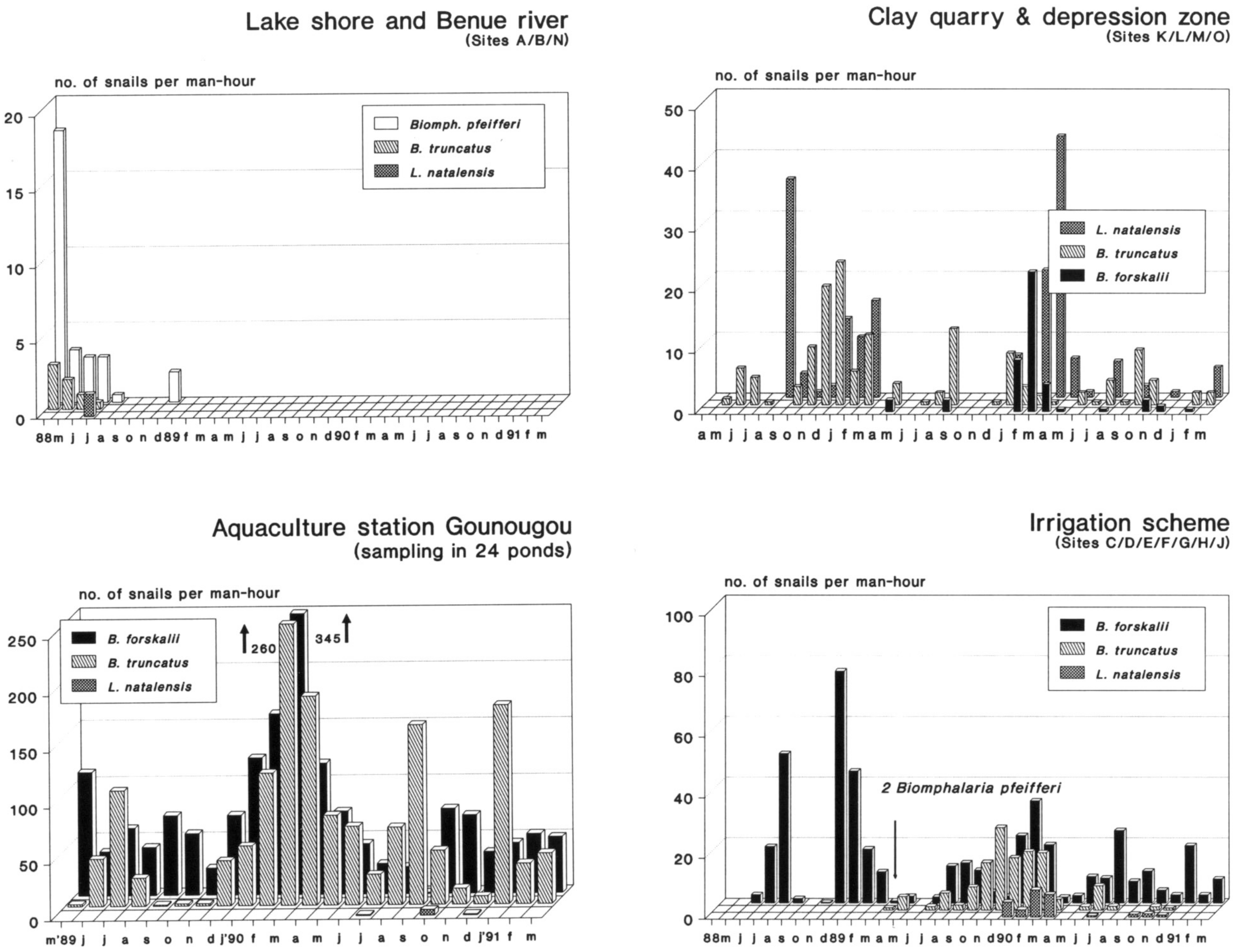
3) Man-made and man-managed small reservoirs. Water temperature and oxygen content rise sharply in morning hours. The oxygen content shows a large difference between minimal and maximal values (Fig. 7.3): rice field, secondary drain and fish pond. The algae living in this fertilized water (fertilizer from rice fields and fishfood in ponds) reach high concentrations and produce oxygen in sunlight, but consume oxygen during the night.



Figs. 7.1 - 7.3: Water temperatures and oxygen contents in different habitats during a clear day in the rainy season.

Sampling results

Only snail species of medical importance are discussed in this section, but several other species have also been encountered: *Pila wernei* (all over the irrigation system and the depression zone), *Lanistes ovum* (the irrigation system, depression and clay quarry), *Ceratophallus natalensis* (all sites except the river and the lake), *Cleopatra bulimoides*, and *Bellamya unicolor* (both in the Lagdo reservoir). We do not have the impression that competition between *P. wernei* or *L. ovum* and host snails occurs, but numbers are too low for statistical analysis. On the sites where P. wernei ever was recorded, this species was found 24 times in 288 samplings, 8 times in association with *B. forskalii*, 7 times with *B. truncatus* and 4 times with *L. natalensis*; *L. ovum* was registered 13 times in 144 samplings, 5 times in association with *B. forskalii*, once with *B. truncatus* and 4 times with *L. natalensis*. These results support findings by Madsen et al. (1988), who were not able to prove competitive exclusion between species in Sudanese irrigation schemes.



Figs. 8.1 - 8.4: Numbers of snails encountered per man-hour search-time during 36 months (23 months for the aquaculture station).

In 36 months of sampling no snails were found shedding cercariae of human schistosomes. (Numbers of snails tested: 6536 *Bulinus forskalii*, 240 *B. senegalensis*, 656 *B. globosus*, 2392 *B. truncatus*, and 74 *Biomphalaria pfeifferi*.)

1) **Large water bodies**

On the lake shore (site A) and in the Benue river (site N), very few snails were encountered (Figure 8.1). From April '88 until July '88, *B. pfeifferi* and *B. truncatus* were regularly encountered in the Benue and the lake in small numbers, but after the sudden rise in water level in the rainy season of 1988 and the subsequent opening of the spillways, no snail has ever since been recorded from the river and only once 2 *B. pfeifferi* have been found at the lake shore. Incidental sampling around Lagdo lake revealed several other temporary snail populations. In April '87 several dead shells and in June '88 living small *B. pfeifferi* (50/m2) were collected in Mai Djamba, a lake shore village with 29% prevalence of intestinal schistosomiasis (Robert et al., 1989). In April '90, *B. truncatus* was found in Mayo Boulel, a southwestern branch of the Lake, but in July of the same year, with rapidly rising water level, the population had entirely disappeared. It seems that the lake does not (yet?) harbour permanent snail populations.

The primary irrigation canal (site B) has always been free of snails, due to high water velocities and fluctuating water level.

2) **Stagnant, semi-natural and medium-sized habitats (permanent or temporary).**

The clay quarry (site O) and the depression zone (sites K/L/M) are characterized by strongly fluctuating populations of *B. forskalii, L. natalensis* and *B. truncatus* (Figure 8.2). Human interventions in the quarry were frequent, making it impossible to recognize a regular pattern in snail dynamics. The same applies to the depression zone where interventions to improve water management started in 1988. The effects of these interventions are described in detail by Slootweg & Keyzer (1993c).

The Lagdo pool (site P) was sampled weekly between November '88 and April '89 (see next paragraph). By then the pool was entirely dry for the first time in years because the inflow of drainage water had ceased. Populations of *B. globosus* and *L. natalensis* vanished completely and never reappeared in the following rainy seasons of '89, '90 and '91, in spite of the presence of water between June and February.

In the laterite quarries in Ouro Doukoudje (sites Q1 and Q2) a population of *B. senegalensis* appeared in the site Q1 in June, and disappeared before the end of the rainy season; the site entirely dried by the end of December. In the site Q2, both *B. senegalensis* and *B. globosus* were found during the rainy season; moreover, a small amount of water remained during the dry season and *B. globosus* had a second appearance.

Seasonal streams and pools (sites R1-R5) harboured either *B. forskalii* or *B. senegalensis*, but never mixed (Mimpfoundi & Slootweg, 1991). Weekly observations are now being made on snail dynamics in these habitats (Vroeg & Tsafack; pers. com.).

3) **Man-made and man-managed habitats**

One year after the aquaculture station Gounougou (Figure 8.3) was put into operation the first *B. forskalii* were recorded in November 1988 and by the end of January 1989 *B. truncatus* had also established itself. From May '89 until March '91 all ponds were sampled. *B. forskalii* and *B. truncatus* were found every month in varying numbers; *Lymnaea natalensis* was recorded for the first time in July '90 and has since been encountered sporadically. High numbers of snails were found during the dry season in the first half of 1990, during and shortly after a prolonged cool period of four months (Fig. 7).

All data from 7 sampling sites in the irrigation scheme have been combined in Figure 8.4. In the first year of sampling only *B. forskalii* was recorded. From shell characteristics it appeared that the population might be mixed with *B. senegalensis*, but iso-enzyme electrophoresis of samples taken in December '88 and July '90 revealed only *B. forskalii* (Mimpfoundi & Slootweg, 1991; Mimpfoundi, 1992). We consider the latter data more reliable since shell morphology of snails in the *B. forskalii* group is highly variable and confusing. In April '89, at the end of the fourth rice cycle since the scheme became operational, *B. truncatus* and *B. pfeifferi* were recorded for the first time in the field canals. *B. truncatus* has succeeded in establishing itself, but *B. pfeifferi* has been found only once. In January '90, at the sixth rice cycle, *Lymnaea natalensis* was obtained for the first time in the scheme, and has since been recorded several times in low numbers. The dynamics of *B. forskalii* populations reflects the irrigation schedule with peaks in the second or third month of an irrigation cycle.

The irrigation scheme provides habitats with different characteristics so it seems therefore useful to go into some detail. The secondary and tertiary irrigation canals (sites C and D) are often dry and do not constitute a favourable habitat for snails. Only *B. forskalii* was found occasionally, probably introduced with rice seedlings which were temporarily stored in the canals after being taken from the seedbeds. In the rice field (site F) the only species present during each cycle of rice is *B. forskalii; B. truncatus* and *L. natalensis* were found rarely in 1990. Both field canal and field drain (sites E and G) harbour populations of *B. forskalii, B. truncatus* and *L. natalensis*. In the third year of sampling *B. forskalii* was permanently present. In the secondary and tertiary drainage canals (sites H and I), *B. forskalii* was partially replaced by *B. truncatus* and *L. natalensis* in the second year of sampling. Due to cleaning and dredging in the drainage system this population was eradicated in the third year.

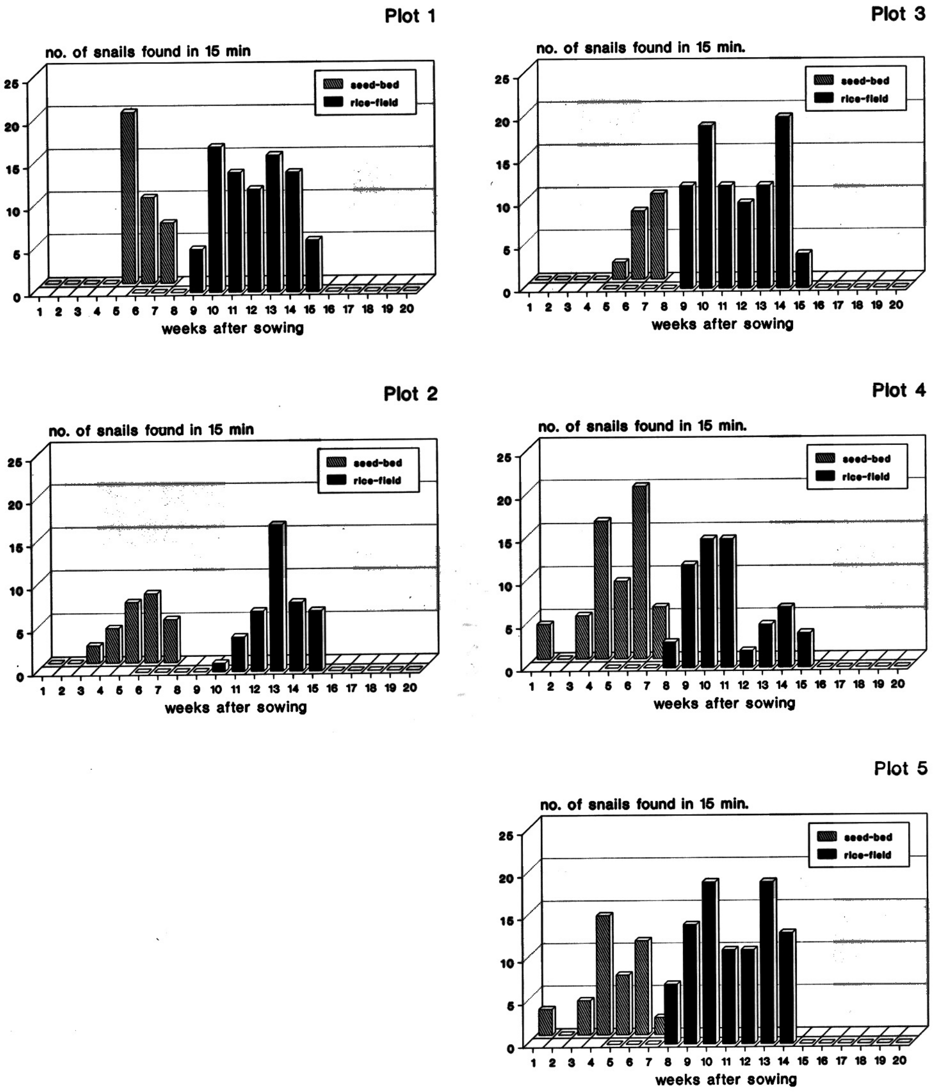


Fig. 9: Weekly sampling of *B. forskalii* populations in rice fields. The shaded bars in the background show numbers of snails found on the seedbeds; in the foreground black bars show the numbers of snails on corresponding fields where seedlings were planted. Small squares on the bottom of the graph indicate the periods when seedbeds and fields were inundated.

Weekly sampling

Bulinus forskalii **in rice fields**

During one entire cycle of dry season rice, the development of *B. forskalii* was followed weekly between November '90 and April '91 in eight plots. Sampling started in the seedbeds and continued at the rice fields corresponding to the seed beds (Figure 9). The development of snails in the seedbeds does not show a consistent pattern. On the rice fields the first snails appear in the fourth or fifth week after replanting; within two or three weeks a first peak in numbers occurred (plots 1,3,4,5), with a second peak 3-4 weeks later. In plot 2 the development of the population was a little slower and only one peak appeared after 7 weeks, coinciding with the second peak on the other plots. Snails completely disappeared 5 to 6 weeks before the fields were drained and dried; the presence of *B. forskalii* never lasted more than 8 weeks.

The mean size of snails in the first week of appearance was 3.1mm (SD 1.1) for the seedbeds, and 3.1mm (SD 1.6) for the rice fields. Length-frequency diagrams showed a constant appearance of juveniles, making it impossible to distinguish between generations. Hence it was impossible to construct a growth curve.

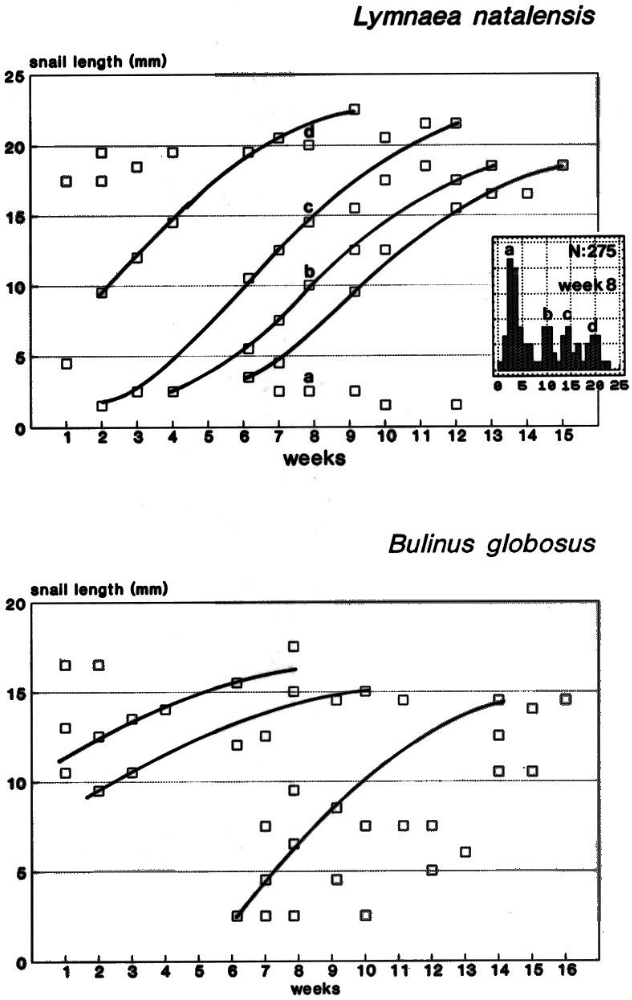


Fig. 10: Plotted peaks in length frequency distribution per week for *L. natalensis* and *B. globosus* The inset shows the length frequency histogram for week 8. The peaks a-d in the histogram correspond to points a-d in the figure.

***Bulinus globosus* / *Lymnaea natalensis* in the Lagdo pool**

Length-frequency histograms of the weekly samples of *B globosus* and *L. natalensis* showed that different generations existed simultaneously, reflected in different peaks in the histogram. In Figure 10 these peaks are plotted per week. Different generations of snails can be distinguished for *L. natalensis*, making it possible to draw a growth curve. In about 10 weeks this species grows from 1.5mm to 22.5mm. Between weeks 9 and 12 (January and February) the largest maximum size is attained. After week 7 newly hatched snails do not seem to survive since only the smallest size class is found.

The data for *B. globosus* are difficult to interpret. Several very speculative growth curves are shown suggesting that young 3.5mm snails reach 10mm in less than 4 weeks. Hatching occurs between week 6 and week 10 which coincides with the coolest water temperatures during the observation period, with afternoon temperature ranging from 23°C to 26°C (Fig. 7).

Discussion and conclusions

General remarks

The relation between water temperature and snail populations is complex, and factors indirectly linked with temperature, such as oxygen saturation and primary production will also influence snail densities, reflected in snail populations lagging one or two months behind the temperature minima. Nevertheless it appears that water temperatures generally exceed the optimal temperature for all three snail species *B. truncatus, B. forskalii* and *L. natalensis*, judging from the negative correlation between temperature and snail numbers.

Of the three habitat types described, the large water bodies hardly harbour any snail populations. It is noteworthy that *Biomphalaria pfeifferi* has only been found in some numbers in this habitat type with very constant temperatures and oxygen levels. The other two habitat types, stagnant semi-natural and man-managed water bodies, harbour permanent or seasonal populations of *B. forskalii, B. truncatus*, and *L. natalensis*, but *Biom. pfeifferi* is absent. The eutrophic man-made habitats harbour the largest numbers *B. forskalii* and *B. truncatus* snails, which corroborates the general opinion that availability of food is one of the crucial factors determining the density of snail populations (Brown, 1980; Slootweg et al, 1993), and that these species are capable of resisting large fluctuations in temperature and oxygen content. Behavioural studies have shown that snails are capable of escaping unfavourable conditions during the day, so habitat measurements do not necessarily reflect the actual conditions experienced by the snails (viz. Shiff, 1964a; Brown, 1980: pp.359-62).

Succession in the irrigation scheme and the artificial lake

The construction of a new irrigation scheme gave us the possibility to study the introduction and succession of snail species. *B. forskalii* was the first pioneering species to be encountered in the new habitat, followed by *B. truncatus* after two years of operation and *L. natalensis* after three years. *Biom. pfeifferi* and *B. globosus* were not found in the scheme. In the Logone valley of the Extreme Northern Province of Cameroon, Wibaux-Charlois et al. (1982) found large numbers of *B. forskalii* and few *B. truncatus* in the SEMRY II scheme, 11 and 23 months after the scheme became operational. In the SEMRY I scheme, which already was operational for over 10 years, *Biom. pfeifferi, B. truncatus, B. globosus* and very few *B. forskalii* were found. In the Gounougou scheme a similar succession pattern is seen, and since *Biom. pfeiferi* and *B. globosus* are present in the surroundings of Gounougou the establishment of these species in the irrigation scheme is to be expected. Examples from other areas in the soudano-sahelian climatic zone show a similar species composition. In the South Chad irrigation project Betterton (1984) described the presence of *B. truncatus, B. forskalii, B. globosus* but also *B. senegalensis* in the irrigation canals. As in the SEMRY area, *L. natalensis* was only present in the lake and also in the intake channel. In the Gezira irrigation scheme in Sudan, already operational for many years, Madsen et al. (1988) found *Biom. pfeifferi, B. truncatus, B.*

forskalii and *L.natalensis*. Contrasting in this respect is the Senegal delta where Diaw et al. (1991) only found large numbers of *Biom. pfeifferi* in March in irrigation canals several years after construction (no exact date is given). It appears that the presence of *Biom. pfeifferi* is most difficult to predict. Possibly high water temperatures in the Sudanian and Sahelian zones are unfavourable for this species, which prefers temperatures between 18°C and 25°C (Sturrock, 1966; Appleton, 1977; Kloos et al., 1988). Microclimatic conditions may determine whether *Biom. pfeifferi* will become established.

Sampling in the Lagdo lake was not extensive. Only the site near the East Dyke was sampled regularly showing initial populations of *Biom. pfeifferi* and *B. truncatus*, which were washed away by the sudden rise in water level in 1988. Irregular sampling revealed temporary populations of the same species. Paperna (1969) showed that in Lake Volta *B. forskalii* was omnipresent in the first year after filling of the lake; in the subsequent years this species was gradually replaced by *B. truncatus*. The dynamics of Lagdo lake seem to be less suitable for the establishment of permanent snail populations.

Bulinus forskalii

B. forskalii was the most common snail species in the area around Gounougou and was found in all habitats except the Benue river and Lagdo lakes. This species rapidly colonizes new habitats as shown by its immediate appearance in the rice fields and irrigation system. Similarly, Greer et al. (1990) found that *B. forskalii* was the most common species in Cameroon, occurring more frequently in flowing than in standing water and in smaller rather than larger reservoirs. Wibaux-Charlois et al. (1982) also found *B. forskalii* to be the most common species in the SEMRY irrigation scheme in the Extreme Northern Province of Cameroon, and the only species occurring in temporary pools. However, collections in the SEMRY study only were made in the dry season, probably overlooking many typical *B. senegalensis* habitats.

B. forskalii apparently prefers dynamic and unstable habitats were it has a competitive advantage over other species. In more permanent and stabilized habitats *B. truncatus* and other species outcompete *B. forskalii* as shown by the succession in the irrigation scheme of Gounougou in this study and in other studies (Paperna, 1969; Wibaux-Charlois, 1982). Furthermore it seems that this species prefers clean water; the onset of rains as well as flooding or the start of an irrigation season all stimulate the reproduction of the snail, but usually the species disappears after some time even if water is still present (McCullough, 1957; Teesdale, 1962; Cridland, 1967; Malaisse & Ripert, 1977; Betterton, 1984); in this study the snails all disappeared from rice fields within 8 weeks without any possible competitor snail being present.

The average size of emerging snails in the seed beds and in the rice fields was 3.1mm, which is remarkably similar to the size of emerging *B. senegalensis* reported by Goll & Wilkins (1984) in rainfed pools in Gambia. The authors state that viable aestivating snails are immature and remarkably constant in size; this apparently also holds for *B. forskalii* in the Benue area, although other authors also describe large adult snails emerging after aestivation (Malaisse & Ripert, 1977).

The rates of growth and reproduction are so fast that even weekly sampling did not allow the construction of a reliable growth curve. Only a mark and recapture technique as applied by Lévêque (1968), could give more detailed information. Lévêque showed that a generation cycle of *B. forskalii* lasts five weeks in alluvial pools in the Sahelian zone of Chad; maximal numbers of snails were encountered 2 months after filling of the pool (2½ months in Malaisse & Ripert, 1977). In the strongly eutrophic rice fields, water quality apparently deteriorates more rapidly compared to rainfed pools and *B. forskalii* disappears earlier. Apart from this it must be noted that it is not sure if Lévêque's study concerns *B. forskalii* and not *B. senegalensis*.

A negative correlation with water temperature was found, indicating that high temperatures limit this species. However, sometimes the snail populations lag 2 months behind temperature, indicating that snail populations are indirectly linked to temperature, with complex intermediary factors.

Bulinus senegalensis

The Benue valley is the southernmost area where *B. senegalensis* has been identified so far (Greer et al., 1990; Mimpfoundi & Slootweg, 1991). The species is only present during the rainy season in temporary streams and laterite pools. As Goll (1981) and Greer et al. (1990) indicated, this species has been overlooked in sampling programmes because of its limited presence in time and the difficulty of collecting during the rainy season. This underrepresentation in sampling programmes can lead to the false conclusion that *B. senegalensis* does not play any significant role in schistosomiasis transmission (e.g: Sellin et al., 1980). Betterton et al. (1983) found that this species disappears from pools even before *B. forskalii.* For the Sahelian zone it is clear now that this species is a principal intermediate host of *S. haematobium*, and that *B. forskalii* is not involved in transmission in this zone. As Mimpfoundi & Slootweg (1991) pointed out, the geographical distribution of *B. senegalensis* is not entirely clear, and this species could yet be found even further south where there are temporary pools that satisfy its aestivating habits.

The report by Betterton (1984) of *B. senegalensis* being found in drainage canals is worrying for irrigation development in the West African region. The scheme studied by Betterton was in an early stage of development so it is imaginable that this species will disappear after some years of operation, when prolonged periods of drought in the canals may cease to occur.

Bulinus truncatus

Bulinus truncatus was most common in the irrigation scheme where in the third year of operation it became permanently established, and in the aquaculture station. In the SEMRY irrigation scheme (Wibaux-Charlois et al., 1984) as well as in the Gezira-Managil scheme in Sudan (Madsen et all, 1988) *B. truncatus* was also found to be the most common species. Greer et al. (1990) describe *B. truncatus* in Cameroon as a species of perennial, man-made habitats, being more frequent in standing than in flowing water. The snails can survive short periods of desiccation in the aquaculture station, but neither in floodplain pools and streams, nor in temporary laterite quarries has this species been found. Very dynamic environments are also disadvantageous for these snails as shown by the disappearance of *B. truncatus* from the Lagdo lake and the Benue river after the rapid rise in water level and the opening of the spillways.

It is remarkable to describe *B. truncatus* as a species of perennial habitats while many field studies have shown this species to be able to survive droughts, especially in the Middle East (Watson, 1958; Malek, 1958; Chu et al. 1967; Appleton, 1978). Betterton et al. (1988) describe *B. truncatus* as poorly adapted to prolonged periods of severe drought (*B. rohlfsi*, later determined as *B. truncatus* by Jelnes, 1985). The complex genetic structure of this species and the possible existence of local strains perhaps explain the contradicting observations in the field.

Although *B. truncatus* can be found in every month of the year and is known to be very tolerant of temperature fluctuations (Watson, 1958) the snail populations show a negative correlation with water temperature; they show highest densities in the coolest months around January. Similar results were found in Volta Lake by Klumpp & Chu (1977) and in northern Nigeria by Betterton (1984). Demian et al. (1972) showed that egg production stopped and mortality increased when water temperatures were highest in Egypt (26-30°C).

Bulinus globosus

B. globosus was found in two semi-permanent water bodies in the Benue valley: in one of the laterite quarries near Ouro Doukoudjé and in the pool near Lagdo. When the latter pool dried completely after the permanent water supply had ceased to exist, this species did not reappear in three following rainy seasons. From these data we conclude that *B. globosus* survives drying of its habitat to a certain extent, but does not resist complete desiccation. In the literature *B. globosus* has often been described as a species of temporary habitats, capable of aestivation during prolonged periods of drought (Greer et al., 1990; Malaisse & Ripert, 1977; Cridland, 1967; reviewed by Appleton, 1978), although the species is not as resistant to desiccation as *B. forskalii* or *B. senegalensis*. Sellin et al. (1980), Betterton (1984) and Greer et al. (1990) state that in the Sudanian zone of West Africa this species is at its northernmost limit. In wetter areas this snail is the most common schistosomiasis intermediate host of permanent habitats. Several authors have described two forms of survival strategies for *B. globosus* or even two distinct morphs (Smithers, 1956; Shiff, 1964b; Hira, 1968; Betterton, 1984; Betterton et al., 1988; Okafor, 1990; Ngonseu et al., 1991). It is imaginable that different strains of *B. globosus* inhabit these different habitats and that the one in the Benue valley prefers permanent habitats with peak reproduction in the cool dry season months. The literature on the biology of *B. globosus* is rather confusing in this respect.

Studies by Shiff (1964a,b) and Woolhouse & Chandiwana (1990) show that *B. globosus* is limited by low water temperatures in Zimbabwe, and achieves its highest intrinsic rate of natural increase at a temperature of 25°C. In the Lagdo pool reproduction was limited to the cool months of January and February when afternoon water temperature did not exceed 26°C, indicating that this species is limited by high temperatures. Similarly, O'Keeffe (1985) found in Kenya that reproduction in *B. globosus* stopped when mean water temperatures exceeded 28.5°C. The temperature tolerance as determined by Shiff (1964a) in the laboratory relates well with observations under field conditions.

Data from the Lagdo pool indicate that the growth rate is much higher than the one calculated by O'Keeffe. The maximum size attained is also larger, 18mm vs. 12mm. The observation that only adult snails remained at the moment of drying of the pool corresponds to observations from the Extreme Northern Province of Cameroon (Ngonseu et al., 1991).

Lymnaea natalensis

This species was found in permanent bodies of water in sometimes high numbers (Lagdo pool and clay quarry), and appeared in man-made habitats shortly after *B. truncatus* became established. In the latter, numbers were never high and no permanent populations were observed. Also *L. natalensis* showed a negative correlation with temperature and was most abundant in the coolest months. The species does not resist desiccation, as shown in the Lagdo pool were snails did not reappear after the interruption of regular water supply. This is in accordance with Cridland (1967) who found that *L. natalensis* performed worst in comparison to *B. globosus* and *Biom. pfeifferi*, and could not survive more than 30 days of drought.

Consequences for transmission of schistosomiasis

Since no infected snails were found in three years of snail collections it is obvious that transmission of schistosomiasis has not intensified dramatically in the first years after creation of the Lagdo reservoir and the introduction of irrigated agriculture. Populations of snails did not reach such high densities as known from other irrigation schemes and many populations were only temporarily present. The impression is that schistosomiasis haematobium transmission may still be limited to seasonal sites where *B. senegalensis* and *B. globosus* are the principal intermediary hosts, as has been suggested by Betterton et al. (1983) and Greer et al. (1990). A detailed analysis of these seasonal sites is at present being carried out in order to assess their transmission potential. The establishment of *B. truncatus* in the irrigation scheme will in the near future increase transmission risks, although in several areas it has been shown that *B. truncatus* does not necessarily play a significant role in transmission of urinary schistosomiasis. Therefore experiments on the susceptibility of various potential intermediate host species will additionally be carried out to understand the transmission dynamics in the Benue valley. A further question that remains to be answered is whether *Biom. pfeifferi*, the intermediate host for intestinal schistosomiasis, will become permanently established in the newly created habitats around the Lagdo reservoir and in the irrigation scheme. Schistosomiasis is still a minor and localized public health problem that can be handled by the existing public health facilities, but there is reason for caution since it is probable that larger and permanent populations of snail intermediate hosts will eventually become established in the drainage systems in the Benue valley if no special preventive measures are taken.

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References

Appleton, C.C. 1977. The influence of temperature on the life-cycle and distribution of Biomphalaria pfeifferi (Krauss, 1948) in South-Eastern Africa. International Journal of Parasitology 7: 335-345.

Appleton, C.C. 1978. Review of the literature on abiotic factors influencing the distribution and life cycles of bilharziasis intermediate host snails. Malacological Reviews 11: 1-25.

Betterton, C. 1984. Ecological studies on the snail hosts of schistosomiasis in the South Chad Irrigation Project Area, Borno State, northern Nigeria. Journal of Arid Environments 7: 43-57.

Betterton, C, Fryer, S.E. & Wright, C.A. 1983. Bulinus senegalensis (Mollusca: Planorbidae) in northern Nigeria. Annals of Tropical Medicine and Parasitology 77:143-149.

Betterton, C., Ndifon, G.T. & Tan, R.M. 1988. Schistosomiasis in Kano State, Nigeria. II. Field studies on aestivation in Bulinus rohlfsi (Clessin) and B. globosus (Morelet) and their susceptibility to local strains of Schistosoma haematobium (Bilharz). Annals of Tropical Medicine and Parasitology 82: 571-579.

Brown, D.S. 1980. Freshwater snails of Africa and their medical importance. Taylor & Francis, London.

Chu, K.Y., Arfaa, F. & Massoud, J. 1967. The survival of Bulinus truncatus buried in mud under experimental outdoor conditions. Annals of Tropical Medicine and Parasitology 61: 6-10.

Cridland, C.C. 1967. Resistance of Bulinus (Physopsis) globosus, Bulinus (Ph.) africanus and Lymnaea natalensis to experimental desiccation. Bulletin of the World Health Organization 36: 507-513.

Demian, E.S., Kamel, E.G. & Mansour, K. 1972. Growth and population dynamics of Bulinus truncatus under semi-field conditions in Egypt. Proceedings of the Egyptian Academy of Sciences 25: 37-60.

Diaw, O.T., Vassiliades, G., Seye, M. & Sarr, Y. 1991. Epidémiologie de la bilharziose intestinale à Schistosoma haematobium a Richard-Toll (delta du fleuve Sénégal). Etude malacologique. Bulletin de la Société de Pathologie Exotique 84: 174-183.

Goll, P.H. 1981. Mixed populations of Bulinus senegalensis (Muller) and Bulinus forskali (Ehrenburg [sic]) (Mollusca: Planorbidae) in the Gambia. Transactions of the Royal Society of Tropical Medicine and Hygiene 75: 576-578.

Goll, P.H. & Wilkins, H.A. 1984. Field studies on Bulinus senegalensis Muller and the transmission of Schistosoma haematobium infection in a Gambian community. Tropenmedizin und Parasitologie 35: 29-36.

Greer, G.J., Mimpfundi, R., Malek, E.A., Joky, A., Ngonseu, E. & Ratard, R.C. 1990. Human schistosomiasis in Cameroon. II. Distribution of the snail hosts. American Journal of Tropical Medicine and Hygiene 42: 573-580.

Hira, P.R. 1968. Microgeographical races of Bulinus (Physopsis) globosus, The intermediary host of Schistosoma haematobium in Ibadan, Nigeria. West African Medical Journal 17: 86-88.

Jelnes, J.E. 1985. Experimental taxonomy of Bulinus (Gastropoda, Planorbidae) - Past and future activities. Vidensk. Meddr dansk naturh. Foren. 146: 85-100.

Kloos, H., LO, C.T., Birrie, H., Ayele, T, Tedla, S & Tsegay, F. 1988. Schistosomiasis in Ethiopia. Social Science and Medicine 26: 803-827.

Klumpp, R.K. & Chu, K.Y. 1977. Ecological studies of Bulinus rohlfsi, the intermediate host of Schistosoma haematobium in the Volta Lake. Bulletin of the World Health Organization 55: 715-730.

Léveque, Ch. 1968. Biologie de Bulinus forskalii (Mollusque, Gastéropode) de la région de Fort-Lamy (Tchad). Cahiers de l'ORSTOM, série Hydrobiologie 2: 79-90.

Mccullough, F.S. 1957. The seasonal density of populations of Bulinus (Physopsis) globosus and B. forskalii in natural habitats in Ghana. Annals of Tropical Medicine and Parasitology 51: 235-247.

Madsen, H., Dafalla, A.A., Karoum, K.O. & Frandsen F. 1988. Distribution of freshwater snails in irrigation schemes in the Sudan. Journal of Applied Ecology 25: 853-866.

Malaisse, F. & Ripert, Ch. 1977. Dynamique des populations de Biomphalaria pfeifferi, B. sudanica rugosa, Bulinus globosus et B. forskali (Planorbidae, Mollusques) dans la region du lac de retenue de la Lufira (Shaba, Zaire). Geo-Eco-Trop. 3: 189-208.

Malek, E.A. 1958. Factors conditioning the habitat of bilharziasis intermediate hosts of the family Planorbidae. Bulletin of the World Health Organization 18: 785-818.

Mimpfoundi, R. 1992. Variations génétiques intra- et interpopulationnelles chez les Planorbidae tropiceaux. Le polymorphisme enzymatique dans les genres Biomphalaria Preston, 1910 et Bulinus Müller, 1781 au Cameroun. Thesis, University of Yaoundé, Cameroon.

Mimpfoundi, R. & Slootweg, R. 1991. Further observations on the distribution of Bulinus senegalensis Müller (Gastropoda: Planorbidae) in Cameroon. Journal of Molluscan Studies 57: 487-489.

Ngonseu, E., Greer, G.J. & Mimpfoundi, R. 1991. Dynamique des populations et infestation de Bulinus globosus en zone soudano-sahelienne du Cameroun. Annales de la Société Belge de Médecine Tropicale 71: 295-306.

Okafor, F.C. 1990. Schistosoma haematobium cercariae transmission patterns in freshwater systems of Anambra State, Nigeria. Angewante Parasitologie 31: 159-166.

O'Keeffe, J.H. 1985. Population biology of the freshwater snail Bulinus globosus on the Kenya coast. 1: Population fluctuations in relation to climate. Journal of Applied Ecology 22: 73-84.

Olivier, L. & Schneiderman, M. 1956. A method for estimating the density of aquatic snail populations. Experimental Parasitology 5: 109-117.

Paperna, I. 1969. Aquatic weeds, snails and the transmission of bilharzia in the new man-made Volta Lake in Ghana. Bulletin de l'Institute Fondamentale l'Afrique Noire, Series A 31: 487-499.

Ratard, R.C., Kouemeni, L.E., Ekani Bessala, M.-M., Ndamkou, Chr.N., Greer, G.J., Spilsbury, J. & Cline, B.L. 1990. Human schistosomiasis in Cameroon. I. Distribution of schistosomiasis. American Journal of Tropical Medicine and Hygiene 42: 561-572.

Robert, C.-F., Bouvier, S. & Rougemont, A. 1989. Epidemiology of schistosomiasis in the riverine population of Lagdo Lake, Northern Cameroon: mixed infections and ethnic factors. Tropical Medicine and Parasitology 40: 153-158.

Same Ekobo, A. 1984. Faune malacologique du Cameroun. Description des espèces et foyers des trématodes humaines. Thesis, Faculty of Sciences, Rennes.

Same-Ekobo, A., Wibaux-Charlois, M., Kristensen, T.K., Frandsen, F., Deniau, M. & Ripert, CH. 1984. Distribution geographique et ecologie des mollusques dulcaquicoles du Cameroun. Cahiers de l'Institute de Médecine et des Plantes Médecinales 2, Yaoundé.

Sellin, B., Simonkovich, E. & Roux, J. 1980. Etude de la repartition des mollusques hotes intermediaires des schistosomes en Afrique de l'Ouest. Médecine Tropicale 40: 31-39.

Shiff, C.J. 1964a. Studies on Bulinus (Physopsis) globosus in Rhodesia. I.-Influence of temperature on the intrinsic rate of natural increase. Annals of Tropical Medicine and Parasitology 58: 94-105.

Shiff, C.J. 1964b. Studies on Bulinus (Physopsis) globosus in Rhodesia. III.-Bionomics of a natural population existing in a temporary habitat. Annals of Tropical Medicine and Parasitology 58: 240-255.

Slootweg, R., Kooyman, M., Koning, P. de & Schooten, M.L.F. van (1993a). Water contact studies for the assessment of schistosomiasis infection risks in an irrigation scheme in Cameroon. Irrigation and Drainage Systems 7: 113-130.

Slootweg, R., Vroeg, P. & Wiersma, S. (1993b). The effects of molluscivorous fish, water quality and pond management on the development of schistosomiasis vector snails in aquaculture ponds in North Cameroon. Aquaculture and Fisheries Management 24.

Slootweg, R. & Keyzer, R. (1993c). Reducing health risks in drainage systems by optimizing waste water use. An experimental trial on integrated management from the Benue valley, Northern Cameroon. Irrigation and Drainage Systems 7: 99-112.

Smithers, S.R. 1956. On the ecology of schistosome vectors in the Gambia, with evidence of their role in transmission. Transactionf of the Royal Society of Tropical Medicine and Hygiene 50: 354-365.

Sturrock, R.F. 1966. The influence of temperature on the biology of Biomphalaria pfeifferi (Krauss), an intermediate host of Schistosoma mansoni. Annals of Tropical Medicine and Parasitology 60: 100-105.

Teesdale, C. 1962. Ecological observations on the molluscs of significance in the transmission of bilharziasis in Kenya. Bulletin of the World Health Organization 27: 759-782.

Watson, J.M. 1958. Ecology and distribution of Bulinus truncatus in the Middle East. Bulletin of the World Health Organization 18: 833-894.

Wibaux-Charlois, M., Yelnik, A., Ibrahima, H., Same-Ekobo, A. & Ripert, Chr. 1982. Etude épidémiologique de la bilharziose a S. haematobium dans le périmètre rizicole de Yagoua (Nord-Cameroun). Bulletin de la Société de Pathologie Exotique 75: 72-93.

Woolhouse, M.E.J. & Chandiwana, S.K. 1990. Population biology of the freshwater snail bulinus globosus in the Zimbabwe highveld. Journal of Applied Ecology 27: 41-59.

3.2 Further observations on the distribution of Bulinus senegalensis Müller in Cameroon

R. Mimpfoundi & R. Slootweg (1991). J*ournal of Molluscan Studies* **57**: 487-489.

Since 1956 when Smithers demonstrated that *Bulinus senegalensis* Müller 1781 was an important intermediate host for *Schistosomosa haematobium* in the Gambia, more information has been sought concerning its distribution. *B. senegalensis* was first reported from the type-locality Podor in Senegal by Adanson (1757). Its distribution range is now known to extend to Gambia (Smithers, 1956), Mauretania and Chad (Wright, 1959), Nigeria (Betterton, et al., 1983) and Cameroon (Mimpfoundi & Greer, 1990; Greer, et al., 1990). All the sites where *B. senegalensis* has been collected in those countries are temporary habitats located in the sub-Saharan belt across Africa. In Cameroon, based on shell characters, Greer et al. (1990) reported that species from two sites located in the wetter sudanian region. But as Betterton et al. (1983) stated, identification of *B. senegalensis* from shell material alone is difficult because of its often close resemblance to the related *Bulinus forskalii*.

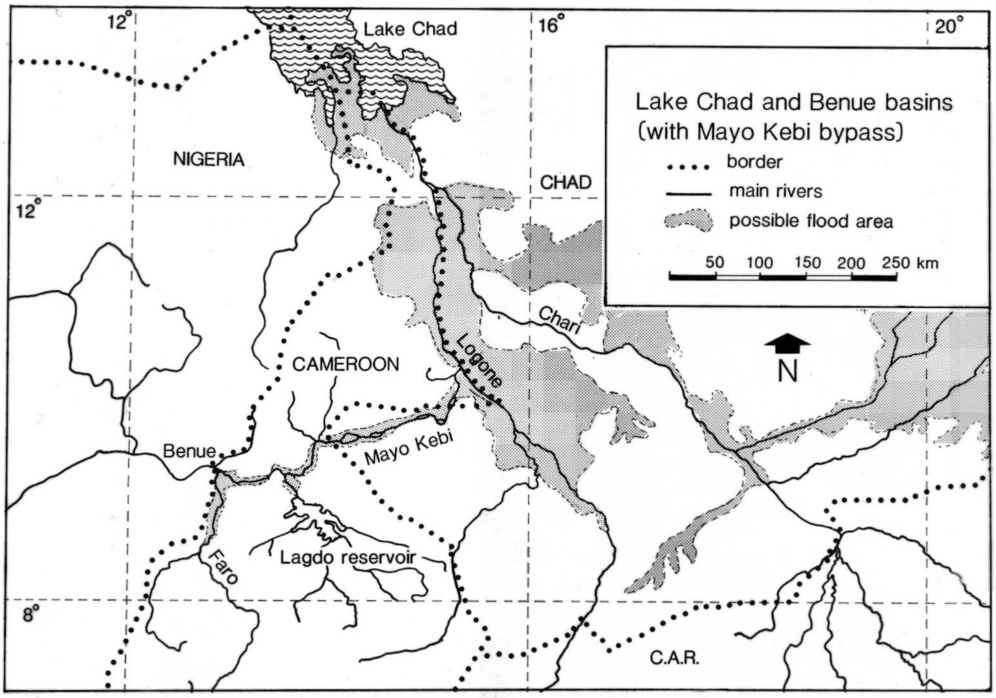

Fig. 11: Map of the Lake Chad and Benue basins.

This study was undertaken to confirm by the use of allozyme electrophoresis the occurence of *B. senegalensis* in the sudanian region in Cameroon.

The area surveyed in our study lies in the North Province of Cameroon, just above 9°N, from 13°33' to 13°36' East, in the valley of the river Benue (Fig.11). Northwards, the valley is connected to the Chad Plain by the Mayo Kebi valley. Westwards, the Benue flows into the Niger, the most important river in West Africa. Southeastwards, a reservoir at Lagdo overflooded most of the former valley. From Lagdo to the Niger, the Benue valley is of alluvial deposits, flat, with an altitude less than 200 metres. The climate in this area is sudanian, with an annual rainfall averaging about 1000mm. The rainy season extends from April to October, and the mean annual temperature is 28.1°C

Location of villages and waterbodies are detailed in Fig. 12. Eighteen sites were visited in July 1990 and examined for the presence of Bulinus. The majority of villagers are farmers and fishermen. Downstreams of the Lagdo dam a scheme for irrigated agriculture is under construction, with 200 hectares already in operation (mainly rice culture).

To investigate the southern occurence of snails resembling B. senegalensis, some sites on the road to Ngaoundere were visited at Garwawo, Nahari and Gouna (Mayo Salah), the last site being located some 120 kilometers south of Garoua (Fig. 12), but no specimen of Bulinus was found.

Snails were picked from emergent vegetation in aquatic habitats with a long-handled net, and initially identified from the shell. Living snails were brought back to the Experimental Taxonomy Unit, Cameroon Schistosomiasis Project, IMPM, Yaounde, and electrophoresis of enzymes was performed on starch gels. Techniques used in enzyme analysis, allozyme systems investigated, and the expression of their mobility are the same as in a previous study (Mimpfoundi & Greer, 1989).

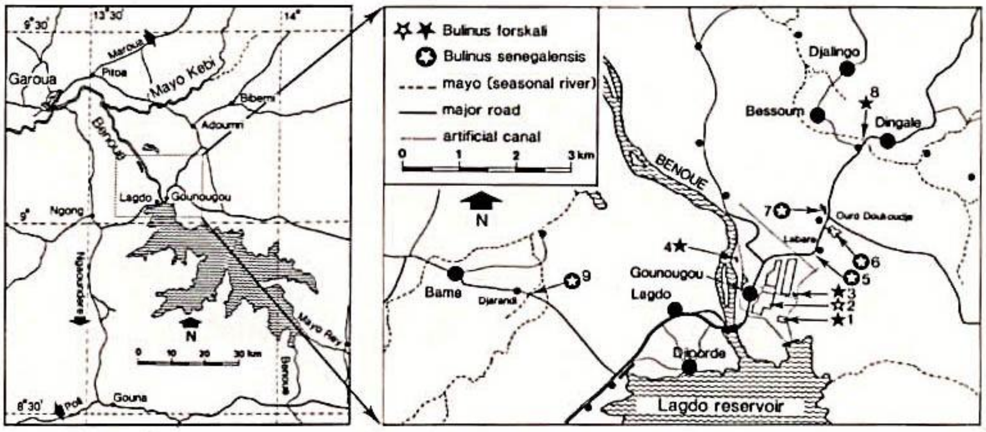

Fig. 12: Map of the study area showing localities where *Bulinus forskalii* and *B. senegalensis* occurred in July 1990. (Numbers correspond to Table 2).

Table 2: Sites, numbers investigated (N) and allozyme mobilities for polymorphic loci among populations of the *Bulinus forskalii* group in Lagdo.

Site		N	ACP	α-GPD	GPI	HBDH	PGM
1a	Fishculture station, pond 21	10	80	70	100	70	100
1b	Fishculture station, pond 22	10	80	70	100	70	100
2	Rice fields	15	80	70	100	70	100
3	Laterite quarry near "CTM"	10	80	70	100/90	70	100
4	Temporary pool near Benue	10	80	70	100	70	100
5	Ford near Labare	15	100	100	100	100	80
6	O. Doukoudje, laterite quarry	12	100	100	100	100	80
7	O. Doukoudje temporay pool	8	100	100	100	100	80
8	Mayo Bessoum	15	80	70	100	70	100
9	Mayo Djarandi	15	100	100	100	100	80

ACP = acid phosphatase; α-GPD = alpha glycerophosphate dehydrogenase;
GPI = glucose-phosphate isomerase; HBDH = hydroxybutyrate dehydrogenase; PGM = phosphoglucomutase.
Migrations are expressed relative to *Bulinus forskalii* from Edea as a reference (Mimpfundi & Greer, 1989; 1990). "/" seperating alleles indicates polymorphism in the sample.

Snails of the *B. forskalii* group were collected from 9 sites. From allozyme mobilities observed in ACP, α -GPD, HBDH and PGM (Table 2), we could identify *B. forskalii* by the allele combination ACP^{80}/ α-GPD^{70}/$HBDH^{70}$/PGM^{100} in the ponds of the fish breeding station (1), the rice fields (2), the laterite quarry near "CMT" (3), the temporary pool near the Benue (4) and the Mayo Bessoum (8). All these populations exhibited the GPI^{100} allele, except for (3) where it occured mixed with the GPI^{90}, without heterozygotes. *B. senegalensis*, identified by the allele combination ACP^{100}/ α-GPD^{100}/$HBDH^{100}$/PGM^{80} were collected near Labare (5), in the laterite quarry and temporary pool at Ouro Doukoudje (6,7) and in Mayo Ndjarandi (9). Mixed populations of *B. forskalii* and *B. senegalensis* were not found in that area, nor did we find the $HBDH^{50}$ allele of *B. forskalii* previously reported in the extreme-north of the country (Mimpfoundi & Greer, 1989). No snail was found shedding mammalian schistosome cercariae.

Based on shell characters alone, we collected *Bulinus globosus* in locality (6), and *Bulinus truncatus* in (1).

Information on the distribution of *B. senegalensis* is of importance, as this snail has been found to transmit *S. haematobium* in Gambia (Smithers, 1956), Nigeria (Betterton et al., 1983, 1988) and Cameroon (Mimpfoundi & Greer, 1989); undetected populations of this snail may be of epidemiological significance (Wright, 1959). In Cameroon, this snail has been identified on shell characters alone from as far south as Poli and Tchollire (Greer et al., 1990) located just under 8°30'N. But until now the occurrence of *B. senegalensis* has been confirmed using allozyme electrophoresis only in localities north of 10°N.

In the present report, we confirm the occurence of *B. senegalensis* in Lagdo, a village located 9°N, south of Garoua. The geographical features of that area are low altitude (<200m.), annual rainfall around 1000 mm in six months, and high temperatures (around 28°C), favouring temporary bodies of water suitable to the estivating habits of *B. senegalensis*. Identifications performed by Greer et al. (1990) from shells collected at Poli and Tchollire remain to be confirmed by further analysis; Tchollire is located in the Benue valley, and Poli in the Faro valley, a tributary of the river Benue. South of Lagdo along the road to Ngaoundere, the area is mostly hilly, raising rapidly to the Adamawa Plateau (1000m.). The few ponds in laterite quarries found in that area seem too temporary to be suitable to snails.

The occurence of *B. senegalensis* at Lagdo can be explained by interconnections between the Benue valley and the Chad plain were that snail is very common (Greer et al.,1990). The low altitude of those regions and general flooding during the rainy season favour temporary bodies of water and population migrations through the Mayo Kebi valley. This method of dispersal could explain the colonization of all the Benue and Faro valleys by this snail. Further investigations including all the Niger basin will be necessary in order to find out how far the distributions of *B. senegalensis* extend southwards.

The finding of the GPI^{90} allele in the *B. forskalii* population from site (3) is worthy a comment. In a previous study (Mimpfoundi & Greer, 1990), we found that allele only in populations collected from sites located in the evergreen forest of the equatorial and subequatorial regions where annual rainfall is higher than 1500 mm. The Benue flows into the Niger, the largest west african river linking the sahelian regions in the north to the equatorial regions in the south. We propose that snails with GPI^{90} allele migrated from the equatorial regions to Lagdo through the Niger-Benue river systems, as did *B. senegalensis* from the sahelian regions to the wetter sudanian regions.

Our theory on the distribution of *B. forskalii* in this region does not explain the absence of the $HBDH^{50}$ allele among the populations sampled in the Lagdo area, since it is connected to the Chad Plain through the Mayo Kebi. The climate in that area is tropical semi-arid. Thus, the $HBDH^{50}$ allele seems limited to the sub-sahelian part of the Logone valley, or it recently derived in that area from the common $HBDH^{70}$. Further investigations including snails from all the Logone valley remain necessary to better assess the geographical distribution of these alleles.

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References

Adanson, M. 1757. Histoire des coquillages. *Histoire naturelle du Sénégal*. Paris: Bauche.

Betterton, C., Fryer, S.E. & Wright, C.A. 1983. *Bulinus senegalensis* (Mollusca: Planorbidae) in northern Nigeria. *Annals of Tropical Medicine and Parasitology*, **77**, 143-149.

Greer, J.G., Mimpfoundi, R., Malek, E.A., Joky, A., Ngonseu, E. & Ratard, R.C. 1990. Human schistosomiasis in Cameroon. II. Distribution of the snail hosts. *American Journal of Tropical Medicine and Hygiene*, **42**, 573-580.

Mimpfoundi, R. & Greer, J.G. 1989. Allozyme comparisons among species of the *Bulinus forskalii* group (Gastropoda: Planorbidae) in Cameroon. *Journal of Molluscan Studies*, **55**, 405-410.

Mimpfoundi, R. & Greer, J.G., 1990. Allozyme variation among populations of *Bulinus forskalii* (Ehrenberg) (gastropoda: Planorbidae) from Cameroon. *Journal of Molluscan Studies*, **56**

Smithers, S.R. 1956. On the ecology of schistosome vectors in the Gambia, with evidence of their role in transmission. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, **50**, 354-365.

Wright, C.A. 1959. A note on the distribution of *Bulinus senegalensis*. *The West African Medical Journal*, **8**, 142-148.

PART II Chapter 4

TRANSMISSION RISK THROUGH WATER CONTACT

4.1 Water contact studies for the assessment of schistosomiasis infection risks in an irrigation scheme in Cameroon

R. Slootweg, M. Kooyman, P. de Koning & M. van Schooten (1993). *Irrigation and Drainage Systems* **7**: 113-130.

The construction in 1982 of the Lagdo dam in the Benue valley of northern Cameroon resulted in important hydrological changes on both sides of the dam. The pattern of water-related behaviour of the people changed as a result and new risks of water-borne diseases arose. Both vesical (*Schistosoma haematobium*) and intestinal schistosomiasis (*S. mansoni*) were present in certain foci of the Benue valley prior to the construction of the dam, and the rapid development of irrigated agriculture is likely to favour the establishment of permanent populations of snail intermediate hosts of schistosomiasis. In 1986, four years after the construction of the dam but before the first irrigation schemes became operational, the prevalence of *S. haematobium* varied from 7 - 43%. In most villages lower prevalences of *S. mansoni* were recorded: between 4 and 29% (Robert et al., 1989). These prevalences indicated that transmission of both species took place, and that transmission was rather focal.

Since 1987, a 200 ha irrigation scheme is operational in the immediate proximity of the village of Gounougou, situated on the right bank of the Benue near the Lagdo dam. In 1986 the prevalences of *S. haematobium* and *S. mansoni* were 21% and 7% respectively (Robert et al., 1989). A recent survey (december 1992) however, showed that prevalence of vesical schistosomiasis had already increased to 43% (Vroeg, unpubl. data), indicating that transmission has intensified since the start of irrigation. A number of different potential transmission sites could be identified (Figure 13): the Lagdo man-made lake, the irrigation canals receiving water from the lake through the inlet at the East Dike, the rice fields, the drainage canals, the marshy depression between the river and the village that is used for discharge of drainage water, the Benue river, and some isolated foci in which permanent or temporary water is to be found. Before the conctruction of the dam and irrigation scheme, only the depression, the river and the seasonal pools used to be potential transmission sites in the rainy season. With the exception of the seasonal pools, all other sites are nowadays permanently filled with water, and may constitute a suitable habitat for snail intermediate hosts of schistosomiasis.

Snail surveys (Slootweg et al., in press) show that *Biomphalaria pfeifferi* (the intermediate host of *S. mansoni*) is very rare in the area and has only been found on rare occasions in some sites along the shores of the lake and river. *Bulinus* species, some of which can serve as intermediate hosts of *S. haematobium*, have been found in the rice fields, in the field and drainage canals of the irrigation system and in the marshy depression. Although monthly surveys of snail populations as a routine have been carried out for 36 months, infected snails, however, have never been found. All snails were tested for infection with schistosome parasites. Indeed it is a characteristic feature that very low densities of snails, and in particular infected snails, are able to result in considerable infection rates in man. Transmission can be limited to a few spots during a short period of time.

In order to minimize the risk of an important increase of schistosome transmission, different options for prevention have been considered. Although snail control and chemotherapeutic interventions might be required in the future, these measures do not seem to be appropriate at the present moment with few snails to be found and relatively low numbers of infected people with light infections. Since schistosomiasis transmission is dependent of contaminating and exposure activities, a reduction of the risk of exposure (contacts with infected water) of the villagers would seem the first measure to be considered. Therefore, the pattern of exposure due to a variety of different occupational, domestic and recreational activities is analysed in the present study. This study is part of a larger programme on the integrated control of schistosomiasis in the Benue valley, which started with a baseline study on snail dynamics, water contact behaviour and a parasitological survey of the region (Slootweg, 1991).

Secondly, we try to find reasons why people use open water reservoirs. The supply of safe drinking water from a borehole well is compared to other available sources. In irrigation schemes the availability of safe water highly influences schistosomiasis transmission. In the Sudan, Oomen et al. (1988; annex 4) found a significant inverse relation between the amount of safe water available and the prevalence of schistosomiasis. Prevalence decreases with increasing amount of water from borehole wells. The decreasing effect stops when more than 70 l/day/person is available. The prevalence decreased from 80% in villages without water supply to 40% in vilages with more than 70 l/day/person. A prevalence of 40% is considered a minimum level in this highly endemic area . These data suggest that a large part of the infections are caused by nonoccupational watercontacts (domestic, recreational and occasional water contacts) that can be prevented.

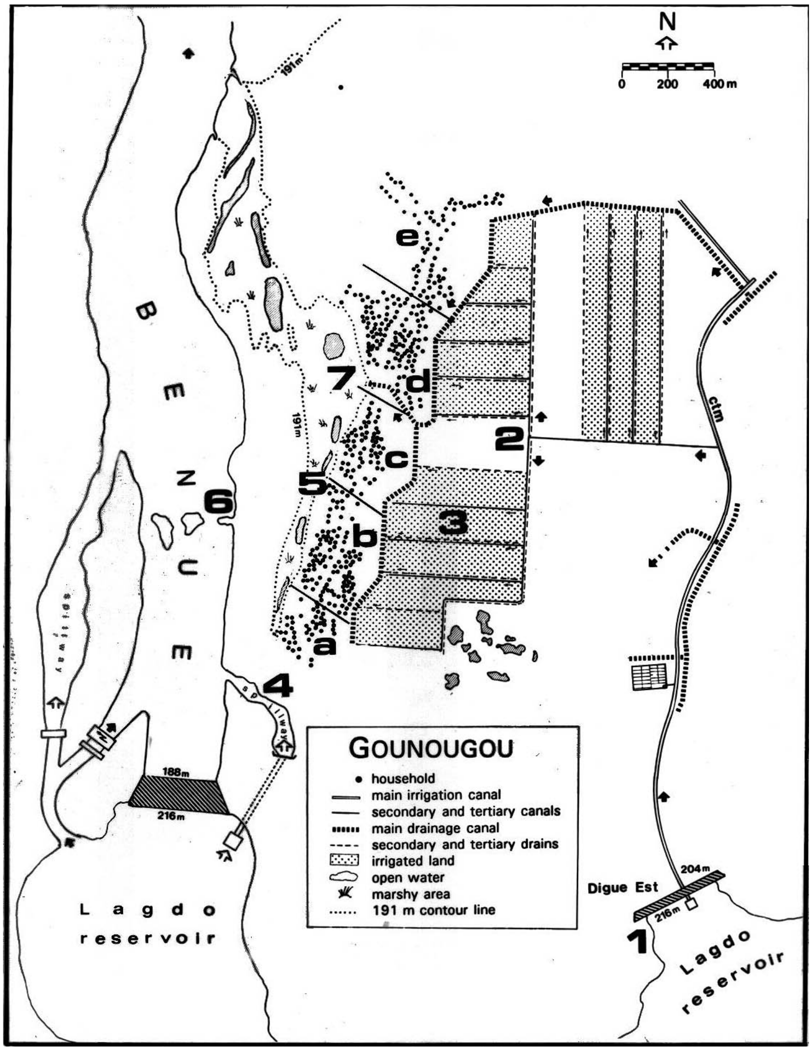

Fig. 13: Gounougou and surroundings before implementation of reconstruction measures (viz. Slootweg and Keyzer, 1993). Indicated are village quarters (a - e) and the seven observation sites. (1) East dike; at 1500m from the village, the main access to the artificial reservoir of Lagdo. Fishermen and traders gather especially in the morning. (2) Irrigation canal (secondary); through a subterranean supply-pipe the irrigation water enters the secondary canals. The first 30m of the two secondary canals are lined. Officially it is prohibited to use the canals for other purposes than irrigation. (3) Rice fields; rice is grown in a 6 months rotation, using high yielding varieties, with production levels reaching 5 tons of paddy/harvest/ha. Fertilizers (NPK and Ureum) are used intensively, pesticides not (yet?). (4) The spillway of the Lagdo dam at the Gounougou side is used for spilling only several weeks a year. The rest of the year it is a dead branch of the Benue. (5) Ford; villagers wanting to visit their lands or going to the washing site at the Benue (6) use this threshold in the depression. The stretch that has to be waded varies between 2m in May and 20m in September. Maximum depth is 70cm. (6) Benue river; at 300m from the village this site is appreciated by the villagers because of its sandy shores and the considerable flow of water. (7) Depression zone; this depression used to be a temporary floodplain pool. Nowadays it is used as the main drain for the irrigation system, resulting in permanent inundation.

Finally, we will describe measures to minimize schistosomiasis transmission, taking into account the very different nature of the observed activities.

The water contact study was performed in and around Gounougou, formerly a village of floodplain fishermen of about 15 families, but nowadays flooded with immigrants from the Extreme Northern Province of Cameroon. The village consists of five quarters (Figure 13), the market quarter (a), Gounougou s.s. (b), Bantaré (c), Lameré (d), crossroads Riao (e) and has 451 households (2234 inhabitants) of multi-ethnic origin, with a large muslim minority (126 households). The main occupations are agriculture (354 household heads) and fishing (34). Paid occupations are held by 35 household heads, working on the hydroelectric station near the Lagdo dam and in government services (teachers, health and extension workers, etc.). The irrigated rice fields of Gounougou are distributed among local inhabitants in 0,25 ha plots. The typical Gounougou family further cultivates maize, cotton, sorgho, groundnuts and cowpeas.

The village possesses a conduit-pipe water supply, a remainder from the period of dam construction. The reliability of this supply is low; often the pipe is dry for several days or has a marginal flow, because of technical difficulties at the pumping station or excessive demand by the upstream users (hydroelectric station and housing area of its personnel). The villagers have agreed not to wash or bath near the waterpoints of the supply pipe in order to avoid long waiting and creation of muddy pools in the middle of the village. Water has to be carried to the homes. Because of these inconveniences many people make use of open water bodies for domestic purposes. No borehole wells are available in the village.

It is impossible to predict to what levels of prevalence schistosomiasis will increase in the future. The scheme is still relavtively new and populations of snails are just beginning to invade the irrigation and drainage system (Figure 14). Slootweg et al. (in press) indicate that the succession of species resambles similar schemes which have been studied in the past. The establishment of more intermediate host species can be expected within several years. For this reason, in the present study we will speak of schistosomiasis transmission risk due to water contact, without considering the actual presence or absence of snail intermediate hosts.

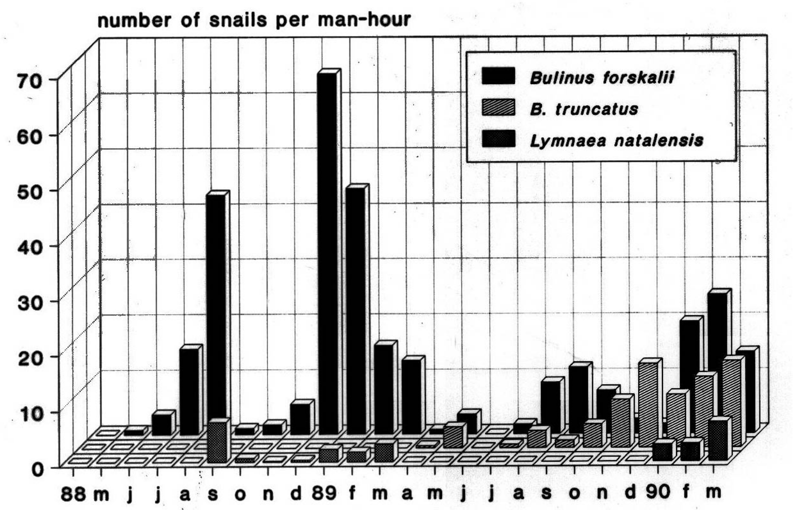

Fig. 14: Development of three frequently encountered snail species at 12 sampling sites in the Gounougou watershed. The colonizing species *B. forskalii* is gradually being replaced by *B. truncatus*, an important intermediate host of vesical schistosomiasis. *L. natalensis* is a snail intermediate host of bloodflukes, a parasite common to cattle.

Methods

Collection of data

After an inventory of the village and all available water reservoirs in the immediate vicinity of Gounougou, seven sites were chosen for the study (Figure 13). All different types of surface water regularly used by the villagers are covered by this choice. Between September 1989 and March 1990, the seven sites were observed seven times using a schedule rotating among the different days of the week. At the end every site has been observed once on every day of the week. The number of observations days thus totals 49 (7 months x 7 sites). Seasonal influence has been eliminated because the observation period covers the rainy season (August and September 1989), the cool dry season (November '89 - January '90) and the hot dry season (February and March 1990). The design of this observation schedule implies that only totalled data on the whole observation period can be interpreted; no comparisons can be made between different months or between different days of the week (cf. Dalton, 1976; Jordan, 1985 ch.3 & 7).

Observation days lasted from 06.00 to 18.00 hours, with two observers (parasitology students) working in three-hour shifts. For each individual water contact the following data were collected: age, sex, body surface exposed to water, type of activity, starting and ending time of an activity (Klump & Webbe, 1987; Kloos et al., 1990). The duration was calculated for each activity; if the same person started with another activity, this was registered as a new water contact. An important phenomenon is the periodicity in activity of schistosome cercariae during the day. About 90% of the active cercariae are usually found between 11.00h and 15.00h (Pitchford et al., 1969; Polderman, 1975; Mouahid et al., 1991). The risk of infection therefore varies considerably during the day, examplified by a study from Sudan where a shift in working hours of canal cleaners to the early morning reduced the prevalence in this highly exposed group (Tameim et al., 1985). So not only duration of the activity but also the moment of the day is considered to be of importance.

Additionally, on a day of uninterrupted water supply through the conduit-pipe, the flow of water was measured at all taps. These data were compared with the number of people depending on these taps per village quarter. The calculation of the amount of water needed per quarter is based on the amount given above of 70 litres/person/day. This is the amount of safe water that is required to minimize the risk of schistosomiasis transmission in the comparable climatic zone of Sudan.

Elaboration of data

The protocol forms were processed with a spreadsheet computer programme. The proportion of body surface area exposed to water was calculated using burn charts after Kloos & Lemma (1980) and Jordan (1985): both feet and ankles (7%); to knees (19%); to thighs (39%); both hands and wrists (6%); to elbows (12%); both entire arms (20%); to neck (88%); entire body (100%).

The activities were classified into 9 groups: bathing, playing (and swimming), washing (clothes and dishes), agriculture (on irrigated rice-fields), fishing with boat, fishing without boat, fetching water, wading, other activities (drinking, cleaning fish, etc.).

Several parameters can be used to estimate the risk of infection with schistosome parasites. In some studies frequency and duration of contact were used (Tayo, Pugh & Bradley, 1980; Husting 1983; Chandiwana, 1987), showing a positive correlation between schistosomiasis prevalence and the product of frequency and duration of contact. Kloos & Lemma (1980) and Kvalsvig & Schutte (1986) proved that the exposure index calculated as the product of frequency, duration and proportion of body surface, was a better predictor of infection. The parameters used in this study follow the authors mentioned above: (a) **frequency**, defined as the absolute number of contacts; (b) **duration**, i.e. the time involved in water contact for one activity (min); (c) **body surface**, i.e. the proportion (%) of total body surface in contact with water, and (d) **exposure index**, i.e. duration x body surface x relative frequency (% of total number of contacts).

Results

Activities and sites that contribute to schistosomiasis infection risk.

Over the eight month period, 3,916 water contacts were observed in 49 days, i.e. on average 80 observed water contacts per day per site. The activities performed by the villagers show very distinct differences in their basic parameters frequency, duration and percentage immersion (Figure 15). The most frequent activity is wading, followed by bathing and washing, together constituting more than 50% of the number of water contacts. Activities of the longest duration are agriculture and fishing without boat. On average people work for one and a half hours continuously on the rice fields; especially the transplantation of seedlings involves prolonged water contact on the fields. Fishing without boat is performed by women entering the water and chasing the fish with baskets; male fishermen are seen with spears, gillnets and fish-traps. On average a person stays for more than one hour in the water. The body surface area in contact with water is highest for (in descending order) bathing, playing and fishing without boat. This is of course to be expected because the other activities only concern contacts with arms and/or legs.

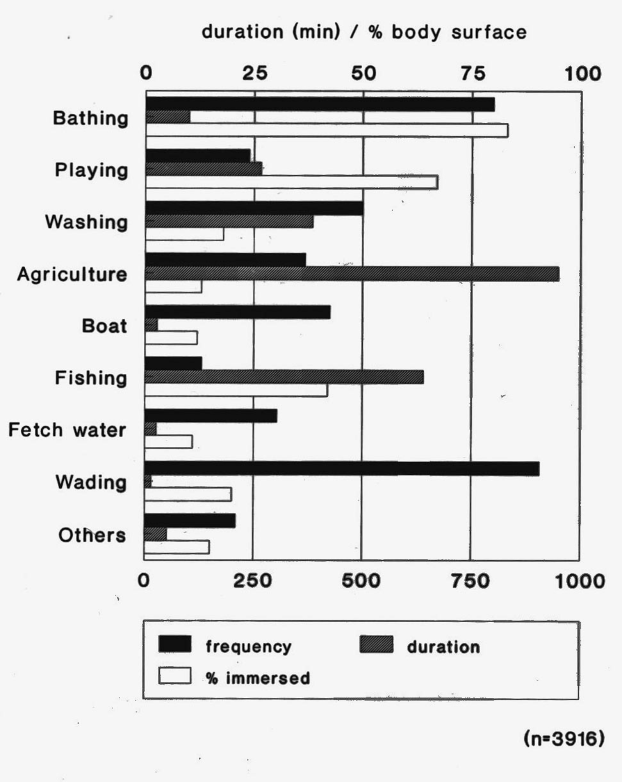

Fig. 15: Total frequency, average duration and average body contact surface per activity, as observed on seven sites during seven months of water-contact study.

The exposure index is a combined measure helping to compare different activities and identify those with high infection risks (Figure 16). Bathing has the highest exposure index, resulting from a very high frequency and over 80% immersion of the body (Figure 15). Fishing without boat, playing, work on the rice fields and washing all have moderate to high exposure indices. The other activities can almost be neglected in a risk analysis (fishing with boat, fetching water, wading and other activities). The exposure index calculated per site gives an impression of the relative importance of water contacts on the different sites (Figure 16). The east dike and the ford have a very low exposure index; the depression zone near the village has by far the highest exposure index, while the other sites take an intermediate position.

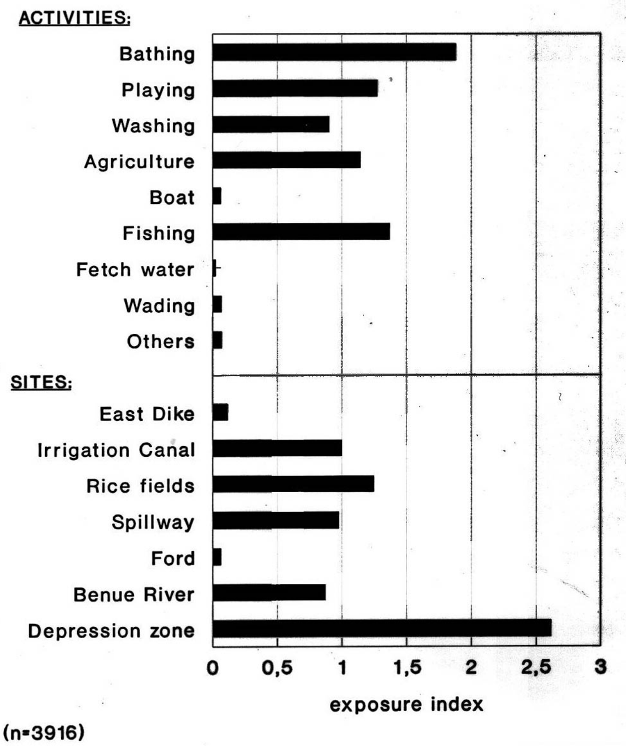

Fig. 16: Exposure index (duration x body surface area x relative frequency) per activity and per site.

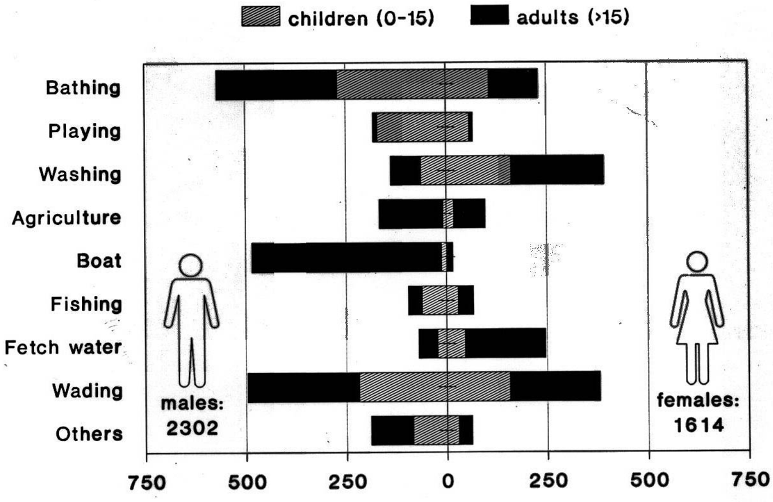

Fig. 17: Numbers of observed water-contacts per activity, differentiated to sexe and age class (children vs. adults).

Differences between the sexes

The differences between the sexes show the classical distribution of tasks (Figure 17). Women are more confined to the compounds performing domestic activities; men are more active outside the households resulting in a higher contact frequency of men (2302 vs. 1614 for women). Women are more often involved in washing and fetching water, i.e. domestic activities. Girls under 15 years of age are also active in domestic tasks (washing), while boys under 15 are more frequently observed playing and bathing, i.e. recreational activities. Fishing with boat is strictly a male activity, while fishing without boat is performed in comparable numbers by males and females, but some additional remarks have to be made. The techniques applied by men and women are entirely different. Men only have water contact when placing their gill-nets, fish traps or when chasing large fish with spear or arrows while women enter the water with baskets and chase the fish to a corner of the pool where the fish are trapped in the baskets and caught by hand. The average duration of the activity is 137.5 min with a body contact surface of 41%; the average duration for males fishing without boat is 19.2 min with 20% contact surface. Women contribute disproportionally to the elevated exposure index for fishing without boat (Figure 15). The overall exposure indices are similar for men and women (3.8 for men vs. 3.6 for women) although some differences exist in total number of contacts (more men), average body surface (higher for men) and duration of activity (longer for women).

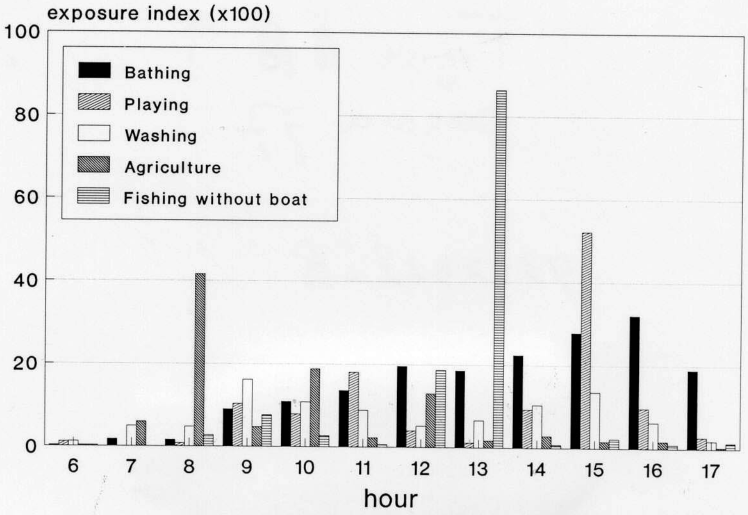

Fig. 18: Exposure index per hour of five high-risk activities throughout the day.

Water contacts in the cause of the day

If we look with some detail into the different activities performed throughout the day (Figure 18) a complicated picture arises. The five activities contributing most to the overall exposure index show a different pattern during the day. Bathing increases gradually during the day towards 17.00 h. Most playing activity is seen between 11-12.00 h and 15-16.00 hours, after school time. Washing is done throughout the day with peaks between 9-10.00h and 15-16.00 h. Agriculture is a morning activity, with a large group starting at 8.00 h. Because the starting moment is represented in the figure it looks as if the activity doesn't continue in the next hours but one must take into consideration the long duration of the activity, on average taking over 90 minutes (Figure 15). The same applies to fishing without boat, being a very irregular and sporadic activity, but nevertheless with a very high exposure in the afternoon after 13.00 hours (average duration of more than 60 minutes).

Taking into account the increased activity of schistosomiasis cercariae between 11-15.00h, all activities can be considered contributing to the transmission risk, although fishing without boat has the highest exposure risk to cercariae.

Water supply and village water needs

The water supply as measured on December 9th, 1989 is compared to the hypothetical water demand of 70 l/person/day, as explained in the introduction (table 3). From these data it is clear that only Gounougou s.s. has enough water at its disposal (if the water supply is not interrupted!). In about six hours the quarter receives the needed amount of water. For the other quarters 12 hours (daylight) are not sufficient to collect the required amount of water. The crossroads quarter has an acute shortage of water. The way people deal with this shortage is shown by a detailed look on the activities per site (Figure 19; the ford is omitted as a source of water since 98% of the registered activity concerns wading). A striking feature is the contact pattern in the irrigation canal which is almost exclusively used for domestic and recreational purposes by large numbers of persons, in spite of its distance to the village. Obviously the clear and running water coming from the lake is highly appreciated. The spillway, Benue river and the depression zone are used for domestic, occupational and recreational purposes, and even drinking water is often fetched in the depression zone, Benue river and the irrigation canal. Water contact at the East dike and on the rice fields principally is of occupational origin (fishing by boat and agriculture). In the first three columns of table 4 the results are summarized. The depression zone, already characterized by the highest exposure index, is considered a high risk area for all three classes of activities.

Table 3: Water supply and hypothetical water demand per quarter in Gounougou

	Quarter (waterpoints)	House-holds	Inhabit-ants[1]	Demand[2] (l/day)	Supply[3] (l/h)	Time[4] (hours)
A	Market (1)	45	227	15,890	780	20.4
B	Gounougou (3)	120	521	36,470	6,228	5.9
C	Bantaré (2)	67	320	22,400	1,170	19.1
D	Lameré (2)	126	699	48,930	2,064	23.7
E	Crossroads (2)	91	484	33,880	306	110.7
	Total	449	2,251	157,570	10,548	14.9

Number of water points per quarters are given between parentheses.

[1]: Total number of inhabitants per quarter (census december 1988).

[2]: Hypothetical water demand per quarter: number of inhabitants x 70 l/day.

[3]: Actual water supply in liter per hour.

[4]: Time needed to provide the necessary amount of water.

Table 4: Summary of schistosomiasis infection risks and possible mitigating measures.

Activity class	High risk activty	Performed at sites	Appropriate control measures	Practical implications
Domestic	Washing Bathing	2: irr. canal 4: spillway 6: Benue 7: depression	Cercariae-free water supply	Washing and bathing facilities.
Occupational	Fishing without boat Irrigated agriculture	3: rice fields 4: spillway 6: Benue 7: depression	Destruction of vector populations. Avoiding cercariae.	Water management and habitat alterations. Mollusciciding of snail breeding sites. (Shift in working hours)
Recreation	Playing/ -swimming	2: irr. canal 7: depression	Cercariae-free water reservoirs.	Choice of safe sites through snail sampling. School education.

Discussion

High risk activities and sites The observed activities with highest exposure indices are occupational (agriculture and fishing), domestic (bathing and washing) and recreational (playing). The most frequent activity, wading, does not count at all in the exposure index because of its short duration and minor contact surface. This does nor imply that wading can be completely forgotten in a risk analysis, because a water contact study is a tool in estimating the relative importance of different activities, but data on snail populations and snail infection levels are necessary to assess the actual infection risk.

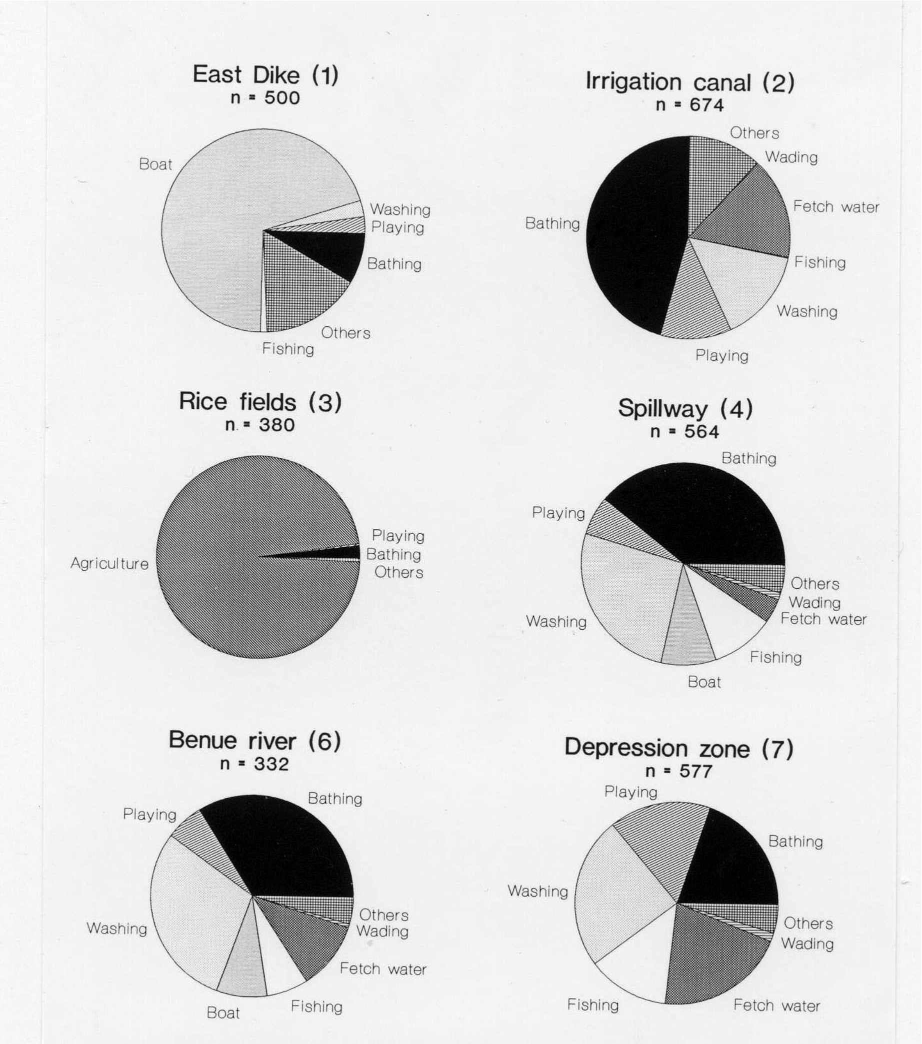

Fig. 19: Relative frequency of activities observed per site (number of observations indicated per site).

All high exposure activities described above are performed in the high risk period between 11-15.00 hours. A special remark can be made concerning the fishing activity in the depression zone (7). This activity has only been registered during one day in the observation period. Nevertheless the exposure index is higher than the index of daily activities like bathing and washing. This illustrates the importance to consider all possible water contacts throughout the year. The epidemiology of schistosomiasis is complex and transmission can depend on these incidental contacts.

The introduction of irrigated agriculture has directly and indirectly created new risks of transmission. Directly, a new type of occupational exposure to potentially infected water was introduced with the work on the irrigated fields, which was found to be a high-risk activity. Indirectly, the creation of the marshy area very near the village by leading the drainage water of the irrigation scheme through the depression has considerably increased the health risks for the local population.

Household use of open water

The household water supply is clearly not sufficient, and the use of open and untreated water constitutes a major health risk for the population. Washing and bathing is commonly done in one of the available permanent reservoirs, with a preference for those with running water (river (6) and irrigation canal (2)). A glance at the map (Figure 13) shows that people from the Bantaré (c), Lameré (d) and crossroads (e) quarters use the depression (7) for domestic purposes, the spillway (4) is used by people from the market quarter (a), while the river bank (6) and the secondary irrigation (2) canal are used by all villagers. Even drinking water is often collected at these sites. The measurement of the piped water supply gives supportive evidence that the demand surpasses the supply. It must be noted that due to the irrigation scheme and the Lagdo dam, só much open water is available in the direct vicinity of the village, that people who have to wait in line for drinking water might quickly be inclined to use another source of water for bathing or washing. Even a sufficient amount of safe water will probably not stop people from using other readily available sources, so additional measures remain a necessity.

Measures to be taken

Evidently any attempt to reduce the risk of transmission should take into account the very different nature of the activities. While domestic and recreational activities can be transferred to other and safer places, occupational exposure requires an entirely different approach. In the next section we only discuss options considered realistic in the African context, which implies that investments must be low and manageable by local people/authorities. In table 4 the results of the study and the measures to be taken are summarized, classified according to the nature of the activity:

Exposure through domestic activities. For domestic needs, washing facilities should be constructed. The availability of relatively clean irrigation water throughout the year can be used to satisfy the inhabitant's domestic water needs. These washing facilities should fulfil a number of parasitological (A) and public requirements (B):

A1: Water must come from a mollusc-free reservoir.
A2: No human or other polluting activities are allowed upstream from the washing facility.
A3 The excess water from the facility must be drained directly, without reusing the water for other purposes. The chance this water is contaminated by eggs of parasites is considerable.
A4: The area around the washing facility should be kept as dry as possible to avoid contamination of the mud (hookworms larvae live in muddy ground).
A5: The ideal washing site should also have a safe playing area for children accompanying their mothers.

Interviews with women during the observation period also led to several public requirements:

B1: If enough space is available no problems concerning ethnic relation or sex are expected in Gounougou. A washing site per quarter is preferred.
B2: The flow of water must be sufficient to rinse clothes without difficulty.
B3: Separate places should be made for bathing, and washing dishes and clothes.
B4: There must be a sandy field to dry clothes; furthermore shade trees are needed to protect little children.

These wishes expressed by women correspond to those described by Husting (1983) for Bantu women in Zimbabwe. The provision of safe water and sanitary facilities has been given high priority by many authors, not only in relation to schistosomiasis control. In irrigation schemes this aspect of water management has often been neglected. Introduction of irrigation often increases the revenues of the farmers, but can also create major health hazards. Therefore it is a pity that a resource as important as water is not used more effectively by also using it for improvement of the sanitary conditions in and around irrigation systems.

Occupational exposure. Water contacts through occupational activities can hardly be reduced. Fishermen and rice growers are obliged to enter the water. Rubber boots for people working on rice fields will reduce water contact but these are expensive and often not appreciated. The solution must be sought in the control of snail populations by environmental and water management, and/or molluscicīding. Regular sampling of the irrigation scheme has revealed the presence of intermediate hosts in field and drainage canals. Regular cleaning of these canals can significantly reduce the number of snails. Even if snail populations cannot be eliminated entirely, transmission can be substantially reduced by regular destruction of the populations. After such an interruption in the development of a snail population, the snails need time to reestablish themselves and, more important, to become infective again. This can take several months. Persisting snail populations can be eradicated by focal molluscicīding, although the high price and toxic effects on aquatic animals (including fish) pleads for a restrained use of these chemicals. Many natural plant molluscicides are known, but no commercial product is available yet. In general the mass production of these products is difficult (Mott, 1987). A shift in working hours is not considered feasible, given the amount of labour required in a short period of time during replanting and harvesting. People work entire days during these periods.

Avoiding water contact is even more difficult for fishermen. For them the biggest problem in Gounougou was created by the draining of excess irrigation water into the depression zone (7), especially putting the fishing women at risk. By environmental and water management this swampy zone has later been restructured for small scale agricultural use, and snail populations in the vicinity of the village were eradicated (Slootweg & Keyzer, 1993). At the East dike most fishermen use boats, which does not entail intense water contact.

Exposure through recreational activities. Recreational activities are very hard to control, especially when they involve children. Provision of safe washing facilities will help to reduce the infection risk for young children. For older children safe swimming places have to be indicated. Results of the snail sampling programme show that the Benue river is a safe place because snails cannot survive the current this close to the hydroelectric station, but any change in water regime or in the environment can result in the development of snail population so regular screening by local health or other authorities is desirable. The school can play an important role in educating the children on behaviour and health risks, and maybe even in monitoring of snail populations.

Conclusions

The water contact study as described above has revealed relevant information on the use of water and the associated risk of schistosomiasis transmission in the newly constructed irrigation scheme of Gounougou. The data of this study were analysed in a non-exhaustive manner in order to show general patterns in water contact and water use. For practical use like the implementation of control measures, more detailed questions can also be answered by further analysing the data per site or per activity.

The summary in table 4 shows that irrigation is only partly responsible for the schistosomiasis problem, as high risk activities are also performed outside of the irrigation scheme. However, it is obvious that work on irrigated fields brings about prolonged water contact and that the drainage water from the scheme has created a high risk area very near the village. To our opinion irrigation development can also have beneficial effects on the public health situation, if the availability of water is fully exploited for sanitation of the environment and for community water supply. The popularity of the secondary canal among the villagers for washing and bathing is indicative that this water should not only be used for irrigation but also for laundry and bathing facilities. With relatively simple means such facilities can be provided during the construction phase of a scheme. Furthermore a better management of the drainage system can reduce the numbers of organisms responsible for transmission of diseases (snails as well as mosquitoes); in Gounougou the drainage system has been reconstructed and the results of this intervention are encouraging (Slootweg & Keyzer; op. cit.)

All measures described above are aimed at reducing the risk of infection, and can never guarantee absolute safety. In case an infected person gets complaints, it is desirable that he or she can find medical treatment without too many difficulty at a local health centre. Preliminary data from the Cameroon project suggest that people with complaints after schistosomiasis infection by far produce the largest numbers of eggs (Slootweg, 1991). By treating these people, the health centre plays an important role in controlling the disease. Therefore the role of the primary health care facilities will always be of crucial importance to the control of schistosomiasis. The availability of safe single dose drugs has much improved the effectiveness of health care. The measures to prevent water contacts and to reduce infection risks described above, will keep the rate of reinfection at a low level and together with an effective health care facility the schistosomiasis problem can be kept under control.

Acknowledgements

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References

Chandiwana S.K. 1987. Seasonal patterns in water contact and the influence of water availability on contact activities in two schistosomiasis-endemic areas in Zimbabwe. *Central African Journal of Medicine* **33**: 8-15.

Dalton P.R. 1976. A socioecological approach to the control of *Schistosoma mansoni* in St Lucia. *Bulletin of the World Health Organisation* **54**: pp. 587-595.

Husting E.L. 1983. Human water contact activities related to the transmission of bilharziasis (schistosomiasis). *Journal of Tropical Medicine and Hygiene* **86**: 23-35.

Jordan P.J. 1985. *Schistosomiasis. The St Lucia project*. Cambridge University Press.

Kloos H. & Lemma A. 1980. The epidemiology of *Schistosoma mansoni* infection in Tensae Berhan: Human water contact patterns. *Ethiopian Medical Journal* **18**: 91-98.

Kloos H., Higashi G.I., Schinski V.D., Mansour N.S., Murrell K.D. & Dewolfe Miller F. 1990. Water contact and *Schistosoma heamatobium* infection: a case study from an Upper Egyptian village. *International Journal of Epidemiology* **19**: 749-758.

Kvalsvig J.D. & Schutte C.H.J. 1986. The role of human water contact patterns in the transmission of schistosomiasis in an informal settlement near a major industrial area. *Annals of Tropical Medicine and Parasitology* **80**: 1

Klumpp R.K. & Webbe G. 1987. Focal,seasonal and behavioural patterns of infections and transmission of *Schistosoma heamatobium* in Lake Volta, Ghana. *Journal of Tropical Medicine and Hygiene* **90**: 265-281.

Mott K.E. (editor) 1987. *Plant molluscicides*. UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases. John Wiley & Sons Ltd.

Mouahid A., Moné H., Chaib A. & Théron A. 1991. Cercarial shedding patterns of *Schistosoma bovis* and *S. haematobium* from single and mixed infections of *Bulinus truncatus*. *Journal of Helmintology* **65**: 8-14.

Oomen J.M.V., Wolf J. de & Jobin W.R. 1988. *Health and irrigation. Incorporation of disease-control measures in irrigation, a multi-faceted task in design, construction, operation*. ILRI Publication 45 Volume 2, Wageningen, the Netherlands.

Pitchford R.J., Meyling A.H., Meyling J. & Toit J.F. du 1969. Cercarial shedding patterns of various schistosome species under outdoorconditions in the Transvaal. *American Journal of Tropical Medicine and Hygiene* **63**: 359-371.

Polderman A.M. 1975. The transmission of intestinal schistosomiasis in Begemder province, Ethiopia. *Acta Leidensia* **XLII**: 1 - 193.

Robert C.F., Bouvier S. & Rougemont A. 1989. Epidemiology of schistosomiasis in the riverine population of Lagdo Lake, Northern Cameroon: mixed infections and ethnic factors. *Tropical Medicine and Parasitology* **40**: 153-158

Slootweg R. 1991. *Rapport final du volet santé*. Contrôle integré de la schistosomiase à Gounougou; réussites et échecs. Rapports du Projet Pisciculture, MEAVSB, B.P. 17, Garoua, Cameroun.

Slootweg R. & Keyzer (1993) Reducing health risks in drainage systems by optimizing waste water use. An experimental trial from the Benue valley, Northern Cameroon. *Irrigation and Drainage Systems*, **7**: 99-112.

Slootweg R., van Rhijn E., van Schijndel J.A., Dijkstra M.J., Colenbrander A.C. & Kitmo, S. (in press). A longitudinal study of snail intermediate hosts of trematode parasites in the Benue valley of North Cameroon. *Journal of Medical and Applied Malacology*

Tayo M.A., Pugh R.N.H. & Bradley A.K. 1980. Malumfashi endemic diseases research peoject, XI. Water-contact activities in the schistosomiasis study area. *Annals of Tropical Medicine and Parasitology* **74**: 347-354.

Tameim O., Abdu K.M., El Gaddal A.A. & Jobin W.R. 1985. Protection of Sudanese irrigations workers from schistosome infections by a shift to earlier working hours. *Journal of Tropical Medicine and Hygiene* **88**: 125-130.

PART II Chapter 5

EPIDEMIOLOGY OF SCHISTOSOMIASIS

5.1 Population structure and schistosomiasis infection in villages on the right bank of the Benue river.

The Benue valley was until recently a sparsely populated area with an autochthonous population of fishermen, farmers, and semi-nomadic pastoralists. At the start of the North-East Benue project for regional development, in 1973, the average population density in the area was 2 person per km2 (excluding the provincial capital of Garoua). The official policy to stimulate migration from the overpopulated Extreme Northern Province, and the construction of a dam in the Benue near Lagdo, was the onset of a dramatic change in the regions' demography. Large numbers of settlers from the North and Extreme Northern provinces were attracted by the labour opportunities created on the construction site of the dam. Simultaneously, the creation of a large water reservoir attracted fishermen, while the subsequent construction of an irrigation scheme near Gounougou created further opportunities for farmers. The improvement of the entire infrastructure in the larger area around Lagdo, e.g. schools, health centres, roads and community training services, largely contributed to the popularity of this area for settlers. In 1991, the average population density of the Northeast Benue region had already increased to 18 inhabitants per km^2. (Data retrieved from unpublished project documents from the library of the MEAVSB, B.P. 17, Garoua).

To be able to assess the actual health situation concerning schistosomiasis in the study area, it was considered necessary first to perform a census in the villages of the pilot area, followed by a schistosomiasis survey. Many villages around the Lagdo reservoir had already been surveyed by a team of Médecins Sans Frontières for vesical schistosomiasis (*Schistosoma haematobium*) as well as intestinal schistosomiasis (*S. mansoni*) (Robert, 1986; 1990), but no data were available on the villages of Gounougou and Riao, situated immediately downstream of the Lagdo dam on the right bank of the Benue. In Gounougou irrigation schemes are under construction since 1987 and it is feared that schistosomiasis transmission will be propagated by the introduction of irrigated agriculture. For Riao an irrigation scheme is scheduled but due to financing problems, construction of this scheme has not even started yet. Both villages are situated on an elevated embankment of the Benue and are characterized by a large inflow of immigrants from the extreme northern province in the last two decades. Since only Gounougou possesses an irrigation scheme, results of a schistosomiasis survey might give interesting differences.

Methods

An inventory of all households in Gounougou and Riao was made, and their location was marked on a map. Data on numbers of inhabitants, age, sex and tribal group were gathered. From the resulting list, households that would be visited for the schistosomiasis survey were randomly chosen. In Gounougou also a school survey was carried out for *S. haematobium* only. On a specific day, the date of which had been announced earlier, sample containers were distributed among the selected people. They were asked to return the containers to their school the next morning. Urine samples were analyzed immediately using Nytrell filters; Kato slides were made on the spot and analyzed the following days. The survey in Gounougou was carried out by Médecins Sans Frontières (MSF) with the assistance of our project students and only a summary of these data can be given in this paper; they will be extensively discussed by Robert (in prep.). In Riao the survey was performed by the project team with assistance of MSF.

Results

Gounougou

In december 1988, Gounougou consisted of 22 ethnic groups and counted 451 households with 2234 inhabitants. Figure 20 shows the division among ethnic groups and religion. It is illustrative for this region that the three largest groups, Guiziga, Moundang and Toupouri, all recently settled in the village. The autochthones are the islamic Dama, Bata and Foulbé, who still have many privileges concerning land tenure rights and customary functions. The settlement history of Gounougou is illustrated by figure 21, that shows the enormous influx of migrants over a 15 year period. In the perception of the inhabitants the distinction between religion is more important than ethnic descent, which is reflected in the division between the two main quarters of Gounougou, i.e. Gounougou s.s. and Labéré.

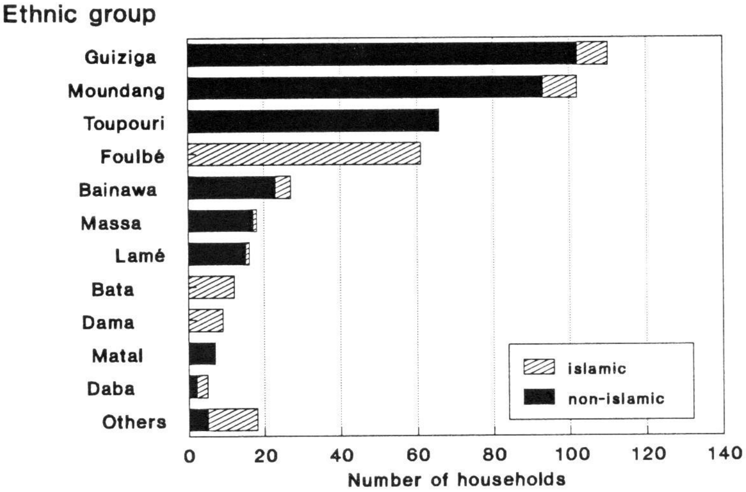

Fig. 20: Ethnic and religious composition of Gounougou

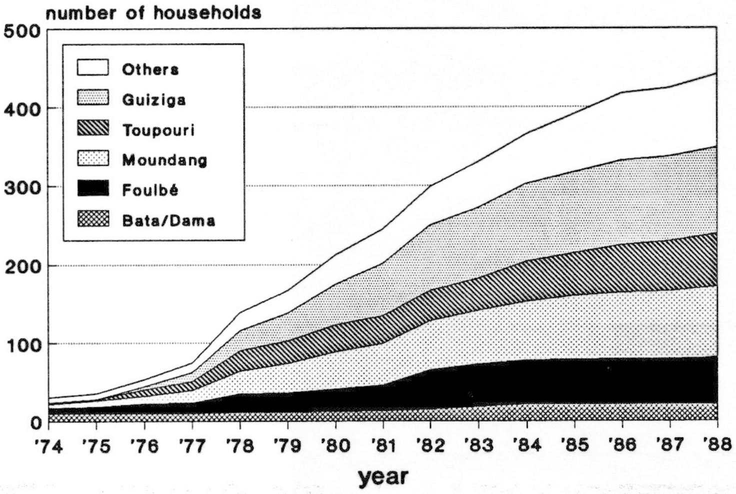

Fig. 21: Settlement history per ethnic group in Gounougou

Only three of the 126 islamic families live in Labaré (217 households); even more illustrative is that the Guiziga, the Moundang and the Bainawa that were "converted" to islam also moved to Gounougou s.s. The village is governed by the autochthonous village chief (djaoro) of Bata descent, assisted by 11 quarter chiefs reflecting more or less the division among ethnic groups. Conflicts are settled by the congregation of djaoros, and despite the diversity of inhabitants no open animosity or hostilities were observed that could not be settled.

The schistosomiasis survey in april 1989 revealed a prevalence of 28.7% for *S. haematobium* (N=87) and 12.2% for *S. mansoni* (N=81). The prevalence per age-class for *S. haematobium* (table 5) more or less shows the classical distribution with highest infections in the 10 to 20 years age-class. For *S. mansoni* the numbers of infected individuals are too low to discriminate between age-classes. A survey in the school of Gounougou on *S. haematobium* only, showed a remarkably high 65.6%

prevalence among pupils between 5 and 20 years of age (N=99). Since many pupils come from outside Gounougou we have tried to verify the residence of all pupils appearing on the 1989 survey list. In November 1991, it was possible to track 55 pupils living in Gounougou, Labaré (at 2 km north-east), Ouro Doukoudjé (at 4km north-east), and Lagdo (on the other side of the Benue at 7km). Table 6 shows that pupils from other villages are more often infected with *S. haematobium* and also have higher geometric mean egg-counts. The prevalence among the pupils living in Gounougou corresponds to the prevalence in this age group in the village survey. Severity of schistosomiasis in the other villages appears to be higher than in Gounougou itself. It must be noted that those villages have no relation at all with the Gounougou irrigation or drainage system.

Table 5: Prevalence rates of *Schistosoma haematobium* and *S. mansoni* in Gounougou in 1989.

	S.	*haematobium*		*S.*	*mansoni*	
age-class	N	infected	prevalence	N	infected	prevalence
0 - 9	40	10	25%	38	4	11%
10-19	20	9	45%	17	1	6%
20-29	12	3	24%	12	2	17%
30-39	7	1	14%	6	2	33%
40-49	5	1	20%	5	1	20%
50-59	1	0	0%	1	0	0%
>59	2	1	50%	2	0	0%
total	87	25	28.7%	81	10	12.3%

Riao

In August 1989, a total of 147 households with 867 individuals were counted in Riao, i.e. 5.9 persons per household. The village consists mainly of autochthonous islamic Foulbé (30 households; 4.1 persons per household) and immigrant christian Toupouri (107 households; 5.2 persons per household). The remaining 10 households from other tribal groups mostly are government appointed persons involved in teaching, community training, etc.). As figure 22 shows, the first wave of immigrants arrived in 1977 when the Northeast Benue project transported 57 families from Kar Hay to Riao. After 1977 the inflow of Toupouri continued, although at a less spectacular pace. The age-class distribution in figure 23 shows the dominance of Toupouri in 1989. Especially the small number of children and adolescents among Foulbé is in marked contrast with the Toupouri. The village chief is a Foulbé bearing the ardo title, one step higher than djaoro in the traditional hierarchy. He is assisted by three Toupouri quarter chiefs.

Table 6: Prevalence and intensity of infection of *S. haematobium* among pupils of Gounougou elementary school, divided according to village of residence. Asterisks (*) indicate if the difference between Gounougou and one of the other villages is significant; $p < 0.05$ (Chi^2 for prevalence rates; ANOVA for geometric mean egg-output).

Residence	Gounougou	Labaré	Ouro Doukoudjé	Lagdo
N survey	82	13	15	7
N infected	37	10	11	6
prevalence	45%	* 77%	* 73%	* 86%
egg-count (geom. mean)	11.8	* 64.7	31.0	19.1

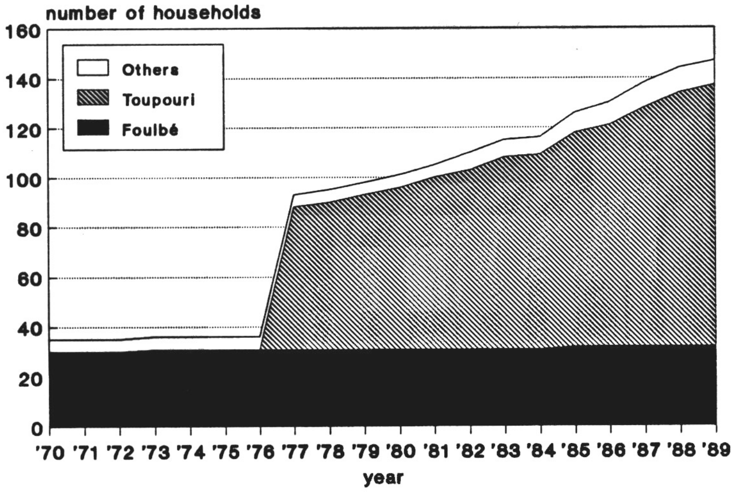

Fig. 22: Settlement history of Riao

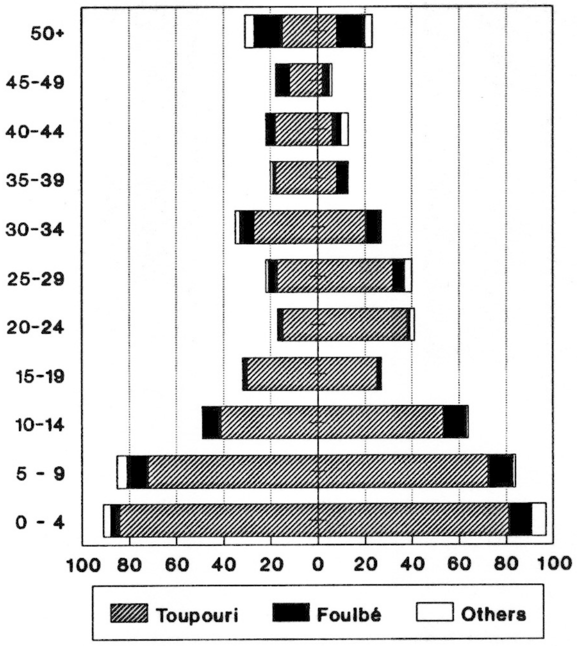

Fig. 23: Age-class distribution and ethnic groups in Riao.

The schistosomiasis survey was held in September 1989. Of 284 persons visited, 265 delivered their samples the next morning at the school building (93%). Only adult Foulbé males seemed somewhat reluctant to cooperate; 27% of them did not return their sample bottles. In 258 urine samples 28 persons (10.9%) were found infected with *S. haematobium* (16 males and 12 females). Fourteen of the infected individuals were born in Riao and could not have imported the disease from their region of origin. Geometric mean egg-output was low: 4.9 eggs/10 ml urine (males 6.0; females 3.8). In table 7 the results of census and survey are summarized. The overall prevalence is highest among persons between 10 and 25 years of age, although this rate can still be considered low. In 189 stools 7 cases of *S. mansoni* were found (3.7%), of which 4 are born in Riao.

Table 7: Census data and schistosomiasis survey in Riao, August 1989.

	Census		Survey		*S. haematobium*		
age-class	males	females	males	females	males	females	total prevalence
0 - 4	91	97	22	26	1	3	8%
5 - 9	85	84	26	30	4	1	9%
10-14	49	64	21	17	5	2	18%
15-19	32	27	7	15	2	2	18%
20-24	17	41	6	10	2	2	25%
25-29	22	40	6	12	1		6%
30-34	45	27	9	8	1	1	12%
35-39	20	13	6	4		1	10%
40-44	22	13	6	3			0%
45-49	18	6	4	4			0%
50+	31	23	8	8			0%
Total	432	435	121	137	16 (13%)	12 (9%)	11%

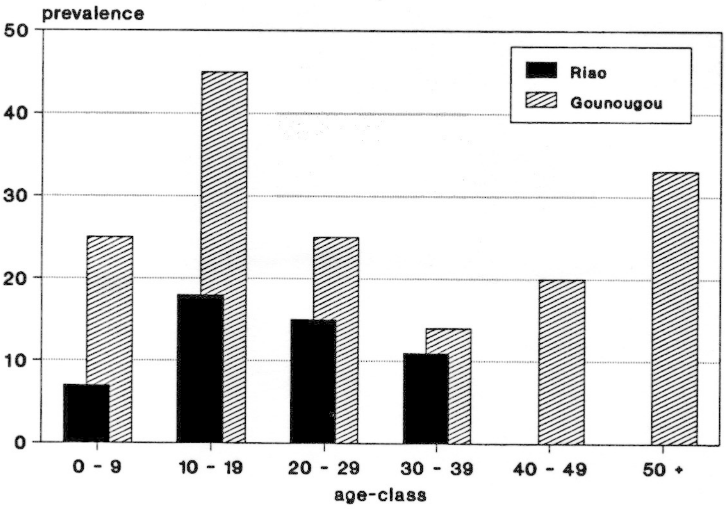

Fig. 24: Prevalence of vesical schistosomiasis per age-class in Gounougou and Riao.

Discussion and conclusion

Both Riao and Gounougou are dominated by recently settled immigrants, mainly coming from the southern part of the Diamaré plateau in the extreme northern province. Vesical and intestinal schistosomiasis are endemic in these regions of origin. Data on schistosomiasis prevalence in Riao and Gounougou must be considered with care, because they will be influenced by people carrying the parasite from elsewhere. Nevertheless, it is clear that transmission is occurring in the Benue valley because children who were born in Riao or Gounougou were found infected.

The prevalence rates for both *S. haematobium* and *S. mansoni* in Gounougou and Riao are moderate to low. The rates in Gounougou, however, are consistently higher than in Riao for all age-classes, as illustrated in figure 24. Although it is tempting to conclude that the influence of irrigation development near Gounougou is responsible for these higher prevalences, the data from the school survey show that this conclusion is not justified. The villages with highest prevalence of *S. haematobium* among school children, Ouro Doukoudjé and Labaré, are situated at a 4km distance from the river and the irrigation scheme and do not possess any source of permanent open water. The occurrence of seasonal transmission in the rainy season, limited to only a few sites, might explain the relatively elevated prevalence of schistosomiasis in these villages. The seasonal rain-fed pools that can be found near O. Doukoudjé and Labaré harbour populations of *B. senegalensis*, an intermediate host of *S. haematobium* that is capable of surviving prolonged periods of desiccation (see chapter 3).

The only justified conclusion so far is that after two years of irrigation no dramatic outbreak of schistosomiasis can be recognized in Gounougou. However, the inflow of large numbers of immigrants that possibly carry parasites, the planned extension of the existing irrigation scheme, and the expected further colonization of these schemes by snail hosts, give reason for caution. According to recent information the prevalence of *S. haematobium* in Gounougou has indeed increased to 43% in January 1993 (Brussel & Contant, pers. com.).

Acknowledgements

Claude-Francois Robert has kindly provided the survey data of Gounougou. Marie-Noelle Panathier and Colette Bruggen of M.S.F.-Suisse assisted with the Riao and Gounougou surveys. Marlies van Schooten is acknowledged for her provision of demographic data.

References

Robert, C.F (1987). *Enquete sur la schistosomiase dans les populations riveraines du lac de Lagdo*. Rapport intermediaire. Unité de Médecine Tropical, Geneva.

Robert, C.F., S. Bouvier & A. Rougemont (1990). Epidemiology of schistosomiasis in the riverine population of Lagdo Lake, Northern Cameroon: mixed infection and ethnic factors. *Trop. Med. Parasit*: **40**, 153-158.

PART III Chapter 6

SNAIL CONTROL BY FISH

6.1 Prey selection by molluscivorous cichlids foraging on snail intermediate hosts of schistosomiasis

Shortened version of: R. Slootweg (1987). *Oecologia* **74**: 193-202, with additional data on *Astatoreochromis alluaudi*.

A large section of the original publication in Oecologia was devoted to observations on encounter rates and its implications for the understanding of the foraging model. For the general understanding of the foraging experiments this information is less relevant and beyond the scope of this thesis. The original paper did not contain information on *A. alluaudi*, so more recent observations on this species were added, confirming that *A. alluaudi* behaves similarly to the other snail-eating cichlids from Lake Victoria.

It has long been suggested that molluscivorous fishes can be used as biocontrol organisms of snails that serve as intermediate hosts of trematode parasites such as *Schistosoma* spp. (Anderson & Gobert 1924). Although some promising results were obtained in small scale field trials, no attempts have been made to formulate an effective method of using fish in biological control of snails (Slootweg 1985). The need for research in this field is well recognized (Hairston et al. 1975; McCullough 1981).

Since 1977 the Haplochromis Ecology Survey Team of the Research Group Ecological Morphology at Leiden University, The Netherlands, has been studying the species distribution and ecology of the haplochromine cichlid fish in the Mwanza Gulf (Tanzania) of Lake Victoria. Based on stomach contents and morphology these cichlids can be classified into eleven trophic groups which together utilize almost all food resources in the lake (Witte 1981 & 1984a). The species used in the present study are molluscivores (snail-eaters). This trophic group has two subgroups: oral shellers and pharyngeal crushers (Greenwood 1974).

- Oral shellers wrench their prey from the shell by taking hold of the exposed soft parts and shaking fiercely; the snail is extracted or torn apart.
- Pharyngeal crushers have a strong pharyngeal jaw apparatus which enables the fish to crush snail shells. The shell fragments are usually separated and ejected after crushing (Hoogerhoud, 1987).

Some 20 species of snail-eating fishes have been caught in the Mwanza Gulf (Witte 1981; Hoogerhoud 1986b). This diversity of snail-eating fishes provides an opportunity to study their comparative potential as biocontrol organisms against snails. Several fish species have been brought to the Zoologisch Laboratorium at Leiden, of which four were used for this study.

Optimal foraging theory can be an important tool in predicting the ability of snail-eating fish species to reduce snail populations. To gain maximal fitness it is plausible that a fish will optimize its foraging to be able to maximize its food intake. Major contributions to the understanding of fish foraging behaviour under laboratory and field conditions have been made by Werner and co-workers (review of optimal fish foraging: Townsend & Winfield 1985). Stein et al. (1984) examined how shell thickness influences selection by a snail-eating sunfish, *Lepomis microlophus*. The authors used an optimal foraging approach in which prey choice was related to energy and time cost/benefit (C/B) ratios. Selection among snail genera was consistent with differences in shell strength and a time C/B construct, operationally defined as handling time divided by prey dry mass. However, within any snail genus neither shell strength (smallest snails had weakest shells) nor time C/B (largest snails had minimal C/B) provided predictions consistent with results from experiments on selective predation. Stein et al. concluded therefore that no size selection occurred within a genus.

The approach in the research described below is based on the classical or first generation optimal foraging models (Krebs et al. 1983). The biomass intake per unit of handling time was calculated from prey dry mass and prey handling time. A fish maximising its food intake should select the prey items with highest reward in prey biomass per second handling time.

Experimental animals

Fish-species

For reasons given by Hoogerhoud (1984) the generic name *Haplochromis* is preferred to the new generic classification as suggested by Greenwood (1980) for a number of species used in this study.

The oral-shelling species used were *Macropleurodus bicolor*, and *Haplochromis xenognathus*. Their diet consist mainly of prosobranche snails (mostly *Melanoides tuberculata* and *Bellamya unicolor*) and insects (Greenwood 1974). Fryer & Iles (1972, p. 75) described *M. bicolor* as being able to crush snails orally, but I never observed this type of prey handling in more than 100 experiments in tanks. Only the shell apertures were damaged by the oral shelling action. Although oral shelling is thought to be their feeding strategy surprisingly all 'oral shellers' used in the experiments were well able to crush smaller snails pharyngeally. It must be stressed, however, that the common prey species in Lake Victoria have a higher crushing resistance than the snails used in the experiments.

Haplochromis ishmaeli and *Astatoreochromis alluaudi* are classified as pharyngeal crushers; very occasionally these species also shell their prey. Their diet consists of prosobranch snails and occasionally bivalves (Hoogerhoud 1986b).

All fishes were caught in the Mwanza Gulf (Tanzania) of Lake Victoria in January/February 1984, and flown to the laboratory in Leiden within 50 h. They were fed a combination of minced heart, dry food, *Tubifex* and snails. All species bred successfully, but with three species only wild-caught animals were used in the experiments. The experiments with *A. alluaudi* were performed in 1989 in the laboratory of the fishculture station of Gounougou in northern Cameroon. Here pond-bred animals were used in tank experiments.

Snails

Biomphalaria glabrata, an intermediate host of *Schistosoma mansoni* in the Americas, was reared on fresh lettuce in 200 l polypropylene transportation containers supplied with running tap water at a rate of 200 l a day and with a 12 h light 12 h dark regime. *Bulinus forskalii*, an intermediate host of *S. intercalatum* in Cameroon, was collected in the Gounougou irrigation scheme and used in the experiments with *A. alluaudi*.

Because of difficulty in extraction, the shells of *B. glabrata* had to be dissolved before the shell and dry tissue mass could be calculated. The snails were first dried in a 60° C oven for 3 days and weighed to the nearest 0.01 mg. The shells were then dissolved in 10% acetic acid for three days and the bodies were dried and weighed again. *B. forskalii* snails could easily be extracted from their shells.

Size selectivity experiments

The relationship between handling time and snail size

Observations were made on isolated fish kept in 50x50x50 cm tanks at 26° C. The fish could see each other, which was most helpful in making them more cooperative. In experiments to determine the relationship between handling time and snail size, snails were sorted into 0.5 mm size classes and offered to the fish in random order of size, five per class. Handling time was defined as the time a fish needs to crush a snail completely, to swallow it, and to eject the remaining shell fragments. Snail length, defined as the maximum shell diameter or length, was measured to the nearest 0,1 mm and handling times to the nearest 0.1s. Because satiation might influence the crushing time, observations were made on hungry fish, and stopped before the animal could be satiated; the number of snails necessary to satiate a fish had been determined previously. If handling times exceeded 4 minutes or snails were rejected, no larger snails were offered.

Experimental set-up

Snails were divided into 1-mm size classes from 3 to 15 mm for *B. glabrata*. In order to study the effect of the quantity of offered food on diet composition, snails were offered in quantities of 2, 5 and 10 per class. The total number offered at once per experiment was therefore 26 (2x13), 65 (5x13), or 130 (10x13). Two snails per class is not enough to satiate an adult fish; 10 per class is more than enough. *B. forskalii* snails were offered to *A. alluaudi* in 10 size classes between 4 and 14 mm, in one density only (5 snails per size class).

One experiment was carried out every day, hence starvation time before an experiment was about one day. The fish were allowed to eat for 1.5 h, the maximum time spent foraging in previous experiments, after which they showed no further interest. The remaining snails were recovered and measured. Snails not recovered were considered to be crushed. From previous observations empty or half-empty shells were scored as shelled orally. Experiments were repeated four or five times with every fish for all three food levels. Five individual *H. ishmaeli* were tested, five *M. bicolor*, and five *H. xenognathus*. The experiments with two *A. alluaudi* were repeated 8 times.

The Spearman rank correlation coefficient was used to test relations between:

- average yield in dry mass per second handling per size class vs. numbers of snails eaten per size class;
- numbers of snails orally shelled vs. snail density;
- numbers of snails orally shelled vs. fish size.

Some series of experiments could not be completed because of the sudden death or illness of some individuals; the incomplete data are given.

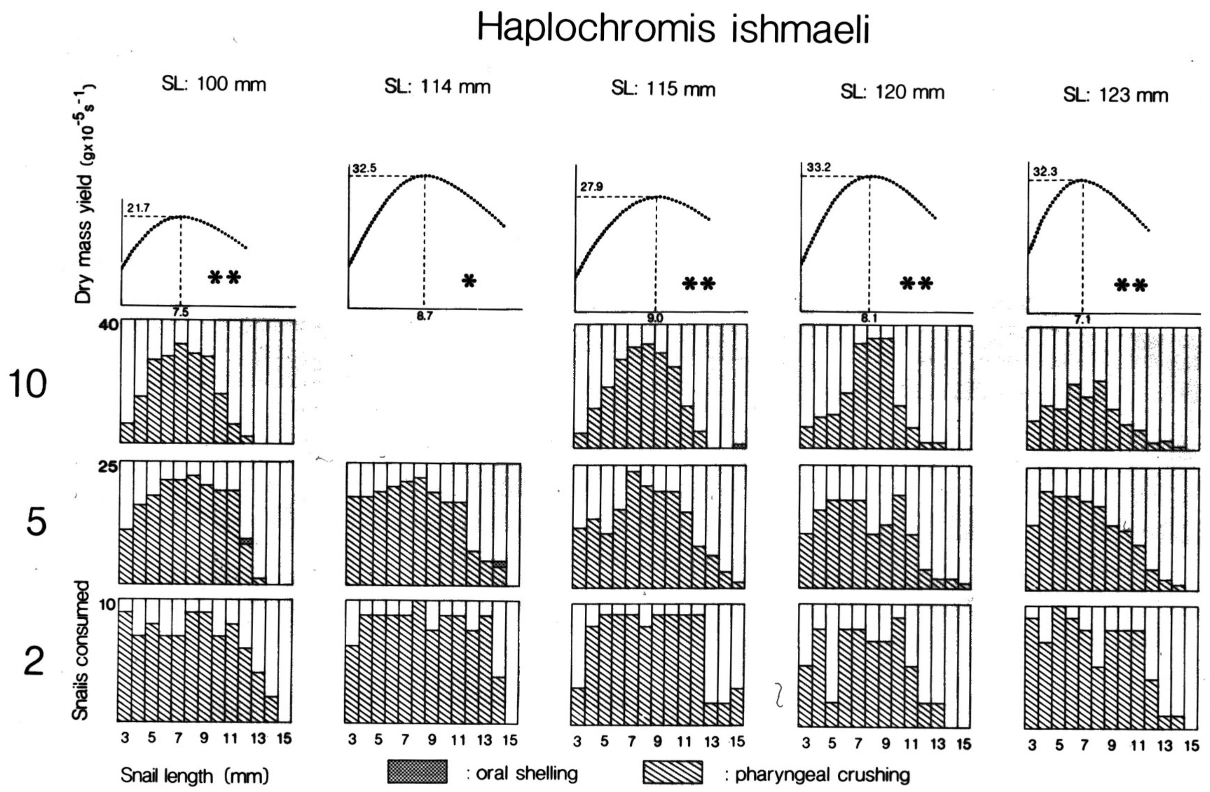

Fig. 25: *Haplochromis ishmaeli*. Individual standard lengths (SL) are shown at top. Top figures: snail dry mass obtained per s handling indicating snail size with highest reward per s. Histograms depict number of snails eaten when offered 10 snails per size class per experiment (upper row; results are the sum of 4 experiments per fish), 5 snails per size class per experiment (middle row; sum of 5 experiments per fish), 2 snails per size class per experiment (lower row; sum of 5 experiments per fish). Asterisks indicate a significant correlation between snail dry mass obtained per second handling (top figures), and the number of snails eaten when offered 10 snails per size class (except for SL 114, where results of 5 snails per size class were tested). Spearman rank correlation coefficient, *P<0.05; **P<0.01.

Results

The handling time versus snail length curves follow a single-logarithmic best fit regression line (least squares, all highly significant). The mean snail dry tissue mass per size-class is divided by the handling time as calculated from the regression line for every individual fish, in order to calculate the biomass intake per unit of handling time for all snail sizes (Figs. 25-28, curves). All curves have a maximum indicating the snail size with the highest reward per second crushing: a fish that maximizes its intake rate per second should select those sizes.

H. ishmaeli (Fig. 25) were able to eat a wide size range of snails; only the largest were usually not eaten. Selectivity increased with increasing numbers of prey offered. (Read histograms from bottom to top for each individual fish.) For all five specimens the number of snails eaten per size class significantly corresponds to the snail dry mass obtained per second handling for these size classes: the fishes eat most of the most profitable snail size class.

The rank correlation for the *A. alluaudi* of 106mm standard length (further referred to as A.a.106) eating *B. forskalii* snails is not significant (p=0.11) due to the steeply descending yield-curve with snails larger than 11mm, while the fish still eats numerous snails from these size-classes. Nevertheless, it is obvious that the fish eats most snails of the most profitable size-class (Fig. 26). For A.a.107 the relation between yield per second handling and numbers of snails eaten is highly significant (p < 0.01).

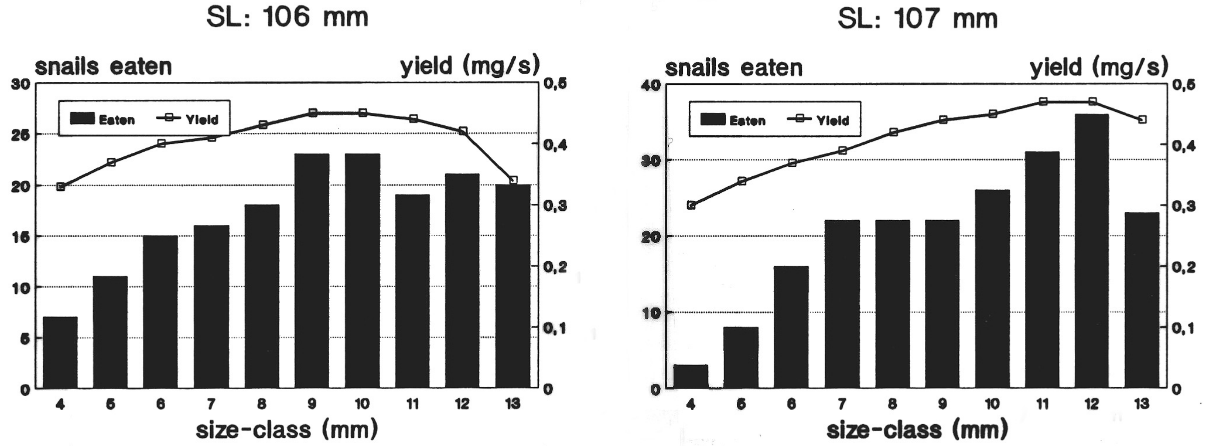

Fig. 27: Astatoreochromis alluaudi feeding on Bulinus forskalii snails.

The feeding behaviour of the so-called oral shelling species deviated strongly from what was expected; many more snails were crushed than shelled (Figs. 27 and 28). Even at the lowest prey density, some fish did not shell a single snail (*Macropleurodus bicolor*, 117 mm, *Haplochromis xenognathus* 107 mm). These fishes could not have been satiated after the experiment because the number of snails eaten was insufficient.

With increasing number of snails offered, selectivity in crushing increases, as with *H.ishmaeli*. Five out of eight actually shelling fishes shelled relatively fewer snails at higher snail densities (Figs. 27 and 28; P <0.05). In two out of three experiments, small *M. bicolor* shelled more snails than larger specimens did (Fig. 27). For *H. xenognathus* this only applied for one series of experiments with 5 snails per class (Fig. 28). The "oral-shelling" species selected smaller snails and did not crush snails as large as *H. ishmaeli* did.

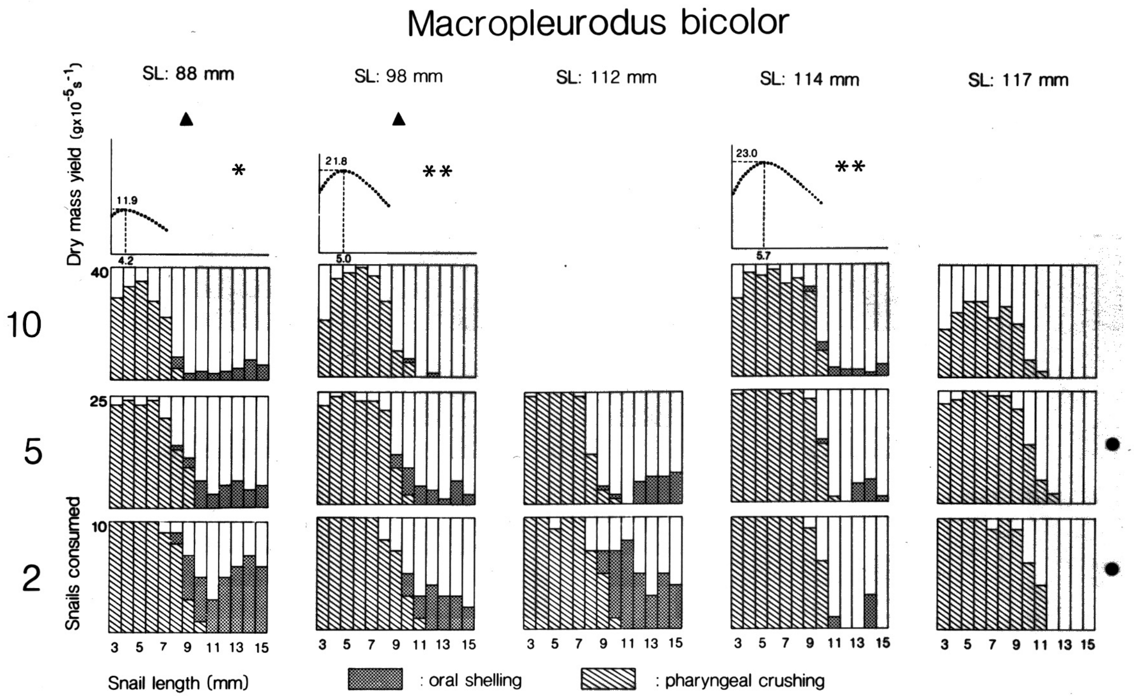

Fig. 27: *Macropleurodus bicolor*. As Fig. 25. A triangle indicates fish that orally shell fewer snails at higher snail densities (Spearman rank correlation P<0.05). A dot indicates a series of experiments (horizontal row) in which smaller fish shelled significantly more snails than did larger ones (Spearman rank correlation, P<0.05)

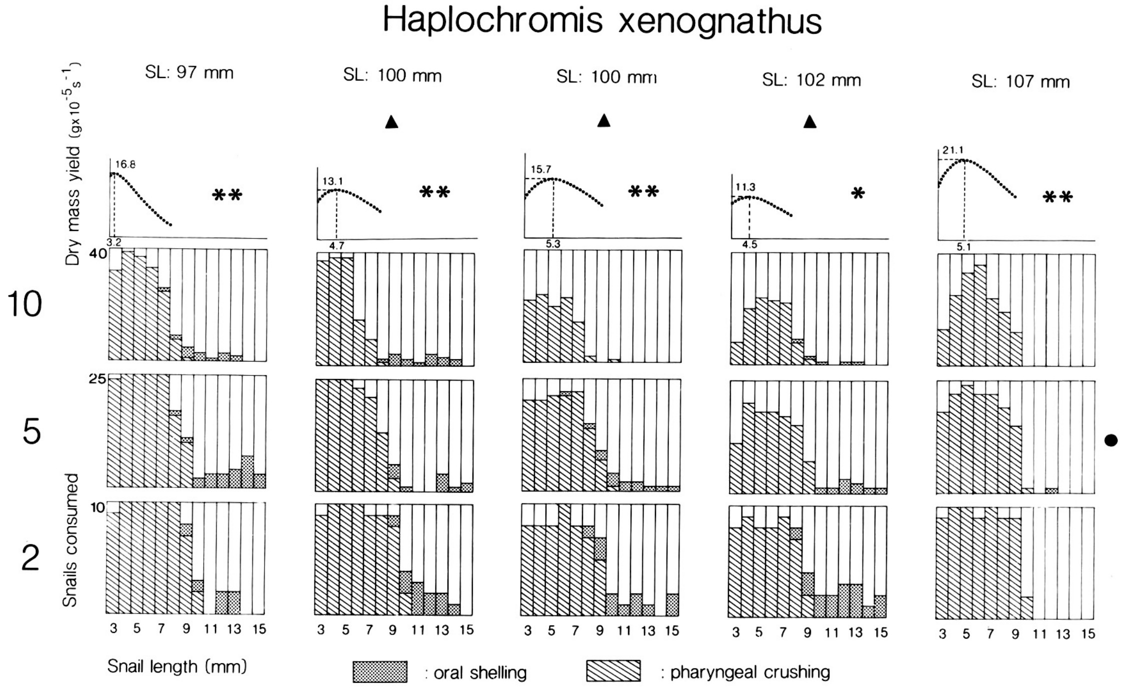

Fig. 28: *Haplochromis xenognathus*. As Figs. 25 and 27.

Discussion

Comparison of prey-size selection and snail dry mass obtained per second handling shows that the oral shellers display a behaviour similar to that of the pharyngeal crusher *H. ishmaeli*. Thirteen out of fifteen tested fishes significantly selected snails according to the reward in dry mass per second handling. The prey size class eaten mostly by *M. bicolor* and *H. xenognathus* is somewhat larger than predicted. In the original version of this paper it is argued that the encounter rate might not be the same for all size-classes of snails. According to the foraging model, this can influence the prey choice of the fish. In additional experiments that were published in the original version (Slootweg, 1987), encounter rates were actually counted and its was shown that the conclusion above remained valid; the fishes indeed select prey items with highest yield per second handling time, and the fish can be considered to forage optimally in this experimental set-up.

The observed prey choice of the molluscivorous cichlid species is remarkable in several ways. In contrast with the results of Stein et al. (1984), who did not find size selection among snails of the same genus for the sunfish *Lepomis microlophus*, the cichlids showed a size selection towards maximal gain in biomass per second handling-time. The wild-caught fishes had hardly ever been able to feed on *Biomphalaria* or *Bulinus* snails before they were brought into the laboratory. Although species of *Biomphalaria* and *Bulinus* are found on the shores of Lake Victoria, densities are very low compared to the common prosobranch snail species. Stomach contents of wild-caught fishes (Katunzi 1983; Witte and Hooger-houd, unpublished work.) suggest that the oral shelling species never crush a snail pharyngeally in Lake Victoria, because the common snail species there are too hard. The fish possibly have a genetically determined foraging behaviour, combined with rapid learning of profitability of unknown snail species.

Mittelbach (1981) demonstrated the feasibility of developing a foraging model that predicts the diet composition of different sizes of bluegill sunfish (*Lepomis macrochirus*; Centrarchidae) foraging in three aquatic habitats. If the intake maximization premise also holds for other food items for the snail-eating cichlids, it may also be possible to predict the diet composition of these fishes in more natural habitats. This knowledge can be of great help in experiments to control snail intermediate hosts of schistosomiasis with snail-eating fish.

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References

Anderson Ch. & Gobert E. (1924). Des mesures prophylactiques applicables contre la biharziose en Tunis. *Arch. Inst. Pasteur Tunis* **13**: 215-218.

Coates D. & Redding-Coates T.A. (1981). Ecological problems associated with irrigiation canals in the Sudan with particular reference to the spread of bilharziasis, malaria and aquatic weeds and the ameliorative role of fishes. *Intern. J. Environmental Studies* **16**: 207-212.

Fryer G. & Iles T.D. (1972). *The cichlid fishes of the great lakes of Africa. Their biology and evolution*. Oliver & Boyd, Edinburgh.

Greenwood P.H. (1964). Environmental effects on the pharyngeal mill of a cichlid fish, *Astatoreochromis alluaudi*, and their taxonomic implications. *Proc. Linn. Soc. Lond.* **176**: 1-10.

Greenwood P.H. (1974). The cichlid fishes of Lake Victoria, East Africa: the biology and evolution of a species flock. *Bull. Br. Mus. nat. Hist. (Zool.) Suppl.* **6**: 1-34.

Greenwood P.H. (1980). Towards a Phyuletic classification of the 'genus' *Haplochromis* (Pisces, Cichlidae) and related taxa. Part II: the species from Lake Victoria, Nabugabo, Edward, George and Kivu. *Bull. Br. Mus. nat. Hist. (Zool.)* **39**: 1-101.

Hairston N.G., Wurzinger K.H. & Burch J.B. (1975). *Non-chemical methods of snail control.* WHO/SCHISTO/75.40 Geneva, Switzerland.

Hart P.J.B. (1986) Foraging in teleost fishes. In: Pitcher T.J. (ed.) *The Behaviour of Teleost Fishes*. Croom Helm, London Sydney, pp. 211-236.

Hoogerhoud R.J.C. (1984). A taxonomic reconsideration of the haplochromine genera Gaurochromis Greenwood, 1981 and Labrochromis Regan, 1920 (Pisces, Cichlidae). *Neth. J. Zool.* **34**: 539-566.

Hoogerhoud R.J.C. (1986a). Taxonomic and ecological aspects of morphological plasticity in molluscivorous haplochromines (Pisces, Cichlidae). *Ann. Kon. Mus. Mid. Afr. Zool. Wetensch***.** **251**: 131-134.

Hoogerhoud R.J.C. (1986b). *Ecological morphology of some cichlid fishes*. Thesis, Leiden.

Hoogerhoud, R.J.C. (1987). The adverse effects of shell ingestion for molluscivorous cichlids, a constructional morphologic approach. *Neth. J. Zool.* **37**: 277-300.

Katunzi E.F. (1983). Seasonal variations in the food of a molluscivorous cichlid *Haplochromis sauvagei* Pfeffer 1896. *Neth. J. Zool.* **33**: 337-341.

Krebs J.R., Stephens D.W. & Sutherland W.J. (1983). Perspectives in optimal foraging. In: Perspectives in Ornithology. *Essays presented for the Centennial of the American Ornithologists' Union*. Cambridge University Press.

McCullough F.S. (1981). Biological control of the snail intermediate hosts of human *Schistosoma* spp.: a review of its present status and future prospects. *Acta Tropica* **38**: 5-13.

Mittelbach G.G. (1981). Foraging efficiency and body size: a study of optimal diet and habitat use by bluegills. *Ecology* **62**: 1370-1386.

Slootweg R. (1985). Biological control of snail intermediate hosts of Schistosoma spp. by fish: a summary of the literature. *Reports of the Research-Group Ecological Morphology of Fishes* **34**. Leiden University, The Netherlands.

Stein R.A., Groose Goodman C. & Marschall E.A. (1984). Using time and energetic measures of cost in estimating prey value for fish predators. *Ecology* **65**: 702-715.

Townsend C.R. & Winfield I.J. (1985). The application of optimal foraging theory to feeding behaviour in fish. In: Tytler P. & Calow P. (eds.) *Fish Energetics; New Perspectives*. Croom Helm, London Sydney, pp. 67-98.

Witte F. (1981). Initital results of the ecological survey of the Haplochromine cichild fishes from the Mwanza Gulf of Lake Victoria (Tanzania): breeding patterns, trophic and species distribution. With recommendations for commercial trawl fishery. *Neth. J. Zool.* **31**: 175-202.

Witte F. (1984a). Ecological differentation in Lake Victoria Haplochromines: comparison of cichlid species flocks in African lakes. In: Echelle A.A. & Kornfield I. (eds.) *Evolution of fish species flocks*. University of Main at Orono Press.

Witte F. (1984b). Consistency and functional significance of morphological differences between wild-caught and domestic Haplochromis squamipinnis (Pisces, Cichlidae). *Neth. J. Zool.* **34**: 596-613.

6.2 Proposed introduction of Astatoreochromis alluaudi, an East African mollusc crushing cichlid, as a means of snail control

R. Slootweg (1989). *Musee Royal de l'Afrique Centrale, Sciences Zoologiques* **257**: 61-64

The first record of schistosomiasis, a hieroglyph in the Kalum papyrus, dates back to 1900 B.C. in ancient Egypt. It lasted until 1851 before the responsible trematode worms were discovered by Theodor Bilharz and another 50 years passed before the life cycle of the parasitical worms was discovered by Manson in 1902, and Castellani in 1903. The sexual generation of adult schistosomes live in the definitive vertebrate host; the asexual stage lives in the intermediate host, freshwater snails. In the appropriate snail species, numerous free swimming cercariae are produced which are infective to the vertebrate host. Approximately 250 million people are affected by the disease worldwide.

Schistosomiasis control

Control is based on the interruption of the parasite's life cycle and was in the past mainly confined to snail control. Recently safe and reliable antischistosomal drugs have been developed, but medication only is often unreliable due to the rapid reinfection of treated people in endemic areas. Consequently snail control still forms an important part of schistosomiasis control strategies.

Several methods of snail control can be distinguished:

A: Environmental management. By changing the habitat it may become unsuitable for snails. This method can be applied in artificial water bodies (e.g. irrigation systems) where vegetation clearing, concrete canal lining, and high water velocities may reduce snail populations.

B: Mollusciciding, the most commonly used practice. Snails can be successfully eradicated for a relatively short period (months). Application of molluscicides is therefore repetitive and hence expensive. It seriously affects other aquatic organisms and can even be lethal to fish. Experiments have been carried out with molluscicides derived from plants.

C: Biological control. In spite of several successful trials in the past, this control method has received little attention. Most commonly used are predatory fishes and competitive snail species. In the next section I shall discuss the possible introduction of the mollusc crushing cichlid *Astatoreochromis alluaudi*, into artificial and semi-natural water bodies in the North of Cameroon.

Possible introduction sites

In the Benue river, a tributary of the Niger, a dam has been constructed near Garoua for the generation of hydroelectricity and for large-scale irrigation works on the former flood plains downstream of the dam. It is expected that with the formation of a permanent lake and the development of irrigation schemes the proliferation of intermediate hosts of parasitic diseases will increase.

Near the dam a fish culture station has been constructed where fry of a tilapia (Oreochromis niloticus) is produced. This fry will be introduced into rainfed permanent pools on the former flood plain. Since the yearly flooding and hence restocking with fish has stopped, these pools lost their fisheries potential for local inhabitants. Restocking of these pools will restore this local autoconsumption fishery. Experiments will be started on the combination of fish and rice culture in the irrigation system. Together with this fish culture program an experimental program of biological snail control will be carried out by introducing A. alluaudi together with O. niloticus. It is thought that with the combined stimulus of economic gain (fish production) and decreased infection risk, the local population is more motivated to cooperate.

Proposed introduction of an exotic fish species

Literature studies did not reveal any suitable specialised snail eating fish species endemic to the Benue/Niger river system (Slootweg, 1987). Many species do include snails in their diet but forage in an omnivorous way. Before having reduced snail populations to a significantly lower level such omnivorous fishes will already have switched to other food items. Therefore the introduction of a specialised snail eater from Lake Victoria (and surrounding waters), already successfully used in field trials, was proposed. The following reasons favour the proposed species:

1: *Astatoreochromis alluaudi* is a well investigated species, taxonomically unequivocally distinguishable from the other Lake Victoria haplochromines (cf. Verheyen, 1989).

2: It has already been introduced in Cameroon (Bard & Mvogo, 1963), Kenya (McMahon et al, 1977), and Ruanda (Snoecks, pers. comm.) as a means of snail control, in the first two cases with some success. Adverse ecological impacts have never been recorded.

3: The fish inhabits shallow waters, especially those overgrown by reeds and papyrus. This is the habitat of pulmonate snail species, intermediate host of schistosomiasis. The fish can survive under low oxygen conditions in these swamp-like habitats, which is confirmed by laboratory experiments (See, pers. com.).

4: Morphologically the fish can be classified as a pharyngeal crushing snail eater. With its enlarged pharyngeal jaws the fish can crush shells of considerable resistance. Stomach contents of Lake Victoria specimens showed that the fish feeds mainly on snails, when available. However, the fish is able to survive on other food items (Hoogerhoud, 1986).

5: Pond experiments already showed that *A. alluaudi* (and other snail eating cichlids) can be successfully reproduced in combination with several tilapia species, cultured for consumption (Mvogo & Bard ,1964).

6: Last but not least; like many cichlid species, *A. alluaudi* is easy to handle and to breed. It is strong, has a high temperature tolerance, and outbreaks of diseases hardly ever occur in captivity.

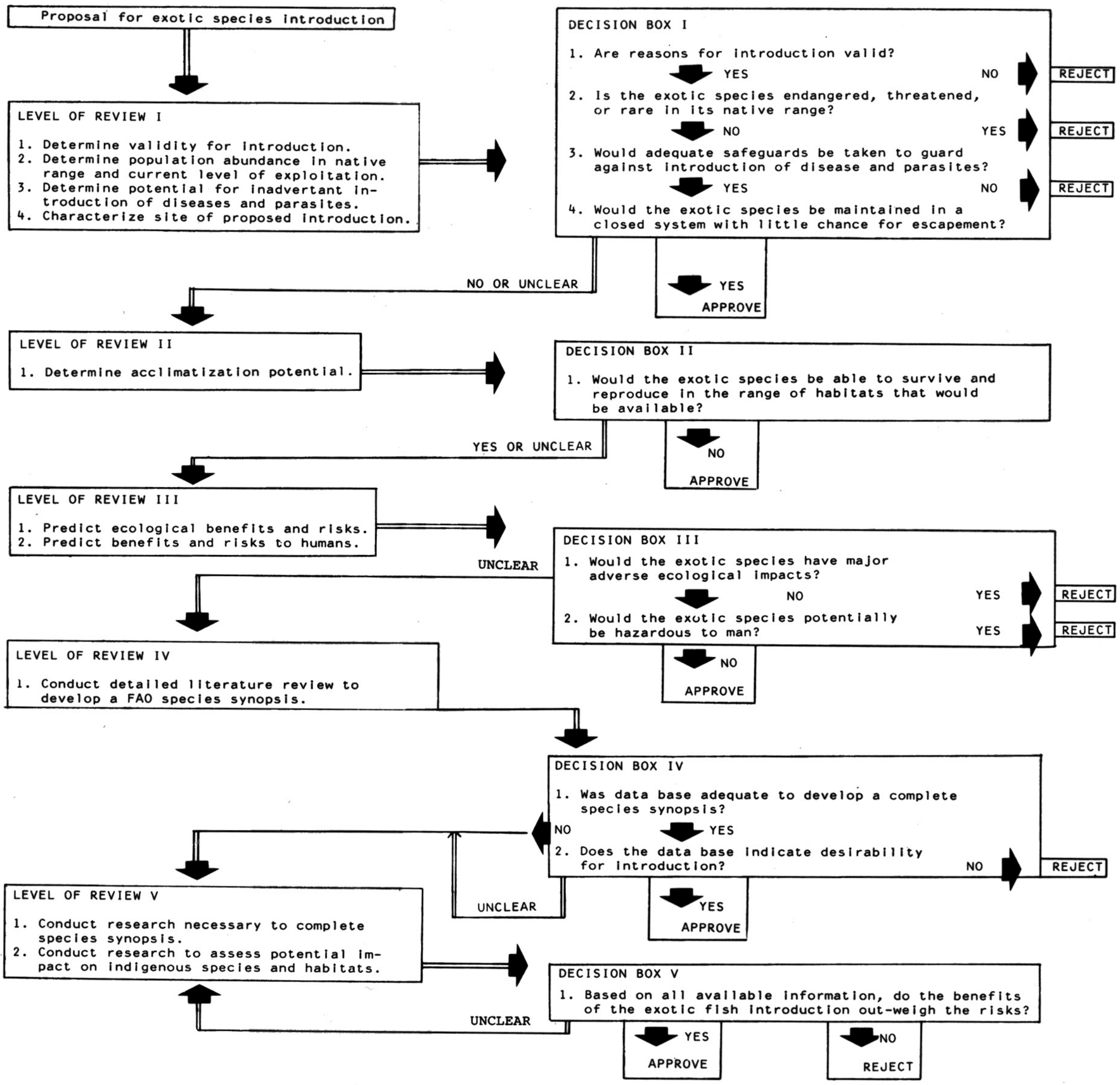
However, since the introductions of exotic species have already caused great ecological disasters, every possible risk should be assessed in advance. Therefore the proposed introduction of *A. alluaudi* is evaluated with the help of a protocol described by Kohler & Stanley (1984) (Fig. 29).

Evaluation of the protocol

Box I: The hazards of schistosomiasis infection are well known and the absence of suitable local fish species makes the introduction valid (1). A. alluaudi is not endangered in its native habitat (2). (In Lake Victoria the fish lives in a habitat less threatened by the Nile perch, and it can also be found in other areas in East Africa.) The fish are laboratory bred and selected before transportation, giving safeguards against disease introduction (3). Although initially the experiments will be carried out in ponds, the chance of escape can never be excluded (flooding, unintentional release). The answer here is thus unclear (4).

Box II: The ability of the fish to survive under the riverain conditions in the Benue system can be doubted. The conditions of this flowing water habitat differ widely from the lacustrine conditions in its native habitat. Its reproductive strategy may not be suitable for this environment (cf. Goldschmidt 1989).

Box III: As mentioned before the earlier introductions in reservoirs and fish culture stations never had adverse ecological impacts. The fish are anatomically best fitted to eat snails, although they occasionally also include insect larvae in their diet. No adverse ecological impacts are expected (1), and I can not think of any hazard to man (2). The introduction of the fish can therefore be approved, although safeguards will be taken to prevent the fish from escaping from the initial pond experiments. A possible unforeseen ecological risk can be assessed through these experiments.



Proposal for exotic species introduction

LEVEL OF REVIEW I

1. Determine validity for introduction.
2. Determine population abundance in native range and current level of exploitation.
3. Determine potential for inadvertant introduction of diseases and parasites.
4. Characterize site of proposed introduction.

DECISION BOX I

1. Are reasons for introduction valid?
2. Is the exotic species endangered, threatened, or rare in its native range?
3. Would adequate safeguards be taken to guard against introduction of disease and parasites?
4. Would the exotic species be maintained in a closed system with little chance for escapement?

LEVEL OF REVIEW II

1. Determine acclimatization potential.

DECISION BOX II

1. Would the exotic species be able to survive and reproduce in the range of habitats that would be available?

LEVEL OF REVIEW III

1. Predict ecological benefits and risks.
2. Predict benefits and risks to humans.

DECISION BOX III

1. Would the exotic species have major adverse ecological impacts?
2. Would the exotic species potentially be hazardous to man?

LEVEL OF REVIEW IV

1. Conduct detailed literature review to develop a FAO species synopsis.

DECISION BOX IV

1. Was data base adequate to develop a complete species synopsis?
2. Does the data base indicate desirability for introduction?

LEVEL OF REVIEW V

1. Conduct research necessary to complete species synopsis.
2. Conduct research to assess potential impact on indigenous species and habitats.

DECISION BOX V

1. Based on all available information, do the benefits of the exotic fish introduction out-weigh the risks?

Fig. 29: Review and decission model for evaluating proposed exotic introductions (Kohler & Stanley, 1984)

Conclusion

If the choice in snail control can only be out of two evils, namely using biocides or introducing exotic biocontrol species, it is hard to speak of making the right choice. Compared to molluscieiding the use of fish has some disadvantages, such as the limited number of habitats which can possibly be controlled, and the lack of experience with this method. Advantageous are the reduced need of foreign currency and the simplicity of the method which allows the involvement of the local inhabitants. Taking into account the disastrous ecological impact of molluscicides, the use of fish deserves to be explored as a helpful tool in the integrated control of schistosomiasis.

References

Bard, J. & Mvogo, L. (1963). Note d'information sur l'Astatoreochromis alluaudi poisson molluscophage utilisable dans la prophylaxie de la bilharziose. *Bulletin de la Société de Pathologie Exotique,* **56**, 119-124.

Kohler, Ch.C. & J.G. Stanley (1984). A suggested protocol for evaluating proposed fish introductions in the United States. In: Courtenay & Stauffer (eds.). *Distribution, biology and management of exotic fishes*. John Hopkins University Press, Baltimore/London, pp. 387-407.

Goldschmidt, P.T. (1989). Reproductive strategies, subtrophic niche differentiation and the role of competition for food in Haplochromine Cichlids (Pisces) from lake Victoria, Tanzania. *Ann. Mus. Roy. Afr. Centr., Sc. Zool.*, **257**, 119-132.

Hoogerhoud, R.J.C. (1986). *Ecological morphology of some cichlid fishes*. Thesis, Leiden University, the Netherlands.

McMahon, J.P., Highton, R.B. & Marshall, T.F. (1977). Studies on biological control of intermediate hosts of schistosomiasis in Western Kenya. *Environmental Conservation*, **4**, 285-289.

Mvogo, L. & Bard, J. (1964). Seconde note d'information sur l'Astatoreochromis alluaudi poisson malacophage utilisable dans la prophylaxie de la bilharziose. *Bulletin de la Société de Pathologie Exotique*, **57**, 21-23.

Slootweg (1987). Schistosomiasis, schistosomiasis vector snails, and snail-eating fishes in Cameroon. A literature survey. *Rapport du Projet Pisciculture*, **3**. MEAVSB, Garoua, Cameroon.

Verheyen, E., Van der Linden, A. & Decleir, W. (1989). The eye lens proteins of haplochromine Cichlids from lake Victoria studied by isoelectric focussing. *Ann. Mus. Roy. Afr. Centr., Sc. Zool.*, **257**, 93-100.

6.3 The effects of molluscivorous fish, water quality and pond management on the development of snail intermediate hosts of schistosomiasis in aquaculture ponds in North Cameroon

R. Slootweg, P.A. Vroeg & S.J. Wiersma (1993). *Aquaculture and Fisheries Management*, **24**: 123-128

The original version of this paper has been published as a short communication in Aquaculture & Fisheries Management. The section on collection and elaboration of data appeared to be difficult to follow, so the material & methods section of a more extended earlier version of the manuscript was inserted.

One of the possible negative side-effects of aquaculture in tropical areas is the spread of water-related diseases, in particular schistosomiasis. Fish ponds can provide breeding sites for freshwater snails transmitting schistosomiasis (Berrie, 1966). Scientific attention has long been concentrated on the use of molluscicides as the most effective means of snail and schistosomiasis control. However, molluscicides have limited use in aquaculture as they are expensive, hazardous to many other forms of aquatic life including fish, and have to be applied regularly because of the rapid recolonization by snails. This paper describes a study made on snail populations in an aquaculture station in Northern Cameroon and their possible relation with water quality, pond management and cultured fish species. Together with production experiments, the development of snail populations in the fish ponds has been monitored during two years, and the biological control potentiality of two fish species has been tested. The experiments are part of a larger programme on the integrated control of schistosomiasis in the upper Benue valley of northern Cameroon (Slootweg, 1991).

Three species of fish were used in the pond experiments. The tilapia *Oreochromis niloticus* (L.) was used for production experiments under different nutritional regimes. To control the excessive reproduction by *O. niloticus*, the African catfish, *Clarias gariepinus* Burch., was introduced in several experiments. *C. gariepinus* is also known to eat snails; based on stomach contents analyses of fish caught in an irrigation scheme in Sudan, Coates (1984) suggested to use C. gariepinus in the control of snail hosts of schistosomiasis. As a third species, the East African cichlid fish *Astatoreochromis alluaudi* Pellegrin was introduced solely to test its capability to control molluscs (Slootweg, 1989). In the literature *A. alluaudi* has often been recommended as a means of biological snail control, but the number of actual field trials is very limited. One experiment in Kenya showed a significant reduction in snail populations over a long period (McMahon, 1960; McMahon, Highton & Marshall, 1977), although contradictory evidence is given by recent research (Kat & Kibberenge, 1990). One successful experiment has been described from an aquaculture station near Yaoundé in Cameroon (Bard & Mvogo, 1963; Mvogo & Bard 1964), but has never been repeated afterwards.

Material and methods

The aquaculture station of Gounougou (North Province, Cameroon) consists of 12 small ponds (25 x 10 x 0.9m: 250 m² floor surface) used for production of fingerlings and storage, and 12 larger ponds (35 x 15 x 1m: 525 m²) for production experiments. Water supply to every pond can be regulated separately by means of a supply-pipe and a concrete drainage monk. Pond experiments lasted from 8 to 45 weeks. Between experimental cycles the ponds were routinely drained and dried for at least one week to stimulate the decomposition of benthic deposits. The station is managed intensively; all vegetation in and around ponds is cleared regularly and unauthorized visitors (except cormorants and kingfishers) are kept outside by an iron fence. Snail sampling was carried out on a monthly routine basis. Each pond was sampled for ten minutes by one person using a small net. In this paper only the two most frequently occurring snail species are considered: *Bulinus forskalii* (Ehrenberg) and *Bulinus truncatus* (Audouin).

Water quality: during the pond cycles the quantities of feed and fertilizer were adjusted according to the growth rate of the fish. Therefore we distinguished only between presence or absence of the three products used: brewery waste (used 46 times in 65 experiments), cotton seed cake (40/65), and cow-manure (8/65). During the experiments the visibility and temperature were weekly measured at 8.00 am in every pond. Visibility, measured with a secchi-disc, is related to the quantity of suspended particles and to the state of fertilization of a pond. In fish ponds a high turbidity is often caused by algal bloom due to a high nutritional level.

Stocking density of fish: stocking densities of fish usually varied between 0.5/m² (adults) to 5/m² (juveniles) for tilapia, and 0,1 - 2/m² for A. alluaudi and catfish. As tilapia production was the first objective of the station these fish were always introduced in experiments. A. alluaudi and catfish were introduced according to the experimental design. A. alluaudi was introduced 11 times and the catfish

33 times in 71 experiments. Due to stocking losses (mortality and predation) it is very hard to give exact estimates of the actual stock density at a given moment. Therefore initial stocking density, and the presence or absence of a species in an experiment were used as a variable. As tilapia were always present in the experiments, a distinction was made between the presence of adults (26 experiments) or juveniles (39 experiments).

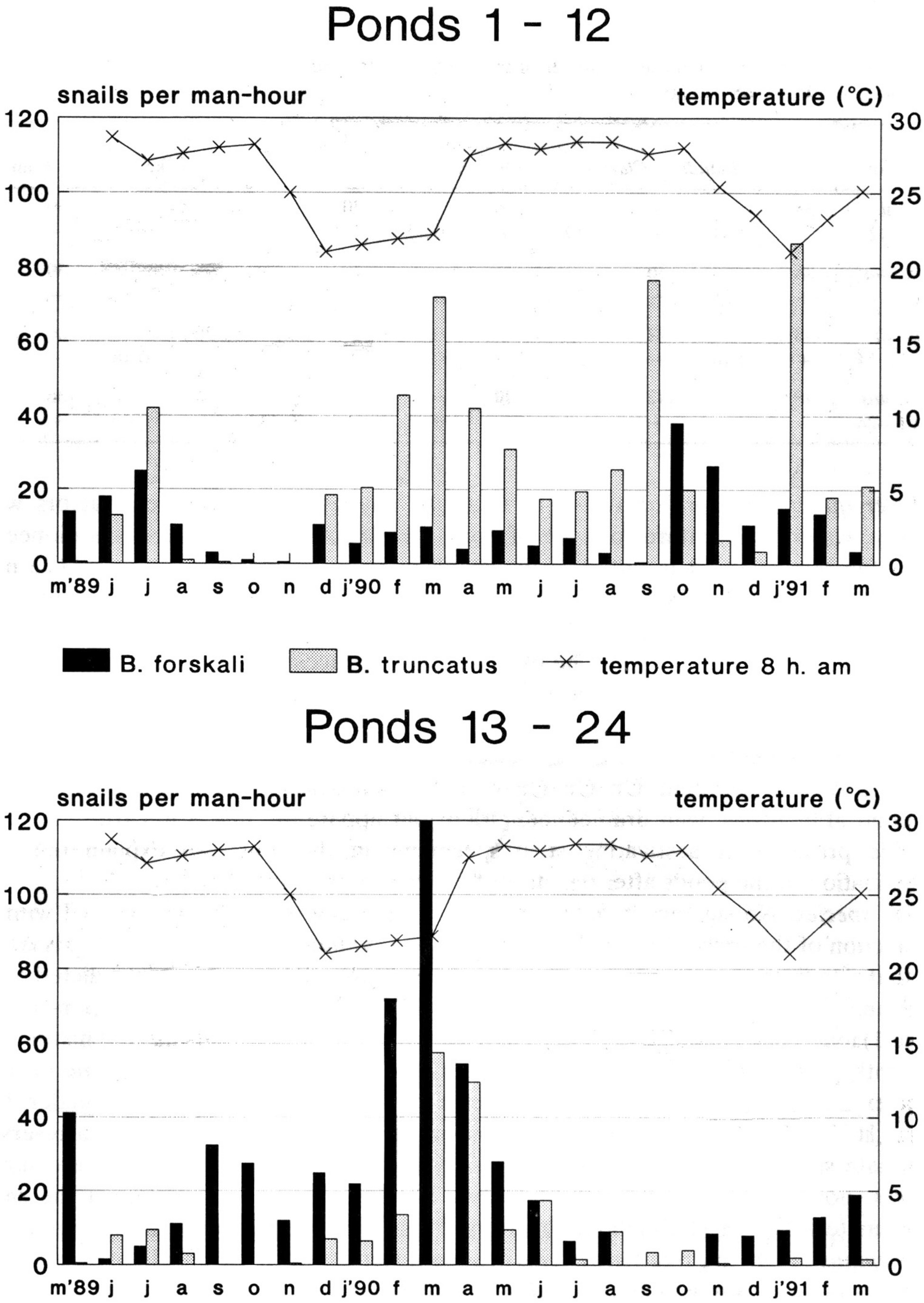


Fig. 30: total numbers of snails collected in ponds 1 to 12 (reproduction and storage) and ponds 13 - 24 (production exper-iments) at the aquaculture station of Gounougou from March 1989 until March 1991, and the monthly average water temperature at 8.00 h in the morning. Snail collections are expressed as the number collected per man-hour search-time.

Elaboration of data. Since the size and management of the small ponds (1 to 12) and the large ponds (13 to 24) differ considerably, the data were split up according to the pond-size used for the experiment. The basic unit for statistical testing is one experiment per pond. Data on 79 experiments were collected between May 1989 and March 1991. Complete sets of data on all variables are available on 62 experiments; in 17 experiments one or more variables had to be treated as missing values.

Every experiment has 8 numerical (1-8) and 6 binary variables (9-14):
1: Mean number of *B. forskali*.
2: Mean number of *B. truncatus*.
3: Visibility of secchi disc; mean over the experimental period.
4: Mean temperature at 8.00 h over the experimental period.
5: Length of the experiment (number of weeks).
6: Initial stocking density of tilapia (number/m^2).
7: id. catfish
8: id. *A. alluaudi*
9: Presence (1) or absence (0) of adult tilapia.
10: Presence or absence of catfish.
11: id. *A. alluaudi*
12: Use of brewery waste as feed/fertilizer.
13: Use of cotton seed cake.
14: Use of cow manure.

To test whether the numbers of snails were significantly correlated to the other numerical variables, the Spearman rank correlation test was applied (table 8). Variables 9 - 14 were tested with the binomial test, as explained in table 9 (Siegel & Castellan, 1988).

Table 8: Spearman rankcorrelation test on numerical variables (Ponds 1-12: number of experiment is 36; ponds 13-24: number of experiments is 43).

	B. truncatus	secchi disk	Temp. 8.00 am	duration	stocking density *O. niloticus*	stocking density *C. gariepinus*	stocking density *A. alluadi*
B. forskalii	r=0.24	r=0.17	r=0.04	r=0.11	r=-.65	r=-.16	r=0.07
Ponds 1 - 12	p=0.14	p=0.31	p=0.79	p=0.49	p=0.70	p=0.35	p=0.67
B. truncatus		r=0.07	r=0.12	r=0.12	***r=-.41***	r=-.15	r=0.16
Ponds 1 - 12		p=0.68	p=0.45	p=0.45	***p=0.02***	p=0.35	p=0.33
B. forskalii	***r=0.51***	r=-.14	r=-.04	r=-.05	r=0.17	r=-.11	***r=0.27***
Ponds 13 - 24	***p=0.0004***	p=0.32	p=0.81	p=0.78	p=0.29	p=0.48	***p=0.07***
B. truncatus		***r=-.26***	r=-.21	r=0.03	***r=0.41***	r=0.07	r=-.07
Ponds 13 - 24		***p=0.07***	p=0.15	p=0.82	***p=0.01***	p=0.65	p=0.64

r = correlation coefficient; p = significance level; significance levels under 10% in bold italics.

Results

The development of snail population throughout the experimental period are summarized in figure 30. The results in the experiments show hardly any significant correlation between snail densities and one of the variables concerning water quality, pond management and fish species (table 8 for numerical variables; table 9 for binary variables).

Water quality: *B. forskalii* does not relate to any of the environmental factors water turbidity, water temperature, or type of pond fertilizer. Apparently, for this pioneering species the pond habitat is suited to its establishment. *B. truncatus* shows a little more dependency on water turbidity and type of pond fertilizer. In ponds 13-24 B. truncatus is found more often in turbid water (table 8). We suppose that nutrient level is the determinant factor for turbidity in fish ponds. The use of manure reduces the number of B. truncatus in ponds 1-12 (table 9), but only 3 experiments in 30 included manure so this result is not considered conclusive.

Presence of:	*A. alluaudi*	*Clarias*	adult *Oreochromis*	brewery waste	cotton seed cake	manure
B. forskalii Ponds 1 - 12	38 + 0.44	36 - 0.49	36 + 0.60	30 - 0.59	30 + 0.62	30 - 0.52
B. truncatus Ponds 1 - 12	38 + 0.25	36 - 0.23	36 + 0.60	30 - 0.59	30 + 0.13	***30*** ***- 0.06***
B. forskalii Ponds 13 - 24	48 + 0.16	42 - 0.35	40 - 0.40	36 + 0.22	36 + 0.18	36 - 0.22
B. truncatus Ponds 13 - 24	48 - 0.51	42 + 0.40	***40*** ***- 0.08***	36 - 0.43	36 + 0.49	36 + 0.43

Table 9: Binomial test; probability levels for binary sets of data. The binary variables were sorted according to descending order of the snail density (numerical variable) shown in the left column. The frequency of occurrence in the first half of the sorted array, was tested to the expected frequency (i.e. the frequency in all trials).
H_0: the frequency in the first half of the array does not differ from the overall frequency.
Upper left: number of trials. Lower left: frequency higher (+) resp. lower (-) than predicted.
Lower right: probability

Pond management: Surprising is the absence of any relation between snail numbers and the length of the experiment. One would expect that snails need some time to get established in a pond after it has been drained and dried, but apparently this is not true. The most probable presence of aestivating snail specimens in the mud can explain the rapid recolonization of the ponds after the start of a new fish production cycle.

Fish species: No significant reductions in snail populations have been found with the introduction of the specialized snail eating cichlid *A. alluaudi*, nor with *C. gariepinus*. The idea that *A. alluaudi* can control snail populations is quite dramatically contradicted by the significant positive correlation between *B. forskalii* snails and *A. alluaudi* in ponds 13-24 (table 8). Obviously *A. alluaudi* is able to live on a diet different to its natural habitat, and apparently even prefers this diet to eating snails. The lack of effect of *C. gariepinus* on snails can be explained by its habits. The fish is known to be an opportunistic bottom feeder. In its natural habitat the fish randomly finds prosobranch snails on the bottom. Pulmonate snails (all African snail hosts of schistosomiasis are pulmonate) usually are surface dwellers, not descending further than 25 cm. The fish simply does not meet the snails. Unfortunately Coates (1984) did not mention the species of snails found in the stomachs of *C. gariepinus* caught in irrigation systems in Sudan. Remarkably the only influence on snails by fish could be shown with adult *O. niloticus* on *B. truncatus*, although it must be stressed that sufficient numbers of snails are remaining to allow schistosomiasis transmission. In ponds 1-12 we found a negative correlation between *B. truncatus* snails and density of *O. niloticus* (table 9). In ponds 13-24 higher stocking density correlates significantly to a higher snail density, which at first sight is in contradiction with the aforementioned reduction. An explanation for this phenomenon can be found in the experimental set-up. In production ponds (13-24) adult fish are always stocked in lower densities than juveniles, whereas in the storage ponds (1-12) adults can be found in higher densities. Hence, only the adults have a reducing effect on *B. truncatus* populations. This observation corresponds to the significant reduction in *B. truncatus* snails in presence of adult tilapia in ponds 13-24 (table 9).

Conclusions

In the aquaculture station of Gounougou in North Cameroon it appeared to be very difficult to prevent the establishment of snails in fish ponds. Even in ponds with hardly any vegetation, high stocking densities of fish, regular drainage and drying, and in the presence of known snail-eating fishes, snails establish themselves without being significantly affected. To be able to show some relationship with factors that might influence snail populations, we raised the level of significance to 10%. This is not considered to be very convincing. Briefly, the reasons for failure of the mollusc crushing cichlid Astatoreochromis alluaudi can be found in the spatial distribution of snails, and in the foraging behaviour and anatomy of the fish. Competition in its original habitat, Lake Victoria, forces the fish to forage on hard-shelled prosobranch snails; compared to wild caught fish, the aquaculture specimens showed a reduction in size of the pharyngeal jaws and in strength of the pharyngeal jaw muscles (used to crush the snails shells). The foraging efficiency and prey choice will consequently be irreversibly altered (e.g. Slootweg, 1987; chapter 6.4 of this book).

It looks as if the presence of snails is inevitable in fishculture ponds. In view of this assumption it is interesting to speculate on the relation between *B. truncatus* (the most important host of urinary schistosomiasis) and water turbidity. If we consider water turbidity under pond conditions as an indicator of the nutritional level of a pond, turbid water having more food available for the fish, then snail control is incompatible with fishculture under optimal conditions. In other words, the risk of having snails in ponds increases when quality of nutrition and fish production levels are increased. This is in accordance with the literature where there seems to be consensus that food availability is one of the crucial factors determining population densities of snails (Brown, 1980: ch.11).

Taking these considerations into account, evidently one should strongly oppose to the introduction of communal village fish ponds in schistosomiasis prone areas, unless measures are taken to fence the ponds from the villagers (especially children!). It is recommended to include a health assessment in the planning phase of an aquaculture development project, because with proper measures centred around the prevention of snails becoming infected and reduction of water contacts, the risk of schistosomiasis transmission can be minimized.

References

Bard, J. & L. Mvogo (1963) Note d'information sur l'*Astatoreochromis alluaudi* poisson malacophage utilisable dans la prophylaxie de la bilharziose. *Bulletin de la Société de Pathologie Exotique* **56**, 119-126.

Berrie, A.D. (1966) Fish ponds in relation to the transmission of bilharziasis in East Africa. *East African Agriculture and Forestry Journal* **31**, 276-281.

Brown, D.S. (1980) *Freshwater snails of Africa, and their medical importance*. Taylor & Francis Ltd., London.

Coates, D. (1984) A survey of the fish fauna of Sudanese irrigation systems with reference to the use of fishes in the management of ecological problems (the control of aquatic weeds, malaria and infective schistosomiasis). *Fisheries Management* **15**, 81-96.

Kat, P. & M. Kibberenge (1990) An evaluation of biological control of snail intermediate hosts of schistosomiasis by the molluscivorous fish *Astatoreochromis alluaudi*. *Utafiti* **3**, 6-12.

McMahon, J.P. (1960) Preliminary observations of the control by fish of snails and mosquitos in dams. *Annual Reports of the East African Fisheries Organisation*. Jinja, Uganda: Appendix "K" pp. 41-46.

McMahon, J.P., R.B. Highton & T.F. de C. Marshall (1977) Studies on biological control of intermediate hosts of schistosomiasis in Western Kenya. *Environmental Conservation* **4**, 285-289.

Mvogo, L. & J. Bard (1964) Séconde note d'information sur l'*Astatoreochromis alluaudi* poisson malacophage utilisable dans la prophylaxie de la bilharziose. *Bulletin de la Société de Pathologie Exotique* **57**, 21-23.

Siegel, S. & N.J. Castellan (1988) *Nonparametric statistics for the behavioural sciences* (2nd edition). McGraw-Hill International Editions.

Slootweg, R. (1987) Prey selection by molluscivorous cichlids foraging on a schistosomiasis vector snail Biomphalaria glabrata. *Oecologia* **74**,193-202.

Slootweg, R. (1989) Proposed introduction of Astatoreochromis alluaudi, an East African mollusc crushing cichlid, as a mean of snail control. *Musee Royal de l'Afrique Centrale, Annales Sciences Zoologiques* **257**, 61-64.

Slootweg, R. (1991) Water resources management and health: general remarks and a case study from Cameroon. *Landscape and Urban Planning* **20**, 111-114.

6.4 The biological control of snail intermediate hosts of schistosomiasis by fish

R. Slootweg, E.A. Malek & F.S. McCullough (1993). *Reviews in Fish Biology and Fisheries* **4:** 67-90.

An estimated 200 million people are infected world-wide by the five known species of human schistosomes, trematode worm parasites which are transmitted by freshwater snails of the genera *Bulinus (Schistosoma haematobium* in Africa and the Middle East, and *S. intercalatum* in Central Africa), *Biomphalaria* (*S. mansoni* in Africa, Caribbean region and South America), *Oncomelania* (*S. japonicum* in the Far East) and *Tricula* (*S. mekongi* in South East Asia) (Jordan & Webbe,1982). The resulting disease, schistosomiasis (or bilharzia), causes significant morbidity to man. Several other snail-transmitted trematode parasites (e.g. *Fasciola* spp.) infect domestic animals and can cause economic loss.

Efforts to reduce the morbidity and adverse economic impact caused by the parasites are presently centred around the health care facilities where the use of effective single-dose medicines can contribute significantly to the control of schistosomiasis. However, the rapid reinfection that often occurs after treatment and the high cost of repeated medication has tempered expectations of the efficacy of medication campaigns on longer term. Actions to reduce the risk of transmission by controlling the intermediate hosts often remain necessary. Snail control can be realised by means of (1) application of molluscicides, (2) habitat modification (e.g. removal of vegetation, concrete lining of irrigation canals, etc.), and (3) biological control. Molluscicides have the disadvantage of being expensive and unspecific (e.g. Corbet et al., 1973); they also kill fish and other useful organisms such as competitors of snails (Hairston et al., 1975), and therefore cannot be used in aquaculture ponds (Slootweg et al., 1993) or places where fish are introduced to control mosquitoes. Habitat modification is of limited applicability, usually only in man-made environments. Against this background, the present paper focuses on the biological control of freshwater snails.

The influence of fish on the invertebrate fauna, snails in particular, cannot be denied. Louda et al. (1985) and McKaye et al. (1986) have shown that predation by molluscivorous cichlids is a significant factor in the distribution of Lake Malawi gastropods. Brown & DeVries (1985) state that fish predators can dramatically alter the population dynamics of a single snail species, although in their research, predation pressure never reached levels where snails were completely eradicated from their environment. Palmer (1979) and Vermeij & Covich (1978) give evidence that the evolution of snails with elaborate shell sculpture is largely induced by fish predation.

Michelson (1957), Malek (1958), Berg (1973), Ferguson (1978) Hairston et al. (1975), and McCullough (1981a) have reviewed and discussed methods of biological snail control, but there does not exist as yet a critical review of the empirical material available from actual field and/or laboratory trials on the use of fish as a biological control agent. In this paper we will review the role of fish in snail control. Special attention will be paid to one particular species that has often been mentioned in the literature as a possible candidate for biological control. Several well documented field studies with varying degrees of success exist which will be discussed extensively. Furthermore, new ecomorphological data on the pharyngeal jaw apparatus of the fish will be presented. The reasons for failure of this fish in snail control will be discussed from an ecological and morphological viewpoint. Finally we will summarize the remaining possibilities and research questions in snail control by fish that need to be addressed in future.

A review of the use of fish in snail control

Table 10 summarizes research on snail-eating fish since 1945. It must be noted that the table is not exhaustive with respect to stomach contents research (field observations category), since we limited our literature search to the relation between fish and snail populations. This also explains the bias towards literature dealing with Africa. Most publications deal either with laboratory or with limited field studies. Fish species which eat snails in laboratory aquaria, or wild-caught fish which stomachs contain snails, are not automatically suitable candidates for snail control. Many species mentioned in Table 10 are opportunistic feeders; within the limits of their mechanical feeding capacities they will eat anything available and do not necessarily specialize on snails. Fish species which tend to specialize on snails are: Protopterus annectens (the lungfish, *Lepidosirenidae*), *Mylopharyngedon piceus* (the black carp, Cyprinidae), some species of the families Mochokidae and Tetraodontidae, *Lepomis microlophus* (the shellcracker sunfish, Centrarchidae), and the cichlids (Cichlidae) *Astatoreochromis alluaudi, Serranochromis mellandi*, some 20 species of the genus *Haplochromis* from Lake Victoria, and *Trematocranus placodon* and several other species of cichlids from Lake Malawi.

Ten field trials were reported to be successful in reducing snail populations (DeBondt & DeBondt Hers, 1952; Andrade, 1959, 1962, 1968; Bard & Mvogo, 1963; Carothers & Allison, 1986; Motta & Gouvea, 1971; McMahon et al., 1977; Gilbert in: McCullough, 1981b; Leventer, 1981; Daffalla et al., 1985; Chiotha et al., 1991 a). Four of these field trials (Bard & Mvogo, 1963; Mvogo & Bard, 1964; Gamet et al., 1964; Carothers & Allison, 1968; Daffalla et al., 1985; Chiotha et al, 1991a) were preceded by laboratory observations, as proposed in the World Health Organization's scheme for screening and evaluating the efficacy and safety of biological agents for control of disease vectors (WHO, 1975 in: McCullough 1981a). The results of noteworthy trials are briefly described below.

1. Cyprinidae: *Mylopharyngodon piceus*, Israel

An example of successful integrated biological control in water reservoirs in Israel is given by Leventer (1981), who introduced several cyprinid fish species to control all biological components simultaneously; e.g. silver carp (*Hypophtalmichtys molitrix*) vs. phytoplankton, grass carp (*Ctenopharyngodon idella*) vs. submerged plants, black carp (*M. piceus*) vs. snails, common carp (*Cyprinus carpio*) vs. insect larvae. With regard to two of these targets, submerged plants and snails, "the biological treatment achieved optimum results". Much knowledge of this type of fish polyculture exists in China, where aquaculture occupies a significant role in the country's overall food production strategy (Zweig, 1985). Also in other Asian countries the combined culture of rice and fish is wide-spread. Rice yields may increase from 5% to 100% through fish, making plant nutrients available to the rice crop. Blom (1983) suggested using molluscivorous fish in combination with rice-culture to control schistosomiasis vector snails, analogue to the successfully introduced mosquito fish, *Gambusia affinis*.

2. Centrarchidae: *Lepomis microlophus*, Puerto Rico

The food preference of the shellcracker sunfish, *Lepomis microlophus* has been tested in the laboratory by Carothers & Allison (1968). This species highly preferred snails above other food items such as mosquito larvae and dragonfly nymphs. Their voracious snail-eating habits was demonstrated in artificial ponds where within a single day the fish could almost eradicate populations of *Physa* sp. and *Lymnaea* sp. Possible evasive behaviour of the snails after the introduction of the fish was not taken into account; according to the authors remaining snails could sometimes be seen on floating vegetation.

Fingerlings of the fish were introduced in aquaculture ponds near Aibonito, Puerto Rico. There were no *B. glabrata* snails in the pond, and when these snails were introduced twice weekly (in unknown quantities) for 32 months they were unable to establish themselves, indicating that the snails were continuously consumed by the fish (Ferguson, 1978). These results are weakened by the lack of control experiments to prove that the snails were able to survive and reproduce in the ponds in absence of the sunfish.

Since 1959, *L. microlophus* has been introduced into about 50 Puerto Rico farm ponds and five lakes. According to the authors the sunfish was an effective predator of snails, and bred well in lakes Guajataka and Garzas, but was apparently decimated by species of *Tilapia* in lakes Loiza, Caonillas and Dos Bocas. In lake Guajataka the sunfish contributed to the control of *Biomphalaria*, but apparently did not harm well-established colonies of other snails such as *Marisa cornuarietis* and *Thiaria granifera* (Ferguson, 1978). Another factor favouring the use of *L. microlophus* is that it is a much appreciated game and food fish (Erdman, 1984). Observations by Osenberg (1989) puts doubts on the efficacy of *L. microlophus*; he states that in the fishes' natural habitat in Michigan, snail production is more limited by the availability of food for snails than by the predation pressure of *L. microlophus*.

3. Cichlidae: *Serranochromis mellandi*, Zaire

DeBondt and DeBondt Hers (1952, 1955, 1956) and DeBondt (1956a, 1956b) reported great success with the local *Serranochromis mellandi* (Cichlidae) (identified in 1952 as *Serranochromis macrocephala*, in later publications named *Haplochromis mellandi* and ultimately named *S. mellandi*; for an update on the nomenclature of African cichlids see Daget et al., 1991) in fish ponds in Southern Zaire. This fish is also considered to be good for consumption. Several types of water bodies were stocked with fish in experiments that started in 1949 and lasted at least until 1956.

i) A pond of about $400m^2$, densely populated with *Bulinus* (*Physopsis*) and *Biomphalaria* snails, was stocked with *S. mellandi*. After one month 87% of a fish sample had eaten snails. After two months this percentage decreased to 44%. Thereafter the fish switched to other food items and reproduced successfully. After this initial experiment more *Tilapia* production ponds were stocked with *S. mellandi* keeping the ponds free of snails.

ii) Rice-cultures stocked with *S. mellandi* were "seemingly free of molluscs", while control fields contained many snails (DeBondt, 1955).

iii) In irrigation canals, overgrown with *Potamogeton* and with dense snail populations, snails disappeared after introduction of the fish. If one fish was released at every meter, the canals were free of snails within eight days; one fish at every 10 meters made the snails disappear within a fortnight.

iv) Introduction of snail-eating fish can also be beneficial to the fish culture itself. A *Tilapia* culture infected with *Diplostomum* was freed of this trematode fish parasite after the introduction of *S. mellandi*; the intermediate snail host was eradicated, and fish production came back to normal levels (DeBondt, 1956a).

The experiments with this snail-eating species were part of a fish culture program; no detailed studies on the population dynamics of the snail hosts were carried out. Nevertheless the reduction of snail populations by the fish cannot be doubted, considering the difference between the introduction and the control experiments.

4. Cichlidae: *Trematocranus placodon* and other molluscivores from Lake Malawi

In Lake Malawi some 20 endemic species of snail eating cichlids can be found, some of which have been tested in recent laboratory and field trials (Chiotha & McKaye, 1986; McKaye et al., 1986; Chiotha et al., 1991ab). In experiments in the lake, McKaye et al. (1986) showed that in open sand habitat where cages prohibited predation by fish, the density of snails increased 40-60% within a week. However, when the molluscivorous cichlid *T. placodon* (earlier described as *Cyrtocara placodon*) was placed in the cage, snail densities equalled the controls outside the cage. Stomach contents revealed that *T. placodon* consumed disproportionally more snails of the genus *Bulinus* relative to those of the more heavily armoured genus *Melanoides*. Open shore areas of Lake Malawi may be relatively free of schistosomiasis because molluscivorous cichlids prevent the snail vector from invading these areas.

Experiments in cement ponds with two molluscivorous species (Chiotha et al., 1991a) showed that after four weeks in presence of *T. placodon* (1 individual per 3 m2) the numbers of snails (*Bulinus* spp. and *Lymnaea* spp.) dropped significantly, although in 10 out of 14 ponds snails remained present; there was no significant difference, however, between the number of snails in ponds treated with *Maravichromis anaphyrmis* as the molluscivore, and the number of snails in the untreated ponds. In 3 earthen ponds, snail numbers dropped dramatically over a five month period after the introduction of

Trematocranus placodon. The authors do not indicate if the molluscivorpus fish were wild-caught or pond-reared and if the results could be maintained over a longer period. It is not clear if the fish can be reproduced under pond conditions.

5. Cichlidae: haplochromines from Lake Victoria

Another area where specialized snail eating fishes can be found is Lake Victoria. Surveys by Greenwood (1974, 1981) and Witte & van Oijen (1990) showed that some 21 species of specialized snail-eating haplochromine cichlids live in the lake, all having different niche-requirements. Differences among species can be found in the way of feeding (pharyngeal-crushing vs. oral-shelling), depth range (shallow vs. deep-water species) and substrate type (sand, mud, rocks) (Witte, 1981). In the mid-eighties the number of cichlids in Lake Victoria has dramatically been reduced by the introduction of the predatory Nile perch (*Lates niloticus*), therefore it is not sure how many species (originally ca. 300) have survived (Witte et al., 1992). Several of these molluscivorous species have been studied under laboratory conditions by Hoogerhoud, (1986a&b; 1987; 1989) and by Slootweg (1987) with the explicit intention of finding a suitable candidate for snail control purposes.

The studies presented in this chapter and in Table 10 give the impression of being registrations of secondary results of research having a different primary goal, such as water supply, fish production, and ecological studies. Although there is general agreement that fish can affect snail populations directly or indirectly, especially the unsystematic character of the experiments on control of snails by fish has precluded the growth of a consistent body of knowledge. This is reflected in the scientific literature where researchers are repeatedly urged to perform systematical research into this matter (e.g: Blom, 1973; Hairston et al., 1975; McCullough, 1981b; Roberts & Sampson, 1987). One species has been extensively investigated in field trials on three occasions in two different countries (Cameroon and Kenya), i.e. the East African haplochromine cichlid *Astatoreochromis alluaudi*. These trials will be discussed in greater detail below. Welcomme (1988) gives 4 other countries (C.A.R., Zaire, Congo, Zambia) where *A. alluaudi* has been introduced, but no written accounts are available in scientific literature.

Biology of **Astatoreochromis alluaudi**

This fish is common to Lakes Victoria, Kioga, Nabugabo, Edward, George, Kachira and Nakavali and to adjoining rivers (Greenwood, 1959; Fryer & Iles, 1972; p.102). Like other haplochromines, *A. alluaudi* is a substratum spawning and mouth-brooding species; large adult females (100mm SL) on average produce 170 eggs (Goldschmidt, 1989), which after spawning are taken into the buccal cavity until several weeks after hatching. *A. alluaudi* does not appear to have a breeding season; in Lake Victoria this species is predominantly found in the littoral zone (Witte, 1981) and feeds mainly on the thick-shelled mollusc *Melanoides tuberculata* by crushing the shells with its pharyngeal mill (Greenwood, 1981; Hoogerhoud, 1986a). The pharyngeal jaw is thick and armed with stout, flat crowned teeth. The muscles used for crushing shells are well developed. Field observations on *A. alluaudi* in Lake Victoria and surrounding smaller lakes showed that specimens caught in areas without *M. tuberculata* snails had less developed pharyngeal jaws (Greenwood, 1965, Hoogerhoud, 1986b). The degree of hypertrophy of the pharyngeal jaw apparatus depends on inclusion of *M. tuberculata* in its diet (Greenwood, 1965; Hoogerhoud, 1989; Witte et al., 1990). Based on these results Barel et al. (1991) and Hoogerhoud (1986b, 1989) postulate the hypotheses that *A. alluaudi* in competition with an anatomically better adapted insectivorous fish species would be forced in early ontogeny to feed on less profitable items, i.e. snails. The resulting hypertrophy of the pharyngeals would make it progressively less efficient to feed on insects. Laboratory experiments with the snail crushing cichlids *Haplochromis ishmaeli* and *A. alluaudi* raised on *Biomphalaria glabrata* snails show that fish feeding throughout their ontogeny on this thin shelled schistosomiasis host only develop slightly hypertrophied jaws compared to fish raised on soft minced meat, but compared to Lake Victoria specimens the jaws are of the reduced type (Overbeek, 1986). So not only eating of snails but also the hardness of the shell determines the level of hypertrophy of the pharyngeal jaws.

Field trials on snail control with A. alluaudi

Yaoundé, Cameroon

Some well described field experiments were performed in the South of Cameroon, in Kenya, and recently in the North of Cameroon. Wild caught *A. alluaudi* have been taken from Uganda to the South of Cameroon where pond trials near the capital of Yaoundé have been carried out which showed that snails were effectively controlled, and that *A. alluaudi* could be successfully cultured together with *Oreochromis niloticus* (=*Tilapia nilotica*) (Bard & Mvogo, 1963; Mvogo & Bard, 1964; Gamet, Brottes & Mvogo, 1964). Two basins (85 m^2) were stocked with about 1600 *O. niloticus*; one basin was additionally stocked with *A. alluaudi*. At the moment of stocking the sides of both basins were covered with snails (*Biomphalaria camerunensis* and *Lymnaea africana*). After three months both basins were emptied. The one with *A. alluaudi* did not contain any snail whereas the other was still full of snails. *A. alluaudi* had reproduced successfully among *O. niloticus* and stomach content analyses revealed that *A. alluaudi* was able to live on other food items. The experiments described cover only one fish production cycle; it is not known if the technique was used for a longer period and if this successful snail control was repeated more often. In 1987, *A. alluaudi* could not be found anymore in aquaculture stations in Cameroon (Hamling, pers. comm.).

Nyanza Province, Kenya

McMahon (1960) and McMahon et al. (1977) conducted an experiment in water impounded by earth dams for local water supply in Nyanza Province, Western Kenya. Control of the snail hosts of schistosomiasis was attempted in 1955 by introduction of *A. alluaudi*. Other species were introduced to control weed growth (*Tilapia zillii* and *Oreochromis leucostictus*, both Cichlidae). One reservoir was left as a comparison reservoir without any introduction of fish. Assessment of snail density was carried out both before and after introduction of fish, over a total period of 15 years. The data indicated that *A. alluaudi* did reduce the numbers of some species of snails, particularly *Biomphalaria pfeifferi* and, to a lesser extent and with less certainty, *Bulinus* spp. The other two introduced fish species, *Tilapia zilli* and *O. leucostictus*, were not associated with reduction in snail numbers, and no information is given about their influence on aquatic vegetation. According to the authors, there can be no doubt that in this study *Biomphalaria pfeifferi* formed the principal diet of *A. alluaudi*, although they do not give any data on stomach contents. The data given by the authors are not very conclusive, but this experiment is especially valuable as it is the first example of a quantitative approach with a detailed study on snail populations over a longer period of time. Unfortunately no information is given by the authors on stocking densities or on survival and reproduction rates of the fish.

In 1986/87, Kat & Kibberenge (1990) have revisited eight of these dam sites in order to see whether *A. alluaudi* was still present and to assess the effect on snail populations. In five sites the fish was recaptured; in one case it was the most abundant species. Nevertheless, *Biomphalaria* as well as *Bulinus* snails were found in similar numbers in test sites as compared to control sites without *A. alluaudi*. From every dam site several fish were collected in order to study the dentition of the pharyngeal jaw apparatus. All specimens showed the reduced type of pharyngeal jaws, described by Greenwood (1965) for aquarium raised fish. This reduction is of course quite important for the long-term applicability of the fish for snail control; it will be discussed more fully later on.

North Cameroon

A second field trial with *A. alluaudi* in Cameroon started in 1988. The possible risks of introducing this exotic species in Cameroon was assessed according to the protocol for exotic species introduction by Kohler & Stanley (1984) (Slootweg, 1989a); no foreseeable risk was determined. In 1988, 500 laboratory-raised fish were transported to a fish-culture station in Gounougou, situated in the Benue valley of the Northern province of Cameroon, in order to perform field experiments

(Slootweg, 1989ab; 1991ab; Slootweg et al., 1993). To be able to effectively control snails two criteria were used to evaluate the field trials:

1) The fish have to be readily available for stocking of snail infested water bodies, implying that reproduction in the breeding ponds should be rapid, preferably throughout the year. Furthermore, the fish must reproduce in the target habitats if these are of a permanent nature.

2) In order to stop schistosomiasis transmission, snail populations must at least be decimated, if not entirely eradicated. One of the difficulties in interpreting the possible reduction in snail populations, is that until now we do not know the threshold of the snail population below which transmission of schistosomiasis is interrupted. Therefore, a certain species of fish may drastically reduce the snail numbers, however, transmission of the disease is still possible. To our knowledge, no study has attempted tackling this question in great detail.

Results on pond trials in the aquaculture station of Gounougou with *A. alluaudi* in combination with *Clarias gariepinus* and *Oreochromis niloticus* showed that neither *C. gariepinus* nor *A. alluaudi* had any influence on resident snail populations in ponds (Slootweg et al., 1993). In fact, only a minor but significant reduction in snail numbers could be shown in presence of adult *O. niloticus*, an omnivorous fish. The authors concluded that fish culture under good nutritional regimes enhances growth and reproduction of snails. Because of a lack of competition for food even the so-called molluscivorous fish prefer to eat "easier" food items, readily available in fish ponds.

A second observation from the pond experiments was that the rate of reproduction of *A. alluaudi* was very low and cannibalism probably caused high mortality among juveniles. Over a 14 month period, 95 adult specimens (about half being female) produced only 1195 juveniles. Mortality among juveniles in stocking ponds could reach 72% over a seven month period.

Three field trials gave additional evidence that the fish was not capable of controlling snails (Slootweg 1989b). (1) After the introduction of 50 adult *A. alluaudi* in an enclosed section of a drainage canal, weekly snail sampling did not reveal significant differences between numbers of snails in the enclosed section and the adjacent section without fish. (2) In a rainfed pool with large numbers of *Lymnaea natalensis* and *Bulinus globosus* snails, 200 juvenile *A. alluaudi* were introduced. Snails were sampled weekly before and after introduction, but no noticeable effect was measured over a four month period. 3) In an experiment on combined rice/fish-culture 240 *A. alluaudi* were introduced together with 1200 *O. niloticus* on a 0.25 ha rice-field just after the replanting of rice-seedlings. The rice-field was surrounded by refuge trenches 100 cm wide and 50 cm deep. After three months, 98 *A. alluaudi* were recaptured. Also 3 juveniles were found indicating that reproduction had taken place. From an aquacultural point of view this introduction was a reasonable success since farmers were pleased with the amount of tilapia produced (53 kg). During the experiment a population of *B. forskalii* snails developed, following a pattern similar to other rice fields.

A number of *A. alluaudi*, born and raised in the aquaculture station of Gounougou, were preserved in formaldehyde and shipped to the Netherlands, where the pharyngeal jaws and muscles were studied and compared to laboratory-raised and wild-caught individuals. These results have not yet been published and will be presented in this paper. The main skeletal element of the pharyngeal jaw apparatus is the lower pharyngeal element (LPE). Hoogerhoud (1986b) found that the horn width of the LPE is a good measure to differentiate between animals with a hypertrophied and a reduced LPE. The muscle complex attached to the LPE, the musculus levator externis 4 and the musculus levator posterior (mLE4/LP), were removed, dried and weighed (muscular and skeletal names according to Anker, 1978, and Barel et al., 1976).

In figure 31 the lower pharyngeal element and the muscle complex mLE4/LP are drawn for two typical A. alluaudi of the same neurocranial length, a wild-caught Lake Victoria specimen and a laboratory-reared specimen, to illustrate to what extent the pharyngeal apparatus can be reduced. For the hornwidth of the lower pharyngeal element, the aquaculture specimens from Cameroon fall within the range of least hypertrophied animals from the mollusc-free lakes (figure 32). Data on the dryweight of the muscle complex that operates the lower pharyngeal element show a similar reduction in muscle size. The morphological measurements from the aquaculture specimens reveal that the pharyngeal jaw apparatus is not adapted to processing snails, suggesting that the fish do not eat snails in the Cameroonian experiments.

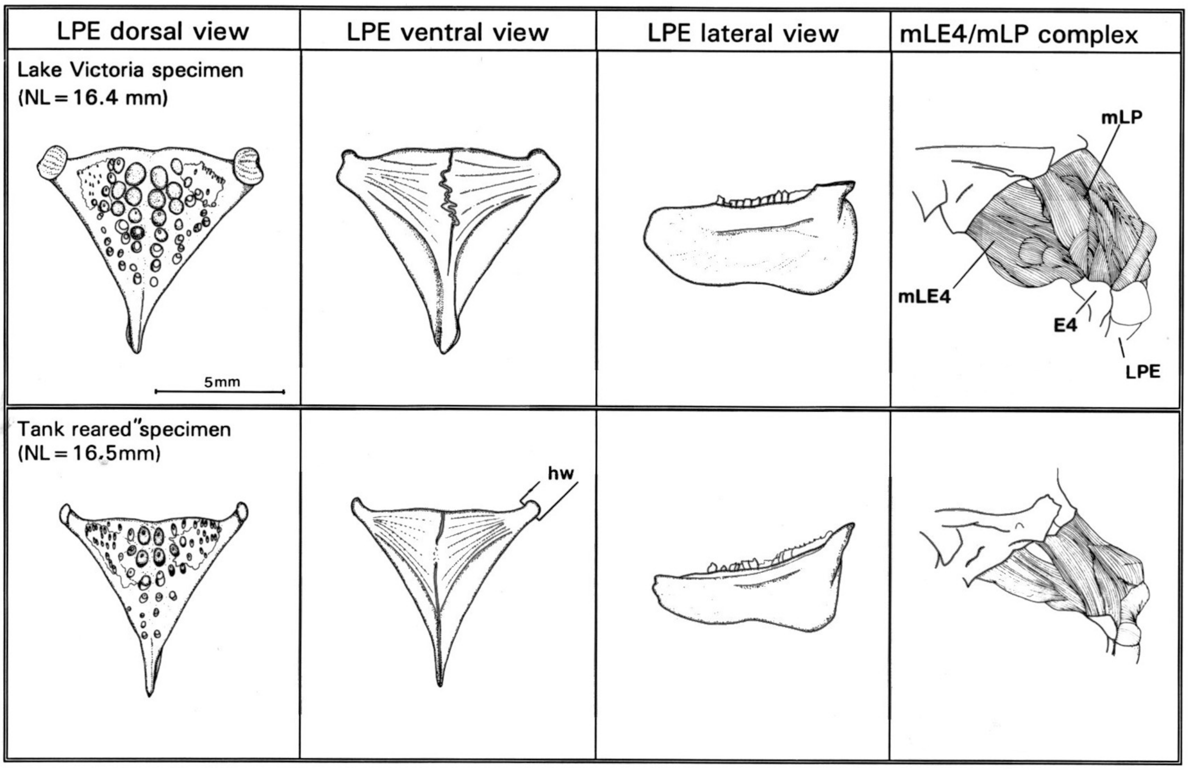


Fig. 31: Lower pharyngeal element (LPE) and muscle complex operating on the LPE of a wild-caught Lake Victoria specimen and a laboratory reared specimen of *Astatoreochromis alluaudi* (Overbeek, 1986). (All drawings to the same scale; abbreviations: NL = neurocranial length; mLE4 = musculus levator externis 4; mLP = musculus levator posterior; E4 = epibranchial 4; hw = hornwidth). Compared to the Lake Victoria specimen, the "tank-reared" specimen shows (1) a reduction in the size of the pharyngeal teeth (LPE dorsal view), (2) a more straightened central suture (LPE ventral view), (3) a more slender outer shape of the jaw, (4) the hornwidth of the LPE is reduced (dorsal, ventral and lateral view), and (5) the volume of muscles attached to the horn of the LPE (mLE4/mLP complex) is reduced.

Reasons for failure of **Astatoreochromis alluaudi**

1. Reproduction

Tilapiine cichlids, such as the mouthbrooding *Oreochromis niloticus*, are well known in fish-culture as species which reproduce easily in ponds. Usually the reproduction is so excessive that special measures have to be taken to prevent fish from breeding. Therefore it is surprising that the mouthbrooding haplochromine cichlid *A. alluaudi* performs so badly in ponds. It is true that the numbers of eggs carried by *Oreochromis* females can be four to twenty times higher than by *A. alluaudi* (Trewavas, 1983, reports 3700 eggs in a 57cm SL female of *O. niloticus*, compared to 170 for *A. alluaudi* as reported by Goldschmidt, 1989), but this does not fully explain the low numbers of offspring in the latter. An *O. niloticus* can produce a brood every two months; our laboratory observations indicate that *A. alluaudi* only produces between two and three broods per year. In his field experiments DeBondt (1956a) had separated couples of the mouthbrooding riverine cichlid

Serranochromis mellandi. The number of eggs carried by females varied from 110 to 366. After 10 months on average 297 juveniles were produced per couple. If each of the ±50 female *A. alluaudi* that were introduced in the aquaculture station in North Cameroon would have produced one brood, the number of juveniles would be 8500, which is seven times higher than the number actually recorded over a 14 months period. Cannibalism and predation by birds may have contributed to a reduced number of juvenile fish. Summarizing the results one may conclude that *A. alluaudi* is not a suitable candidate for large scale biological control activities where large numbers of fish have to be produced and introduced into water reservoirs. Especially where repeated introductions are necessary, such as in temporary reservoirs, the low reproductive success is a constraint.

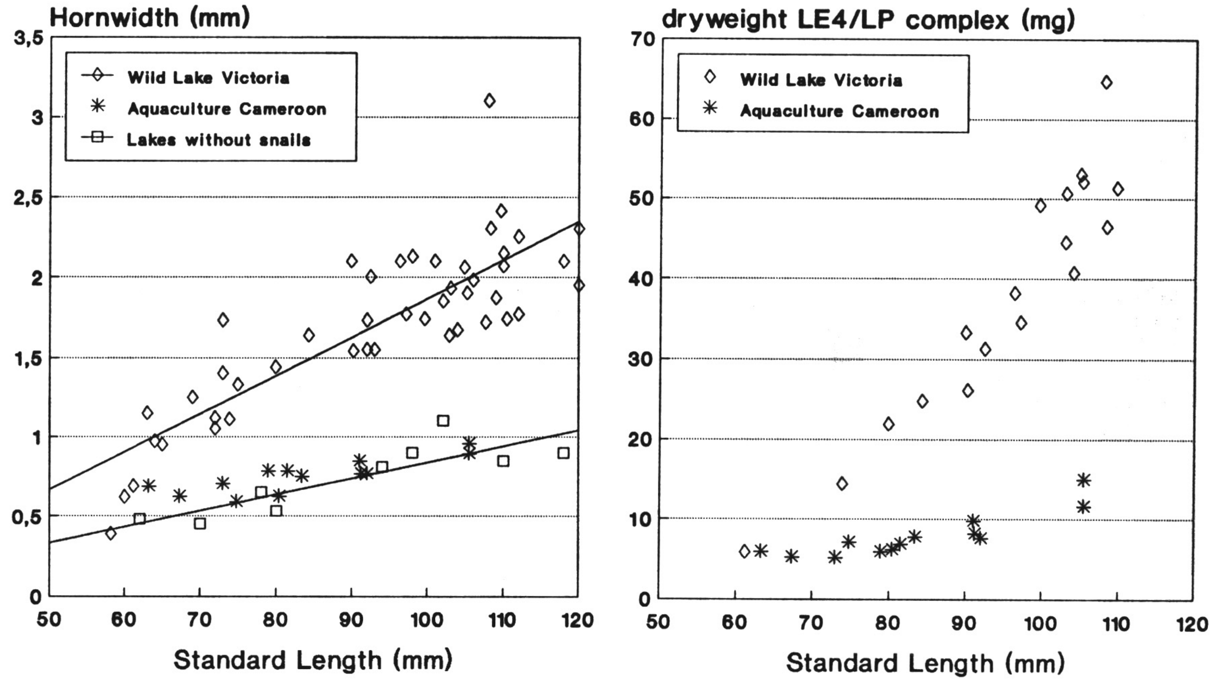


Fig. 32: Reduction of the pharyngeal jaw apparatus in *Astatoreochromis alluaudi*, reared in the aquaculture station of Gounougou, North Cameroon. Data on hornwidth and regression lines of animals from Lake Victoria and Lakes without snails are taken from Hoogerhoud (1986a); muscle weight data of Lake Victoria specimen were provided by J.D. Smits of the Department of Ecological Morphology of Leiden University (N.B: measurements on hornwidth and dryweight are taken from different specimen).

2. Foraging behaviour and prey choice

Using a foraging model, the prey choice of a wide range of animal species searching for food has been explained and could with a certain reliability even be predicted. (For a review on foraging models see Stephens & Krebs, 1986.) In the most simple foraging model the parameters energetic prey content (E), handling time (=searching time plus processing time = Ht) and encounter rate (l) have to be known. When offered a choice of different prey types, these preys can be classified according to their profitability, defined as energetic yield per unit of handling time: E/Ht. According to the average-rate maximizing model, a forager will, upon encounter, always accept the type of prey with highest profitability (type 1). The prey type rating second in energy yield will only be accepted if the total energy yield when foraging on both prey types is larger than the yield when only type 1 prey is chosen. Mathematically this can be described as in inequality 1:

$$\frac{\lambda_1 E_1}{1+\lambda_1 Ht_1} < \frac{\lambda_1 E_1 + \lambda_2 E_2}{1+\lambda_1 Ht_1 + \lambda_2 Ht_2} \tag{1}$$

Written differently it shows that the encounter rate with the highest yielding prey must be lower than a threshold before prey type 2 will be included:

$$\frac{1}{\lambda_1} > \left(\frac{E_1}{E_2}\right) Ht_2 - Ht_1 \tag{2}$$

In other words, the acceptation of a lower-ranked prey type is not influenced by its own density but by the density of the higher ranking prey type only. Laboratory experiments with various species of snail-crushing cichlids indicate that these fish behave according to the average-rate maximizing model preferring the prey type with highest profitability when offered a range of different sizes of snails (Slootweg, 1987). For other snail eating fish this model has also been applied with partial success (Stein et al., 1984; Mittelbach, 1984). Furthermore, when offered a combination of insect larvae and snails in a situation where density is no constraint (excess of preys), insect larvae have a higher E/Ht ratio, and hence are the most profitable prey type (Zoetemeyer, unpublished data). Snails will thus only be eaten when the encounter-rate with insects is below the threshold defined in inequality 2. For field conditions this implies that the willingness of the snail crushing fish to actually eat snails does not depend on the amount of available snails but on the amount of other, more profitable food items. Especially in aquaculture situations the amount of food will not be a limiting factor, because fish have to be produced at the highest possible growth rate and "easy" food (i.e. of the most profitable type) is provided in abundance. If fish forage optimally, they will in this case never switch to eating snails. This observation corroborates with the hypothesis cited above that in Lake Victoria the fish only specialize on snails under the pressure of heavy competition with other species of cichlids that are specialized in handling other food items.

From prey selection experiments where a molluscivorous cichlid, *Trematocranus placodon*, chose thin-shelled *Bulinus* intermediate host snails of schistosomiasis over hardshelled *Melanoides* snails, McKaye et al. (1986) draw the conclusion that this species would be a selective feeder on disease transmitting snails, and thus a suitable candidate for biological vector control. Following the logic of the foraging model this prey choice is understandable since the hardshelled *Melanoides* has a longer handling time and consequently a lower yield per second handling time compared to *Bulinus* snails. This does not imply however, that the fish will choose *Bulinus* when other more profitable prey items are available.

3. Phenotypic plasticity of the pharyngeal jaw apparatus

The absence of hypertrophy in the pharyngeal jaw apparatus of the fish reduces their capability to crush snails. This does not imply that they are not able to eat snails but that handling times for the crushing of snails will increase, especially for larger snails (Slootweg, pers. obs.). Following the foraging model, the encounter rate with more profitable prey types must decrease even further before snails are included in the fishes' diet.

The combination of optimal foraging theory and functional morphology of the pharyngeal jaw apparatus makes us understand the initial partial success of *A. alluaudi* in Kenya where later observations showed that the fish had no influence at all on snail densities, even in reservoirs where fish were still abundant. The introduced fish were wild-caught animals from Lake Victoria with almost certainly hypertrophied pharyngeal jaws. The initial reduction in snail numbers was caused by this wild-caught generation. In due course this generation has been replaced by next generations with less developed jaws. Competition for food in the artificial reservoirs might be low compared to Lake Victoria because they lack an endemic fish fauna. The hardshelled Melanoides tuberculata or similar snails do not occur in these reservoirs, thus the necessary conditions to develop a hypertrophied jaw apparatus are absent. The resulting omnivorous fish is capable of eating snails, but does not specialize on snails and consequently also does not search for them. Similar differences in prey choice between animals with hypertrophied and reduced pharyngeals were observed in other polymorphic cichlid species. Meyer (1989), studying the trophically polymorphic cichlid *Cichlasoma citrinellum*, observed that the molariform morphs (with stout pharyngeal teeth) was able to crack snails that were twice as hard as those cracked by the papiliform morph (reduced type). Liem & Kaufman (1984) studied the prey preference of two morphs of *C. minkleyi* in competition, one having reduced and the other hypertrophied pharyngeal jaws. In an abundant food situation the fish were omnivorous whereas a lowered food availability polarized the feeding behaviour in accordance with their pharyngeal jaw phenotype; the hypertrophied fish specialized on snails.

Probably the phenomenon described above also affected experiments in the Yaounde (Cameroon) fish-culture station where one successful trial was described (Bard & Mvogo, 1963). For this trial also wild-caught *A. alluaudi* were imported from Lake Victoria. After the initial success, the fish was never heard of again.

4. Snail ecology

Other factors reducing the efficacy of snail-eating fish are the spatial distribution of snails and the snails' reproductive capacity. Except for the Oriental intermediate hosts of *S. japonicum*, all other schistosomiasis snail hosts are pulmonate snails, dependent of oxygen-rich water near the surface. Usually they are found at the fringes of a water reservoir or on floating vegetation. Although *A. alluaudi* and some other molluscivorous cichlids are shallow water animals, behavioural studies and the high detritus content of their stomachs indicate that they are bottom feeders (Katunzi, 1983; Kat & Kibberenge, 1990). McKaye et al. (1986) suggest that open shore areas of Lake Malawi are relatively free of schistosomiasis because the bottom dwelling intermediate host snails are selectively controlled by molluscivorous fish. Snails hidden in vegetation near the surface can easily escape this kind of predation, so less open shore areas with aquatic vegetation can be potential sites of schistosomiasis transmission.

The reproductive capacity of snails is enormous; research suggest that the number of offspring is not a limiting factor in the colonization of habitats. Eisenberg (1966) changed densities of a pond snail, *Lymnaea elodes*, to 1/5 and 5 times the initial density. In the next generation, the numbers of snails in the three treatments were equal, regardless of the number of snails in the parental generation, indicating that the numbers of snails very rapidly reach the carrying capacity of the habitat and that reproduction is not a limiting factor. After addition of food, the numbers of snails increased immediately, indicating that food is the limiting factor. Thus, even if a predator is capable of eating large numbers of snails, the population levels may not be lowered to any significant degree.

5. Transmission dynamics of schistosomiasis

For the Sahelian and part of the Soudanian region of Africa another important factor limits the possible use of fish as a biological control agent against schistosomiasis host snails. The most important intermediate hosts of vesical schistosomiasis in this semi-arid region are *Bulinus senegalensis* and *B. globosus*, two species being capable of aestivating in humid mud and surviving periods of drought. When the rainy season starts, surviving snails rapidly recolonize water reservoirs that serve as transmission sites for the following weeks or months. Clearly it is difficult and economically unfeasible to stock all of these seasonal reservoirs with fish.

Prospects of the use of fish in snail control

In the preceding section reasons for the failure of *Astatoreochromis alluaudi* in snail control are given. Other species of molluscivorous haplochromines will also fail to control molluscs for the same reasons. Many examples of intraspecific variability within the family of Cichlidae are known (Witte et al.(1990) for Lake Victoria haplochromines; Kornfield & Taylor (1983), Liem & Kaufman (1984) and Meyer (1987; 1989) for Southamerican cichlids; Cataldi et al. (1988) and Kornfield (1991) for *Oreochromis* species, etc.), Therefore it is likely that the reduction of the pharyngeal jaw apparatus is not limited to *A. alluaudi* only. Overbeek (1986) has already shown a similar reduction in the pharyngeal jaw apparatus of the mollusc crushing cichlid *Haplochromis ishmaeli*. Problems related to reproduction and foraging behaviour will probably not differ much among the other lacustrine molluscivorous cichlids from Lake Victoria. Therefore, it is does not seem advisable to invest further research efforts in this group from Lake Victoria. Molluscivorous cichlids from other African Lakes and/or rivers that may seem suitable candidates for biological snail control should be carefully studied with respect to reproduction and phenotypic plasticity.

Other species of possible snail-controlling fish from Table 10 are unsuitable as well, either because of their omnivorous foraging behaviour or because they are bottom feeders. They appear to be effective against snails in tank experiments, but under field conditions they prefer to forage on other prey items, as explained by the foraging model. However, several examples of snail control by fish from the literature cannot be neglected. The shellcracker sunfish, *Lepomis microlophus*, successfully controlled snails in Puerto Rico, but from the available data it is not clear whether schistosomiasis transmission was interrupted. A renewed visit to the lakes where this species has been introduced, such as has been done in Kenya, can give valuable additional information. Caution must be taken when revisiting these Puerto Rican reservoirs because on this island the competitive snail *Marisa cornuarietis* has successfully been introduced in the biological control against *Biomphalaria glabrata* (Jobin & Laracuente, 1979; also see Pointier & McCullough, 1989 and Gomez Perez et al., 1991).

The black carp, *Mylopharyngodon piceus*, was effective in controlling nuisance snails, obstructing water meters and irrigation equipment in artificial reservoirs in Israel (Leventer, 1981). The method of fish culture and integrated control as applied in Israel is restricted to a limited number of environments and requires an advanced level of knowledge on aquaculture and limnology. Especially on the African continent where aquaculture is not wide-spread, such knowledge is often not available. However, more research on the reproduction methods and usefulness of this species in snail control seems justified, especially in relation to aquaculture.

Most convincing field evidence comes from Zaire where the riverine cichlid *Serranochromis mellandi* was successful in controlling molluscs in fish ponds, irrigation canals and rice fields. The fish successfully reproduced in fish ponds, although numbers of offspring were relatively low. The level of reduction in snail population was such that transmission of schistosomiasis was seriously hampered. Unfortunately no recent information is available on this species; the latest publication dates back to 1956. The author of the early publications on *S. mellandi* still is convinced that this species has much potential in the biological control of snails (DeBondt, pers. com.). The renewed attention for aquaculture in Africa can hopefully stimulate further research into this species which can be found in Lakes Bangweulu (Zambia) and Mweru (Zaire) and certain rivers in South Central and South West Africa (Fryer & Iles, 1972).

The more recent experiments that were performed in Malawi with the cichlid fish *Trematocranus placodon* gave some encouraging results. However, as the authors already indicated, it is difficult to assess wether the reduction in snail population is sufficient to reduce schistosomiasis transmission. We suggest that additional pond experiments with different stocking densities, changes in feeding regimes, and clearing of vegetation might lead to higher reductions in snail density. It is also necessary that questions pertaining to the reproduction of fish and phenotypic plasticity will be answered. Keeping the high risk of schistosomiasis transmission in aquaculture in Africa in mind, we hope the authors will be able to continue the valuable experiments on *T. placodon.*

From the available evidence it has become clear that if fish are to be used in snail control, it should be limited to permanent habitats and in combination with other control measures. The role of fish must be seen as part of an integrated approach where habitat alterations and appropriate water management can reduce snail breeding and refuge sites, and where natural or introduced competitors and predators put further pressure on snail populations. Studies on the population dynamics of snails have shown that the availability of food is often the major constraint (Eisenberg, 1966; Brown, 1980; Thomas et al., 1983). Schayck (1986) has shown that the introduction of the Chinese grass carp, *Ctenopharyngodon idella* in irrigation canals in Egypt had a significant effect on the reduction of snail populations. Clearing of aquatic weeds reduces the amount of food and also exposes snails to predators that might be naturally present (e.g. McKaye et al., 1986). Even if these predators are omnivorous their contribution in the reduction of snail populations might be considerable if the environment is made more hostile to snails. Future research activities should concentrate on this area of integrated research, rather than hoping to find a fish predator of snails that will fully eradicate intermediate hosts of schistosomiasis in all potential transmission sites.

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References

Andrade, R.M. (1959). The problem of schistosomiasis mansoni in the artificial lake of Pampulha, Belo Horizonte, Minas Gerais, Brasil. *Revista Brasileira de Malariologia e Doenças Tropicais,* **11**, 653-674.

Andrade, R.M. (1962). Ecology of Australorbis glabratus in the artificial lake of Santa Lucia, Belo Horizonte. Spontaneous disappearance. *Revista Brasileira de Malariologia e Doenças Tropicais*, **14**, 29-62.

Andrade, R.M. (1968). Nota ecologica sobre o Lago da Pampulha (Belo Horizonte, MG), com especial referencia aos planorbideos (Pulmonata, Planorbidae). *Revista Brasileira de Malariologia e Doenças Tropicais*, **21**, 59-116.

Andrade, R.M. & Antunes, C.M.F. (1969). Combate biologico: *Tilapia melanopleura* Dumerill versus *Biomphalaria glabrata* (Say) em condições de laboratorio. *Revista Brasileira de Malariologia e Doenças Tropicais*, **21**, 49-58.

Anker, G. Ch. (1978). The morphology of the head-muscles of a generalized Haplochromis species: *H. elegans* Trewavas 1933 (Pisces, Cichlidae). *Neth. J. Zool*., **28**, 234-271.

Bard, J. & Mvogo, L. (1963). Note d'information sur l'*Astatoreochromis alluaudi* poisson molluscophage utilisable dans la prophylaxie de la bilharziose. *Bull. Soc. Path. Exot*., **56**, 119-124.

Barel, C.D.N., Witte, F.W. & van Oijen, M.J.P. (1976). The shape of skeletal elements in the head of a generalized Haplochromis species: *H. elegans* Trewavas 1933 (Pisces, Cichlidae). *Neth. J. Zool*., **26**, 163-265.

Barel, C.D.N., Ligtvoet, W., Goldschmidt, P.T., Witte, F. & Goudswaard, P.C. (1991). The Haplochromine cichlids in Lake Victoria: an assessment of biological and fisheries interest.

In: M.H.A. Keenleyside (ed.). *Cichlid fishes, behaviour, ecology and evolution.* London/New York: Chapman & Hall. Chapter 13: pp 258-279.

Berg, C.D. (1973). Biological control of snail-borne diseases: a review. *Exp. Parasit.*, **33**, 318-330.

Blache, J. (1964). Les poissons du bassin du Tchad et du bassin du Mayo Kebbi. *Memoires ORSTOM*, **4**, 483 pp.

Blom, P.S. (1983). Rice land fisheries in the tropics. *Abstracts on Tropical Agriculture*, **9**, 9-19.

Bowmaker, A.P. (1968). Some upper Congo fish which offer a means of biological control of the snail vectors of bilharziasis. *Proceedings and Transactions of the Rhodesia Scientific Association*, **52**, 28-37.

Brown, D.S. (1980). *Freshwater snails and their medical importance*. London: Taylor & Francis. 350 pp.

Brown, K.M. & DeVries, D.R. (1985). Predation and the distribution and abundance of a pulmonate snail. *Oecologia*, **66**, 93-99.

Carothers, J.L. & Allison, R. (1968). Control of snails by the redear (shellcracker) sunfish. In: Proceedings of the FAO World Symposium on Warm Water Pond Fish Culture (ed. by T.V. Pillay). *FAO Fisheries Reports*, **44**, 399-406.

Cataldi, E., Crosetti, D., Conte, G., D'Oridio, D. & Cataudella, S. (1988). Morphological changes in the oesophageal epithelium during adaptation to salinities in *Oreochromis mossambicus*, *O. niloticus* and their hybrid. *J. Fish Biol.*, **32**, 191-196.

Chiotha, S.S. & McKaye, K.R. (1986). Possible biological control of schistosomiasis (Bilharzia) by Lake Malawi molluscivores. *Luso: J. Sci. Tech. (Malawi)*, **7**, 11-24.

Chiotha, S.S., McKaye, K.R. & Stauffer Jr., J.R. (1991a). Use of indigenous fishes to control schistosome snail vectors in Malawi, Afrca. *Biological Control*, **1**, 316-319.

Chiotha, S.S., McKaye, K.R. & Stauffer Jr., J.R. (1991b). Prey handling in Trematocranus placodon, a snail-eating cichlid fish from Malawi. *Ichtyol. Explor. Freshwaters*, **2**, 203-208.

Coates, D. (1984). A survey of the fish fauna of Sudanese irrigation systems with reference to the use of fishes in the management of ecological problems (the control of aquatic weeds, malaria and infective schistosomiasis). *Fisheries Management*, **15**, 81-95.

Corbet, P.S. (1961). The food of non-cichlid fish in the Lake Victoria basin, with remarks on their evolution and adaptation to lacustrine conditions. *Proc. Zool. Soc. Lond.*, **136**, 1-101.

Corbet, S.A., Green, J. & Betney, E. (1973). A study of a small tropical lake treated with the molluscicide Frescon. *Environmental Pollution*, **4**, 193-206.

Daffalla, A.A., Elias, E.E. & Amin, M.A. (1985). The lungfish *Protopterus annectans* (Owen) as a biocontrol agent against schistosomiasis vector snails. *J. Trop. Med. Hyg.*, **88**, 131-143.

Daget, J. (1954). Les poissons du Niger Supérieur. *Mémoires de l'Institut Français d'Afrique Noire,* **36**, 391 pp.

Daget, J. Gosse, J.-P., Teugels, G.G. & Thys van den Oudenaerde, D.F.E. (1991). Checklist of freshwater fishes of Africa (CLOFFA). Volume IV. Bruxelles: ISBN, Tervuren: MRAC, Paris: ORSTOM.

DeBondt, A.F. (1955). Premiers essais de rizipisciculture à la station de recherches piscicoles (Katanga). *Bulletin Agricole du Congo Belge*, **46**, 1550-1553.

DeBondt, A.F. (1956a). Controle biologique des mollusques d'eau douce et des maladies qu'ils transmettent. *Ann. Soc. Belge Med. Trop.*, **36**, 667.

DeBondt, A.F. (1956b). Lutte contre les mollusques dans les eaux africaines. *Bulletin Agricole du Congo Belge*, **47**, 337-380.

DeBondt, A.F. & DeBondt Hers, M.J. (1952). Mollusc control and fish farming in Central Africa. *Nature,* **170**, 323-324.

DeBondt, A.F. & DeBondt Hers, M.J. (1956). *Haplochromis mellandi* Blgr. poisson malacophage (Fam. Cichlidae). *Revue de Zoologie et de Botanique Africaines*, **53**, 370-376.

Eisenberg, R.M. (1966). The regulation of density in natural populations of the pond snail, *Lymnaea elodes*. *Ecology*, **47**, 889-906.

Erdman, D.S. (1984). Exotic fishes in Puerto Rico. In: *Distribution, biology and management of exotic fishes* (ed. by W.R. Courtenay Jr & J.R. Stauffer Jr), pp. 162-176. Baltimore/London: John Hopkins University Press.

Ferguson, F.F. (1978). The role of biological control agents in the control of schistosome-bearing snails. Atlanta G.A: U.S. DHEW Public Health Service, Center for Disease Control. 107pp.

Fryer, G. & Iles, T.D. (1972). *The cichlid fishes of the great lakes of Africa. Their Biology and Evolution.* Edinburgh: Oliver & Boyd. 641 pp.

Gamet, A., Brottes, H. & Mvogo, L. (1964). Premiers essais de lutte contre les vecteurs des bilharzioses dans les étangs d'une station de pisciculture au Cameroun. *Bull. Soc. Path. Exot.*, **67**, 118-120.

Goldschmidt, P.T. (1989). *An ecological and morphological fieldstudy on the haplochromine cichlid fishes (Pisces, Cichlidae) of Lake Victoria*. Thesis, Leiden University. 170 pp.

Gomez Perez, J., Vargas, M. & Malek, E.A. (1991). Displacement of *Biomphalaria glabrata* by *Thiaria granifera* under natural conditions in the Dominican Republic. *Mem. Inst. Oswaldo Cruz, Rio de Janeiro*, **86**, 341-347.

Graber, M. Euzeby, J.A. & Gevrey, J.P. (1981). Lutte biologique contre les mollusques vecteurs de bilharziose. Action prédatrice de *Tilapia rendalli* Boulenger et *Sarotherodon mossambicus* Peters à l'égard de *Biomphalaria glabrata* Say. *Hydrobiologia*, **78**, 253-258.

Greenwood, P.H. (1959). The monotypic genera of cichlid fishes in Lake Victoria. Part II. *Bull. Br. Mus. (Nat. Hist.)*, **5**, 7-177.

Greenwood, P.H. (1965). Environemental effects on the pharyngeal mill of a cichlid fish, *Astatoreochromis alluaudi*, and their taxonomic implications. *Proc. Linn. Soc. Lond.,* **176**, 1-10.

Greenwood, P.H. (1974). The cichlid fishes of Lake Victoria, East Africa: the biology and evolution of a species flock. *Bull. Br. Mus. (Nat. hist.), Zool. Suppl.*, **6**, 134 pp.

Greenwood, P.H. (1981). *The Haplochromine fishes of the East African lakes: collected papers on their taxonomy, biology and evolution (with an introduction and species index).* München: Kraus International Publications. 839 pp.

Hairston, N.G., Wurzinger, K.-H. & Burch, J.B. (1975). *Non-chemical methods of snails control.* WHO/VBC/75.573, Geneva: World Health Organization. 29 pp.

Holden, M.J. (1970). The feeding habits of *Alestes baremose* and *Hydrosynus forskali* in Lake Albert, *East Africa. J. Zool. (Lond.),* **161**, 137-144.

Hoogerhoud, R.J.C. (1986a). *Ecological morphology of some cichlid fishes*. Thesis, Leiden University, the Netherlands. 133 pp.

Hoogerhoud, R.J.C. (1986b). The ecological and taxonomic aspects of morphological plasticity. *Ann. Mus. Roy. Afr. Centr. Sc. Zool.*, **251**, 131-134.

Hoogerhoud, R.J.C. (1987). The adverse effects of shell ingestion for molluscivorous cichlids,a constructional morphological approach. *Neth. J. Zool.*, **37**, 277-300.

Hoogerhoud, R.J.C. (1989). Prey processing and predator morphology in molluscivorous fishes. *Progress in Zoology*, **35**, 19-21.

Hora, S.L. (1952). Control of molluscan fauna through the culture of *Pangasius pangasius* (Hamilton). *Curr. Sci.*, **6**, 164-165.

Jobin, W.R. & Laracuente, A. (1979). Biological control of schistosome transmission in flowing water habitats. *Am. J. Trop. Med. Hyg.*, **28**, 916-917.

Jordan, P. & Webbe, G. (1982). *Schistosomiasis. Epidemiology, treatment and control*. London: Heinemann Medical Books. 361 pp.

Kat, P. & Kibberenge, M. (1990). An evaluation of biological control of snail intermediate hosts of schistosomiasis by the molluscivorous fish *Astatoreochromis alluaudi*. Utafiti, **3**, 6-12.

Katunzi, E.F.B. (1983). Seasonal variation in the food of a molluscivorous cichlid *Haplochromis sauvagei* Pfeffer 1896. *Neth. J. Zool.*, **33**, 337-341.

Kohler, Ch.C. & Stanley, J.G. (1984). A suggested protocol for evaluating proposed exotic fish introductions in the United States. In: *Distribution, biology and management of exotic fishes* (ed. by W.R. Courtenay Jr & J.R. Stauffer Jr), pp. 387-406. Baltimore/London: John Hopkins University Press.

Kornfield, I. (1991). Genetics. In: In: M.H.A. Keenleyside (ed.). *Cichlid fishes, behaviour, ecology and evolution*. London/New York: Chapman & Hall. pp. 103-128.

Kornfield, I. & Taylor, J.N. (1983). A new species of polymorphic fish, *Cichlasoma minckleyi*, from Cuatro Cienegas, Mexico (Teleostei: Cichlidae) *Proc. Biol. Soc. Wash.*, **92**, 253-269.

Lagrange, E. (1953). La lutte contre les planorbes. *Ann. Soc. Belge Med. Trop.*, **33**, 227-236.

Lagrange, E. (1964). Le cyprin doré (*Carassius auratus*) mangeur de *Australorbis glabratus*. *Rivista Parassitologia*, **25**, 244-251.

Lauzanne, L. (1972). Régimes allimentaires des principales espèces de poissons de l'archipel oriental du Lac Tchad. *Verh. int. Verein. Limnol.*, **18**, 636-646.

Leitar, J. (1956). Biologie et écologie des mollusques vecteurs de bilharziose à Jadotville. *Ann. Soc. Belge Med. Trop.*, **36**, 921-1036.

Leventer, H. (1981). Biological control of reservoirs by fish. *Bulletin of Fish Culture in Israel,* March 1981, 3-23.

Liem, K.F. & Kaufman, L.S. (1984). Intraspecific macroevolution: functional biology of the polymorphic cichlid species *Cichlasoma minckleyi*. In: Echelle, A.A. & Kornfield, I. (eds.). *Evolution of fish species flocks*. Orono Ma: Univ. Maine Orono Press, pp. 203-215.

Louda, S.M., Gray, W.N., McKaye, K.R. & Mhone, J.M. (1985). Distribution of gastropod genera over a vertical gradient at Cape McLear, Lake Malawi. *The Veliger*, **25**, 387-391.

McCullough F.S. (1981a). Biological control of the snail intermediate hosts of human Schistosoma spp.: a review of its present status and future prospects. *Acta Tropica*, **38**, 5-13.

McCullough, F.S. (1981b). *Appraisal of the potential of the use of fish for control of disease vectors other than mosquitos*. TDR/BCV/IC.81.2/WP.22. Geneva: World Health Organization. 9 pp.

McKaye, K.R., Stauffer, J.R. & Louda, S.M. (1986). Fish predation as a factor in the distribution of Lake Malawi gastropods. *Exp. Biol.*, **45**, 279-289.

McMahon, J.P. (1960). Preliminary observations on the control by fish of snails and mosquitos in dams. *Annual Report for 1959 of the East African Fisheries Organisation*. Jinja, Uganda. Appendix K, 41-46.

McMahon, J.P., Highton, R.B. & Marshall, T.F. (1977). Studies on biological control of intermediate hosts of schistosomiasis in Western Kenya. *Env. Cons.*, **4**, 285-289.

Mahdi, M.A. & Amin, M.A. (1966). An attempt to control bilharziasis by fish. *Hydrobiologia*, **28**, 66-72.

Malek, E.A. (1958). Factors conditioning the habitat of bilharziosis intermediate hosts of the family Planorbidae. *Bull. Wrld. Hlth. Org.*, **18**, 785-818.

Meyer, A. (1987). Phenotypic plasticity and heterochrony in *Cichlasom manguense* (Pisces, Cichlidae) and their implications for speciation in cichlid fishes. *Evolution*, **4**, 1357-1369.

Meyer, A. (1989). Cost of morphological specialization: feeding performance of the two morphs in the trophically polymorphic cichlid fish, *Cichlasoma citrinellum*. *Oecologia*, **80**, 431-436.

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

Mittelbach, G. (1984). Predation and resource partitioning in two sunfishes (Centrarchidae). *Ecology*, **65**, 499-513.

Miyashita, M. Tanaka, H. & Shirasaka, A. (1977). Studies on the biological control of an intermediate host of Trematoda by tropical fishes. *Japanese Journal of Sanitary Zoology*, **28**, 291-300.

Motta, J.G. & Gouvea, J.A.G. (1971). Utilizaçaõ de *Astronotus ocellatus* (peixe) no controle biológico da Biomphalaria glabrata. *Gazette de Médicina da Bahia*, **71**, 55-58.

Mozley, A. (1953). *A background for the prevention of bilharzia.* London: H.K. Lewis and Co., Ltd. 77 pp.

Mvogo, L. & Bard, J. (1964). Seconde note d'information sur l'*Astatoreochromis alluaudi* poisson malacophage utilisable dans la prophylaxie de la bilharziose. *Bull. Soc. Path. Exot.*, **57**, 21-23.

Oliver-Gonzalez, J. (1946). The possible role of the guppy, *Lebistes reticulatus* on the biological control of schistosomiasis mansoni. *Science*, **104**, 605.

Osenberg, C.W. (1989). Resource limitation, competition and the influence of life history in a freshwater snail community. *Oecologia*, **79**, 512-519.

Overbeek, M. van (1986). Vormplasticiteit van het pharyngeale kaakapparaat van twee molluscivore cichlidensoorten, *Astatoreochromis alluaudi* en *Haplochromis ishmaeli*, onder invloed van een voedselfactor. Department of Ecological Morphology, P.O.Box 9516, 2300 RA Leiden, the Netherlands. 31 pp.

Palmer, A.R. (1979). Fish predation and the evolution of gastropod shell sculpture: experimental and geographic evidence. *Evolution*, **33**, 697-713.

Pointier, J.-P. & McCullough F.S. (1989). Biological control of the snail hosts of *Schistosoma mansoni* in the Caribbean area using *Thiaria* spp. *Acta Tropica*, **46**, 147-155.

Roberts, R.J. & Sampson, D.R.T (1987). *Data sheet on biological control agents: Tilapiine fish*. WHO/VBC/87.945 Geneva: World Health Organization. 14 pp.

Schayck, C.P. van (1985). Laboratory studies on the relation between aquatic vegetation and the presence of two bilharzia-bearing snail species. *Journal of Aquatic Plant Management*, **23**, 87-91.

Schayck, C.P. van (1986). The effect of several methods of aquatic plant control on two bilharzia-bearing snail species. *Aquatic Botany*, **24**, 303-309.

Slootweg, R. (1987). Prey selection by molluscivorous cichlids, foraging on a schistosomiasis vector snail, *Biomphalaria glabrata*. *Oecologia* (Berlin), **74**, 193-202.

Slootweg, R. (1989a). Proposed introduction of *Astatoreochromis alluaudi*, an East African mollusc crushing cichlid, as a means of snail control. *Ann. Mus. Roy. Afr. Centr., Sc. Zool.*, **257**, 61-64.

Slootweg, R. (1989b). Lutte expérimentale contre la schistosomiase. Compte-rendu des activités de recherche pendant la période d'avril 1988 au mois d'avril 1989. Rapports du Projet Pisciculture, 19, MEAVSB, B.P. 17, Garoua, Cameroon.

Slootweg, R. (1991a). Water resources management and health: general remarks and a case study from Cameroon. *Landscape and Urban Planning*, **20**, 111-114.

Slootweg, R. (1991b). Rappport final du volet santé. Contrôle integré de la schistosomiase à Gounougou: réussites et échecs. Rapports du Projet Pisciculture, 46, MEAVSB, B.P. 17, Garoua, Cameroon.

Slootweg, R., Vroeg, P.A. & Wiersma, S. (1993). The effects of molluscivorous fish, water quality and pond management on the development of schistosomiasis vector snails in aquaculture ponds in North Cameroon. *Aquaculture and Fisheries Management*, **24**, 123-128.

Stein, R.A., Gosse Goodman, C. & Marshall, E.A. (1984). Using time and energetic measures of cost in estimating prey value for fish predators. *Ecology*, **65**, 702-715.

Stephens, D.W. & Krebs, J.R. (1986). *Foraging theory*. Princeton NJ: Princeton University Press. 247 pp.

Thomas, J.D., Grealy, B. & Fennell, C.F. (1983). The effects of varying the quantity and quality of various plants on feeding and growth of *Biomphalaria glabrata*. *Oikos* **41**, 77-90.

,Trewavas, E. (1983). Tilapiine fishes of the genera *Sarotherodon, Oreochromis* and *Danakilia*. London: British Museum (Natural History). 583 pp.

Vermeij, G.J. & Covich, A.P. (1978). Coevolution of freshwater gastropods and their predators. *American Naturalist*, **112**, 833-843.

Welcomme, R.L. (1988). International introductions of inland aquatic species. *FAO Fisheries Technical Papers*, **294**. 318 pp.

Witte, F. (1981). Initial results of the ecological survey of the Haplochromine cichlid fishes from the Mwanza Gulf of Lake Victoria (Tanzania): breeding patterns, trophic and species distribution. *Neth. J. Zool.*, **31**, 175-202.

Witte, F.W., Barel, C.D.N. & Hoogerhoud, R.J.C. (1990). Phenotypic plasticity of anatomical structures and its ecomorphological significance. *Neth. J. Zool.*, **40**, 278-298.

Witte, F.W. & van Oijen, M.J.P. (1990). Taxonomy, ecology and fishery of Lake Victoria haplochromine trophic groups. *Zoologische Verhandelingen*, **262**, 3-47.

Witte, F., Goldschmidt, T., Wanink, J., van Oijen, M., Goudswaard, K., Witte-Maas, E., & Bouton, N. (1992). The destruction of an endemic species flock: quantitative data on the decline of the haplochromine cichlids of Lake Victoria. *Environmental Biology of Fishes*, **34**: 1-28.

Zakaria, H. (1963). Heteropneustes fossilis (Bloch), a possible agent for the biological control of the snail host of schistosomes. *Ann. Trop. Med. Parasit.*, **30**, 157-160.

Zweig, R.D. (1985). Freshwater aquaculture in China: ecosystem management for survival. *Ambio*, **14**, 66-74.

Tabel 1: Summary of laboratory and field research on snail-eating fish

Family; *Species*	Code		Special remarks (authors)
Protopteridae			
Protopterus annectens (Owen)	a	lo	Fish eats thousands of snails in tanks; *Tilapia* fry was left unharmed, but earthworms were eaten in equal quantities (Mahdi & Amin, 1966).
P. aethiopicus Heckel	a	lo/fe	Omnivorous fish with some preference for snails; in ponds the fish could reduce snail populations by 90%, maintained over a 4 month period (Sudan: Daffalla et al., 1985).
	a	fo	95% of a sample had eaten molluscs; in 56% molluscs were predominant (Lake Victoria: Corbet, 1961)
Mormyridae			
Hyperopisus bebe (Lacépède)	j	lo	Omnivorous (Lake Chad: Blache, 1964).
		fo	Mainly snails in stomach (Lake Chad: Lauzanne, 1972).
	a	fo	Many snails in strong muscular stomach which probably assists with dealing with snails (Sudan: Coates, 1984).
H.b. occidentalis Günther (*= H.o. tenuicauda* Pellegrin)	j	fo	Snails in stomach (Lake Chad: Blache, 1964).
Characidae			
Alestes baremoze (de Joannis)	a	fo	Eats mainly snails but also other food items (Sudan: Coates, 1984).
		fo	In contradiction with Coates; eats only zooplankton, insect larvae and plant material (Lake Albert: Holden, 1970).
Cyprinidae			
Carassius auratus L.	e/j	lo	Eats planorbid snail in tanks (Lagrange, 1964).
Barbus bynni Forskahl	a	fo	Larger specimens had frequently eaten snails (crushed) (Sudan: Coates, 1984).
Barbus altianalis Boulenger	a	fo	By volume molluscs are the main food (Lake Victoria: Corbet, 1961).
Mylopharyngodon piceus (Rich.)	a	fe*	Introduction of various species of carp reduced snail populations and submergerd plants in large reservoirs in Israel (Leventer, 1981).
Umbridae			
Umbra pygmaea (De Kay)	j	lo	Eats small planorbids, but prefers *Daphnia* and *Tubifex* (Lagrange, 1953).
Poeciliidae			
Poecilia (=Lebistes) reticulata Peters	e	lo	Appearance of guppies coincided with disappearance of *B. glabrata* snails in reservoirs (Puerto Rico: Oliver-Gonzalez, 1946).

Continued on next page.

Bagridae			
Clarotes laticeps (Rüpell)	a	fo	Piscivorous and malacophagous (Upper Niger River: Daget, 1954; Lake Chad: Blache, 1964).
			Potential for snail control in large permanent waters; shells remain unbroken in digestive tract
Chrysichthys mabusi	a	fo	(Zaire: DeBondt & DeBondt Hers, 1952).
Boulenger			Snails in stomach (Upper Zaire River: Bowmaker, 1968).
	a	fo	
Clariidae			
Clarias lazera Cuv. et Val.	j	fo	Omnivorous fish (Lake Chad: Blache, 1964).
=*Clarias gariepinus*	a	fo	Eats large quantities of snails but not considered to be selective (Sudan: Coates, 1984).
	a	lo	Eats snails in tanks (Mozley, 1953).
		fe	No reduction in numbers of snails in fish ponds (Cameroon: Slootweg et al., 1993).
Pangasiidae			
Pangasius pangasius Hamilton	a	fo	Fish ingested large quantities of molluscs of any kind (India: Hora, 1952).
Osteoglossidae			
Heterotis niloticus Ehrenberg		fo	Feeds mainly on snails. (L. Chad: Lauzanne, 1972)
Heteropneustidae			
Hetropneustes fossilis (Bloch)	a	lo/fo	Inflicts a painful sting which might deter man from wading in infested waters; presumed predatory agent for control in irrigation canals (Iraq: Zakaria, 1963).
Schilbeidae			
Schilbe mystus L.	a	fo	Omnivorous fish (Sudan: Coates, 1984).
Mochokidae			
Synodontis courteti Pellegrin		fo	Exclusive malacophagous (Upper Niger River: Daget, 1954); id. (L. Chad: Blache, 1964).
	a	fo	Snails in stomach (Lake Chad: Blache, 1964).
S. gambiensis latifrons Blache	a	fo	Selective molluscivorous (Lake Chad: Blache, 1964).
S. clarias L.	a	fo	Omnivorous fish with preference for snails (Sudan: Coates, 1984).
S. sorex Günther		fo	Eats mainly snails (Lake Chad: Lauzanne, 1972).
S. schall (Block Schneider)	a	fo	Omnivorous fish with preference for snails (Sudan: Coates, 1984).
S. victoriae Boulenger	a	fo	Main food items are molluscs and insects (Lake Victoria: Corbet, 1961).
Tetraodontidae			
Tetraodon schoutedeni	a	lo	Known from aquaria in Europe as a very good snaileater; eats large snails (Lagrange, 1953)
Pellegrin	a	fo	Snails in stomach (Upper Niger River: Daget, 1954).

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T. fahaka (strigosus) (Bennett)	a	fo	Piscivorous and malacophagous (Lake Chad: Blache, 1964).
	a	fo	Exclusively malacophagous; one specimen (340 g) contained over 1000 snails. Flesh of this family is often poisonous (Sudan: Coates, 1984).
Centrarchidae			
Lepomis microlophus Günther	a	lo/fe*	Preference for snails in laboratory and ponds; controlled *Biomphalaria* snails in farm ponds (Puerto Rico: Ferguson, 1978; U.S.A.: Carothers & Allison, 1968); appreciated game and food fish (Erdman, 1984)
Cichlidae			
Oreochromis upemba (Thys) (= *Tilapia chrysti*)	a	fo	Ate large and small *Bulinus (Physopsis*) sp. but not the hard-shelled *Thiaria tuberculata* (Zaire: Leitar, 1956).
Oreochromis niloticus	a	fe	Minor but significant reduction of numbers of snails in presence of adult fish (Cameroon: Slootweg et al., 1993).
T. melanopleura Duméril	e/a	lo	Presumed predatory agent for control in a lake (Brazil: Andrade, 1959; 1962; 1968; Andrade & Antunes, 1969).
(= *T. rendalli*)	j	lo	Fish is not selective in its food choice (Lagrange, 1953).
	j	lo	Reduced snail populations in tanks with 90% (Graber et al., 1981).
T. zilli (Gervais)	a	lo	In absence of aquatic plants fish eats more snails (Schayck, 1985).
Cichlasoma biocellatum	a	lo	Pharyngeal crusher; 8 cm specimen was capable of crushing planorbid snails of 30 mm (Lagrange, 1953).
C. nigrofasciatum Günther	a	lo	Eats snails in tanks (Miyashita et al., 1977).
Astronotus o. ocellatus (Cuvier)		fe	Introduction in a lake considerably reduced *B. glabrata* populations for at least 3 years (Brazil: Motta & Gouvea, 1971).
Hemichromis bimaculatus Gill	a	fe	Eliminated *B. tenagophila* snails in a 75 m^2 pond, itself increasing in numbers from 20 introduced specimens to 500 (Brazil: Gilbert in: McCullough, 1981b). In a lake the fish was not effective in controling snails (Bahia, Brazil: Ayala, pers. com.).
Pelmatochromis aff. kribensis	j	lo	Eats only very small planorbid snails (1-2 mm) after fierce crushing (Lagrange, 1953).

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Serranochromis mellandi (= S. macrocephala = Haplochromis mellandi)	a	fo/fe*	Effective in controlling snails in rice fields, irrigation canals and fish ponds (Zaire: DeBondt & DeBondt Hers, 1952; 1956, DeBondt, 1955, 1956a; 1956b).
Trematocranus placodon (=*Cyrtocara placodon)*	a	fe*	*C. placodon* chooses vector snails over *Melanoides* snails. Predation presure on gastropod communities is heavy (L. Malawi: Louda et al., 1985, McKaye et al., 1986).
	a	fe*	Dramatic drop in numbers of snails after introduction in cement and earthen fish ponds (Malawi: Chiota et al., 1991ab).
Haplochromis spp.	a	fo*	21 species of haplochromine cichlids are described as specialized snail-eaters in different habitats (L. Victoria: Greenwood, 1974; Witte, 1981; Katunzi, 1983; Witte & Oijen, 1990)
	a	lo*	Laboratory observations on prey handling (Hoogerhoud, 1986ab) and prey preference showing that prey choice can be explained by an energy maximizing model (Slootweg, 1987)
Astatoreochromis alluaudi Pellegrin	a	lo/fe*	Controlled snails in fish ponds and reproduced successfully (Cameroon, imported from L. Victoria, Uganda: Bard & Mvogo, 1963; Mvogo & Bard, 1964; Gamet et al., 1964).
	a	fe*	An initial reduction in numbers of snails was lost after several years (Kenya, imported from L. Victoria: McMahon, 1960; McMahon et al., 1977). Reduction of pharyngeal jaws in following generations (Kat & Kibberenge, 1990).
	a	fo*	No significant reduction in numbers of snails in fish ponds (Northern Cameroon, imported from L. Victoria, laboratory reared, transported to Cameroon: Slootweg et al., 1993).

Code:	Food preference	Source of data
	a: adult and juvenile snails	lo: laboratory observation
	j: juvenile snails only	fe: field experiment
	e: egg masses	fo: field observation (stomach contents)

* indicate experiments that are described in more detail in the text.

PART III **Chapter 7.1**

WATER AND HABITAT MANAGEMENT AS A MEANS OF SNAIL CONTROL

7.1 Reducing schistosomiasis infection risks through improved drainage.

R. Slootweg & R. Keyzer. *Irrigation and drainage systems* **7**: 99 - 112

Intensification of floodplain agriculture by controlling seasonal floods and construction of irrigation schemes is an important option for development in the semi-arid regions of Africa. Most of Africa's large rivers have already been dammed and large irrigation schemes have been constructed. The spread of some well-known water-related diseases such as malaria and schistosomiasis is often associated with irrigation, as these schemes include permanent breeding sites for disease-transmitting mosquitos and snails. There is a wealth of literature on the relationship between irrigation and health. An extensive review on this subject is given by Oomen, Wolf & Jobin (1990). Many authors state that the link between schistosomiasis and irrigation is most strongly associated with faulty or inefficient irrigation, poor land preparation and lack of free drainage, rather than with irrigation per se. Engineering measures to control schistosomiasis is to a considerable degree just good irrigation practice (e.g. Mather, 1984; Imevbore, 1987; Webbe, 1988). This paper focuses on a possible solution to health problems created by drainage of irrigation waste-water.

Irrigation in Africa is hampered by budget difficulties, often resulting in neglected drainage systems and minimal investments in canal construction (earth instead of concrete lining, etc.). Any additional measures which are advocated (whether for public health reasons or any other desirable purpose) are likely to be subjected to cost scrutiny. One of the very few quantitative studies describing a drainage system which was reconstructed because of health reasons comes from Iran. Here, drainage improvement, combined with land reclamation in swampy areas, and agricultural development resulted in a positive cost-benefit ratio and a decrease in schistosomiasis prevalence (Oomen et al., 1988). According to Abernethy (1987) there is increasing need for demonstration and measurement of the benefits of these alternative policies in irrigation development. Although no data on economic benefits are available at this stage of the project described hereafter, the approach is similar to the Iranian case.

The project area

In 1982, the Benue river in Northern Cameroon was dammed near Lagdo for the generation of hydroelectricity and the development of irrigated agriculture. As a result, seasonal flooding of the former floodplain of the Benue downstream of the Lagdo barrage has greatly diminished, and the plain has lost part of its production functions, e.g. fisheries, cattle grazing, dry season agriculture, etc. Floodplain fishery for example, was an important source of revenue and proteins for the local population, but this activity virtually ceased to exist. By preventing floods and storing water, the Lagdo barrage has created the conditions for the transformation of a considerable area into a large-scale irrigation development scheme which will eventually include thousands of hectares of irrigated fields. In 1987, a first 200 ha scheme was put into operation on the right bank of the Benue near the village of Gounougou. At the moment of writing another 800 ha scheme near the villages of Ouro Doukoudje and Bessoum is under construction. To save on construction costs, drainage water is discharged through natural floodplain depressions which as a consequence turn into permanent marshy areas due to the presence of drainage water throughout the year. These habitats are optimal breeding grounds for freshwater snails, some of them being intermediate host species of schistosomiasis. Data on schistosomiasis suggest a rise in prevalence (percentage of population infected per age class) over the past three years compared to neighbouring villages where there was no influence of irrigation development (Robert, unpubl.; Slootweg, 1991a). Also malaria mosquitoes reproduce in large numbers in such areas. In the case of Gounougou, with a depression all along the village, the nuisance caused by mosquitos is enormous and malaria prevalence has risen dramatically (Slootweg & van Schooten, 1989).

In 1987, a pilot project started in the village of Gounougou with the dual objective of (1) restoring the former floodplain fish production and (2) controlling intermediate hosts of schistosomiasis (Slootweg, 1991b). In close cooperation with the villagers a reconstruction plan for the drainage system was developed and implemented between September 1988 and June 1991. During this period a sampling programme on the snail-hosts of schistosomiasis was carried out in order to monitor the effects of this reconstruction on the snail populations. A key element in this project is water management. With water available throughout the year, the depression can be turned into a productive area for fishculture and horticulture; however, this requires regulation of the water running through the depression. The establishment and reproduction of snails can to a large extent be controlled by effective water and environmental management, such as clearing of vegetation, regular drying of reservoirs and canals, and high water velocities. In this article we show that an effective drainage system can have economic benefits, as well as reduce the irrigation related health risks.

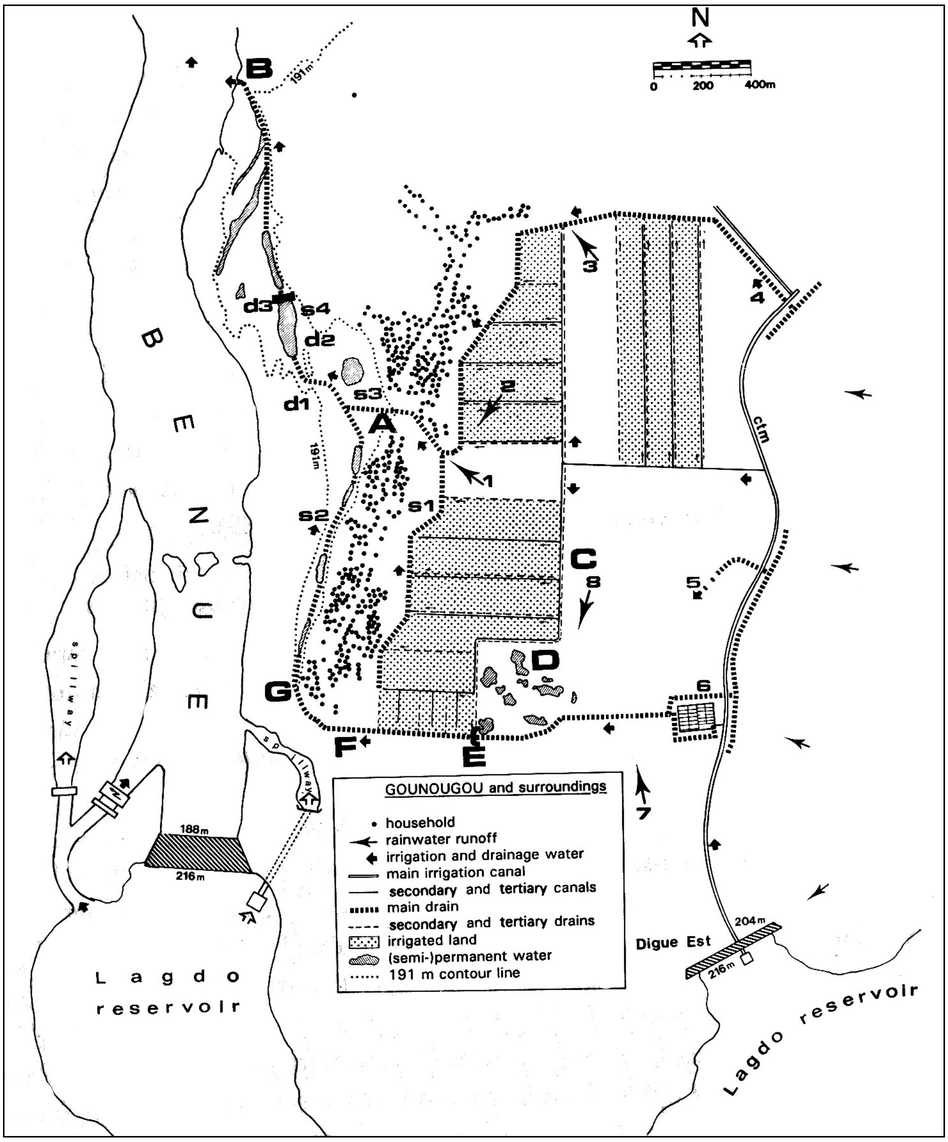

Fig. 33: Waterflow in and around the Gounougou irrigation scheme after reconstruction activities. Indicated are: locations referring to the text (**A** to **G**), general directions and quantities of rainwater run-off (arrows **1** to **8**; explained in text), dam sites (**d1, d2, d3**) and snail sampling sites (**s1** to **s4**).

The water flow around Gounougou before reconstruction

The map in figure 1 illustrates the different flows of water around Gounougou. The schematic cross-section in figure 2 gives an impression of the relief in the area. Before the construction of the irrigation scheme, rainwater accumulated on the plains East of Gounougou before passing a threshold at the centre of the village (A) and entering the depression. Ultimately the depression discharged into the Benue (B). The irrigation scheme that has been constructed on these plains in 1987, uses this same drainage system. As a result, the rainwater coming from the hillsides is now blocked by the main irrigation canal (ctm in figure 1) where three culverts lead the water under the canal towards the irrigation scheme. Initially in the construction of the scheme no provision was made for a proper drainage of rainwater south-east of the scheme, although the design provided for a 4m wide stormwater drain. The maximum run-off in a one in ten years rainy season is calculated to be 15 - 20 m3/s during 4 hours (Timmerman, 1989). The heavy rains of 1988 clearly demonstrated the need for better drainage structures. The accumulated rainwater was blocked on its course by the secondary irrigation canal (C), endangering the embankment of the scheme. Ultimately the water found its way towards the Benue, by breaking a road embankment.

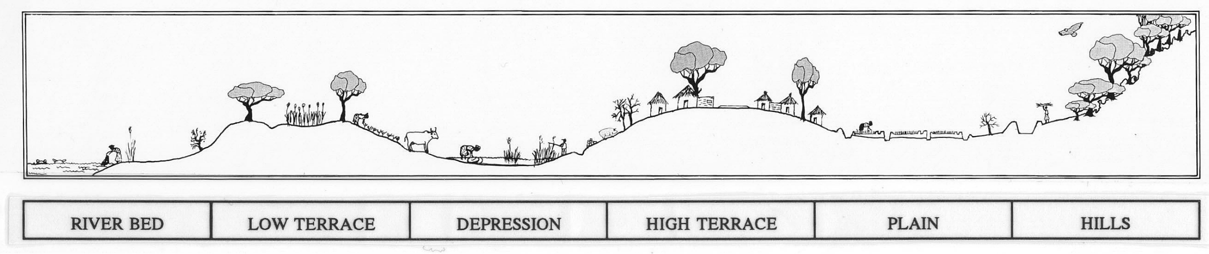

Fig. 34: Schematic West to East cross-section of the Gounougou area. The low terrace is reserved for rain dependent cultures (millet, groundnuts, etc.); the depression is shown in its former state without central canal; the high terrace is occupied by the village and main road; the plain is ised ofr irrigated rice and polyculture; the wooded hills provide fir wood (modified after Leeuwerik, 1989).

In the rainy season of 1988 the Lagdo reservoir reached its maximum capacity and the spillways of the barrage had to be opened for the first time at 1800 m3/s. The depression near Gounougou filled up to the 191m contour line (fig. 1), and many parts of the downstream plains flooded. The following years less than 1000 m3/s were released, causing a rise of 2m in water level (190m) which did not result in floodings.

The intermediate hosts of schistosomiasis

A sampling programme in the region (Greer at al., 1990; Slootweg et al., in press a) revealed the presence of three snail species that are known to be intermediary hosts of vesical schistosomiasis (*Schistosoma haematobium*), i.e. *Bulinus globosus*, *B. truncatus* and *B. senegalensis*, and one intermediate host of intestinal schistosomiasis (*S. mansoni*), i.e. *Biomphalaria pfeifferi*. Furthermore *Bulinus forskalii*, the vector for *S. intercalatum*, was found very often. This parasite only occurs in the rainforest zone of Central Africa (including the south of Cameroon). *Lymnaea natalensis*, host of blood flukes of the genus *Fasciola*, were registered regularly. Especially for cattle this parasite constitutes a health risk.

B. forskalii and *B. senegalensis* are known to live in habitats that can be dry for long periods (up to seven months). *B. forskalii* is also known as a rapid colonizer of newly created habitats. The two species can only be distinguished unequivocally through iso-enzyme analysis. A detailed study revealed that *B. forskalii* is present throughout the year, but that *B. senegalensis* can only be found during the rainy season in temporary habitats (Mimpfundi & Slootweg, 1991). *B. globosus, B. truncatus* and *L. natalensis* colonize new habitats less rapidly but can withstand considerable fluctuations in habitat. *Biomphalaria pfeifferi* prefers permanent habitats without too many disturbances. (Brown, 1980; Wibaux-Charlois et al., 1982).

The principal reproduction period for snails in this region is the cooler dry season (December - March), when water temperatures are optimal for reproduction (between 20°C and 25°C). The second half of the rainy season (July - September) is a minor reproduction period. The rotation in the irrigation scheme more or less follows a similar seasonal time schedule with two crops a year: a dry season (November - March) and a wet season crop (May - October). Two snail reproduction peaks can be recognized in the irrigation schemes, coinciding with the rotation cycle in rice culture.

Analyzing the problems

Because the success of the project relied to a large extent on the participation of the villagers, regular village meetings were organized with the chiefs and other interested persons. Although most people thought the introduction of irrigated agriculture was good for the village, some problems related to the recent developments were raised by the inhabitants. Their main concerns included the loss of fishing grounds, the loss of agricultural land for traditional cultures, and the destructive feeding behaviour of the hippopotamus family residing near the barrage. Based upon the physical characteristics of the region, the foreseeable health risks, and the problems stated by the villagers, additional technical demands which the drainage system should meet were formulated:

1. The 2 m^3/s of maximum water discharge from the irrigation scheme should be able to pass through the main drain that crosses the village (A).
2. The system must be also able to deal with the maximal flow of rainwater during a once in a decennium downpour (data taken from Timmerman, 1989):
    - main drain at village level: 6.5 m^3/s (arrows 1+2+3+4 in figure 1);
    - accumulation in southern area: 15.3 m^3/s (arrows 5+6+7+8 in figure 1).
3. If the adjacent land around water reservoirs is to be put into agricultural use in the dry season, the water level in the reservoirs must be stable, so the system must include regulation devices.
4. Fish must be prevented from escaping towards the Benue.
5. Since high water velocities and regular drying prevent snail breeding, a drainage canal has to be dug through the depression zone; this also facilitates harvesting of fish.
6. In order to further reduce snail (and mosquito) breeding, the creation of marshes near the village must be prevented; the water level in the depression should never overflow the embankment of the canal.
7. During (rare) periods of maximal discharge of the spillways at the barrage, the rising water enters the depression at the outlet (B) and floods the entire depression. This implies that all structures in the depression should be able to withstand inundations of the area.
8. Water contact should be limited as much as possible in order to prevent schistosomiasis infection. From the village, the low terrace between the river and the depression can only be reached by wading through the permanently filled depression (Slootweg et al., 1999(b; a pedestrian bridge would reduce the frequency of water contacts considerably.
9. An alternative grazing area for the hippopotamus family should be found in order to prevent the destruction of gardens around the depression; the same applies to cattle.

Design

Storage of rainwater.

As already stated the accumulation of rainwater in the southern part of the scheme poses a threat. Instead of digging a huge and expensive canal towards the Benue, capable of discharging some 15m^3/s, a storage basin in the clay quarry (D) lying at the lowest point east of the scheme has been planned. A small cofferdam with removable plates and grille (E) at the outlet diminishes the waterflow to a maximum of 1m^3/s through the drainage canal and prevents fish from leaving the basin. This would allow for a canal (F) of smaller dimensions, saving considerably on construction costs. The capacity of this 19 ha basin is large enough to store the maximal run-off in a decennial four hours downpour. Requirements 2, 4 and 5 are met by these measures. At the end of the rainy season the outlet structure (E) can be closed, storing water for dry season purposes. The area is unsuitable for agriculture, but it is a good grazing area for both cattle and hippopotamus. The perennial floodplain grasses Echinichloa stagnina ("bourgou") and Oryza longistaminata (wild rice) constitute an important protein source for herbivores (requirement 9). By storing water in the deeper clay-pits for dry season use, the cattle can be restrained from drinking in irrigation canals. At the end of the dry season the basin can be drained and fish can be collected. The original plan foresaw a drop structure towards the Benue, that would require an enormous investment (> US$ 25,000), as the difference in height in water level between the canal and the Benue is three meters over less than 50 m. A deviation of the drain (G) towards the southern part of the depression proved to be a much cheaper solution. A beneficial side-effect of this deviation is that water from the storage basin (D) can be reused in the depression.

The depression

The modification of the depression was implemented in four steps; after each step the reactions of the villagers were assessed at village meetings.

Step 1: In september 1988, three sandbag dams were built by manual labour by the villagers at sites d1, d2, d3 to meet requirements 3 and partly 4. Surplus drainage water could spill over the dams. The rise in water level created an even larger swampy area along the village, but at least the level was steady and the depression now could be used for agricultural purposes and fisheries.

Step 2: In april 1989 the dams were demolished in order to drain the depression and to estimate the fish production. The evolution of schistosomiasis snail populations were continuously monitored.

Step 3: In the first half of 1990 a canal was dug all the way through the depression towards the outlet into the Benue (from G to B). Drainage could now be established at 188.5m, enabling complete drying out of the depression. Requirements 1, 2 and 5 were met by this canal.

Step 4: Following the digging of the canal, a cofferdam was constructed at site d3. When the valves are closed the water level will rise to the 190m level, creating a small reservoir behind the dam and filling the canal. Small trenches perpendicular to the main canal were dug in order to irrigate the garden plots along the canal. Furthermore a pedestrian bridge was constructed over the canal. With these final constructions in step 4, a proper management of the depression meeting all requirements (1 - 8) has become possible. Between the southern end of the depression and the dam about 15 ha of land has become suitable for dry season cultivation, and a 6 ha reservoir has been created for fish production.

Results

Schistosomiasis intermediate hosts

During three years the drainage system has been sampled for snails on a monthly basis. Four sites were chosen: the main drain near the school (s1), the ford in the middle of the depression (s2), the entrance of the main drain (s3) and the pool near the dam site (s4). The different steps in the reconstruction of the depression can be recognized in the dynamics of the snail populations (figs. 3.1 - 3.4):

Main drain (s1; figure 3.1): In the first year of snail sampling (April '88 - March '89) two distinct reproduction peaks of *Bulinus forskalii* can be recognized. In the second year these two peaks were found again. A more important finding was that a large population of *B. truncatus*, the intermediate host of vesical schistosomiasis, has established itself. After the dredging of the drain in June '90 (step 3), snails have been encountered only once in December 1990. The establishment of *B. truncatus* has been halted by this activity.

Ford (s2; fig. 3.2): After the damming of the depression (step 1) an important population of *Bulinus forskalii* was found in the main reproduction season. After the demolition of the sandbag dams (step 2) the ford virtually dried up. Since then the snail population has not recovered.

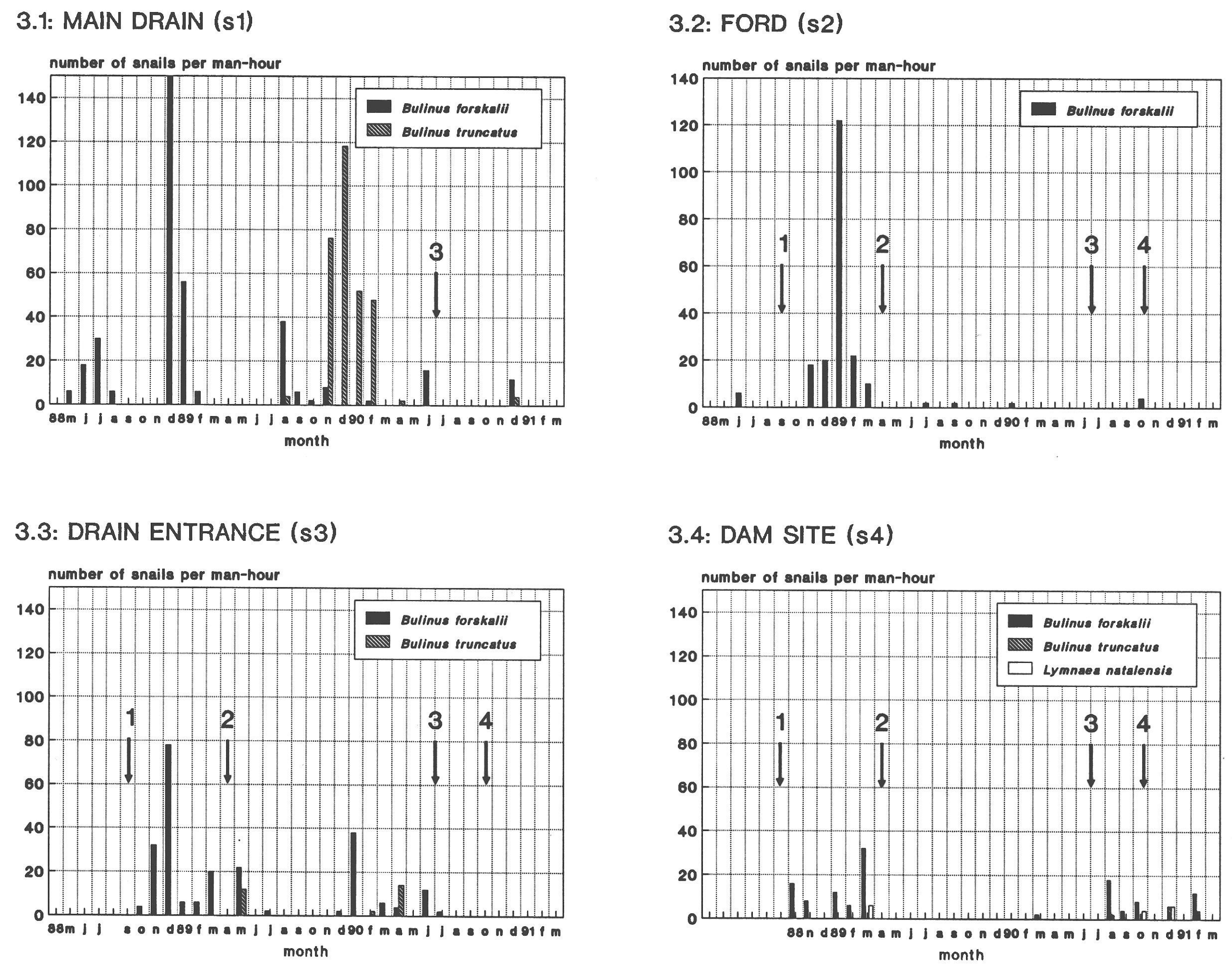

Fig. 35: Influence of stepwise reconstruction on the development of snail populations at four sampling sites in the drainage system of Gounougou. Step 1: building of sandbag dam at sites **d1**, **d2** and **d3**; step 2: demolition of sandbag dams and partial drainge of depression'step 3: cleaning of main drain and completion of the canal through the depressionl step 4: closure of cofferdam at site **d3**.

Entrance of main drain (s3; fig. 3.3): *Bulinus forskalii* was found in large numbers in the first reproduction season following the installation of the sandbag dams (step 1). Drainage of the depression (step 2) only had a very temporary effect because a large amount of water coming from the irrigation scheme still flows into this part of the depression. Within a month *B. forskalii* reestablished itself and, more importantly, *B. truncatus* was found for the first time. The next major reproduction season, starting in december 1989, showed a return of both *B. forskalii* and *B. truncatus*. It was only after the canalization of the depression (step 3) that snails disappeared and did not reappear in the following months.

Dam site (s4; fig 3.4): As for the other two sites *B. forskalii* was resident in the pool near the sand bag dam. *Lymnaea natalensis* was also registered once in march 1989. Drainage of the area (step 2) caused a temporary disappearance of snail populations but the permanency of a reservoir at this site stimulated the proliferation of vector snails. After the closure of the dam in october 1990, three snail species were found regularly (*B. forskalii, B. truncatus*, and *L. natalensis*) but in much lower quantities compared to sites s1, s2 and s3 before the modification of the depression.

Summarizing the results of the reconstruction of the depression zone along the village, one can say that the risk of schistosomiasis transmission has considerably diminished. However, a potential transmission site with low numbers of snails remains present near the dam at considerable distance from the village.

Additional beneficial effects

After 1989, the storage basin (D) has performed well and no inundations or damages caused by excess rainwater were recorded. In the dry season the area was visited daily by several herds from the village and by herds of nomadic pastoralists, together counting several hundreds of heads (sheep, goats and cattle). Occasionally tracks of nightly grazing hippopotamus were found. Unfortunately the animals also continued to visit the depression zone causing much damage to vegetable gardens.

The installation of the sandbag dams (step 1: October '88 - February '89), and the creation of a reservoir with stable water level provided the villagers a basis for dry-season agricultural activities. Without stimulation from outside 18 gardens for horticulture and 7 plots of spontaneous rice cultivation were created, together covering about 3 ha. These activities proved that villagers would be interested in the creation of a management structure for the depression, because of the economic benefit derived from the dry-season activities around the water. This active participation of the village population is a prerequisite for an effective management of the depression zone.

After the first harvest, the sandbag dams were demolished (step 2) in order to drain the depression. The remaining pools were fished by the villagers who used a variety of traditional techniques. Especially groups of women were very successful in trapping fish in shallow water with the help of woven baskets. In a one day joint effort the estimated catch was 500 kg.

The second dry season (November 1989 - April 1990) was lost because of the modification of the depression. In june 1990 the canal was completed (from G to B), so the depression could be drained to the level of 188.5m (step 3). In the same period the main drain of the irrigation scheme was dredged and cleared of vegetation in order to improve water discharge and to eradicate a resident snail population. Four months later the construction of the dam (d3) was finished, and the gates closed at 190m (step 4). At this level the water does not overflow the embankment of the canal, so the former swamps are now permanently dry, and a larger area of arable land has become available. Again the inhabitants of Gounougou spontaneously started making gardens, but discussions between autochthones and immigrants on land-use rights had become very intense. Clearly the value of this formerly useless marshy land had risen considerably. Immigrants constitute by far the majority in the village. The provincial authorities had promised free access to land, so the immigrants put much pressure on the autochthones to be allowed to use depression lands but the latter still refuse to give up their traditional land rights. Obviously the village needs time to adjust to the new situation.

Fish production decreased to + 250 kg, which more or less represents the yearly natural production of a 6 ha waterbody (estimated at 50 kg/year/ha; Welcomme, 1979). The initial catch of 500 kg was abnormally high because the depression had never been entirely drained before, and fish from different year-classes could be caught. One must keep in mind that figures on fish catch represent minimal production levels. In reality the production is much higher because throughout the year people are regularly seen fishing in the area. Very rough estimates of fish production in the entire Gounougou watershed (excluding the Benue river and Lagdo reservoir) add up to 1 - 2.5 tons per year.

Conclusions

Although it is still too early to draw a definite conclusion on the Gounougou pilot-study, some important observations can already be made. The modification of the drainage/depression system alongside the village has drastically reduced the number of snails. Both the pedestrian bridge and the dam are used very often by people and cattle to cross the depression, thus reducing the water contact frequency. As a result of the decrease in snail density and the number of water contacts, the risk of schistosomiasis transmission has been reduced. Consequently, it is likely that the depression no longer constitutes a health risk for the village. This reduction of snails can only be maintained if the area is properly managed in future by the villagers themselves. This is obviously the most difficult part of the project, but since the agricultural and aquacultural production capacity also depends on proper management, this economic incentive might secure a continued active village participation.

Since schistosomiasis transmission is a slow process and other transmission sites occur in the region one cannot expect a sudden lowering of schistosomiasis prevalence in the village. Monitoring will be continued in the coming years in order to register any change in the prevalence of the disease. Furthermore, anecdotical evidence given by people living near the depression, suggest that the numbers of mosquitos have decreased.

The ongoing creation of new irrigation schemes in the Benue valley and beyond is reason enough to continue the monitoring of this pilot study. Hopefully the results obtained sofar will be used in the planning and realisation of these new activities. The ideas presented in this study cannot just be copied to other areas; each irrigation and drainage system has its own characteristics, such as topography, water management, and crop rotation. Consequently, also snail populations differ. Moreover, the people living and working in a scheme can have very different traditional skills, hierarchical structures, etc. towards irrigation management. If one wants to study the possibilities of reducing health risks by optimizing the use of water resources, it is imperative to study each irrigation system individually. Health risks will probably always be associated with irrigation development, but these risks can be minimized. We would like to stress the necessity to invite experts in other disciplines to comment on newly designed irrigation systems before they are actually constructed. Usually these people are confronted with the problems after the scheme has already been built, making it very difficult to suggest any changes in the system. In this study we were confronted with topics related to fisheries, agriculture, animal husbandry, wildlife management, vector biology, and extension work. Evidently irrigation engineers cannot address all these areas because many of these problems are not in their field of expertise. Therefore, an integrated multidisciplinary approach to irrigation development is in our opinion necessary. This will insure that the benefit of increased agricultural production will not be offset by health and other problems that are so often associated to irrigation in developing countries.

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References

Abernethy C.L. 1987. Trends in irrigation development and their implications for vector-borne disease control strategies. In: FAO. *Effects of Agricultural Development on Vector-borne Diseases* (pp. 75-81). AGL/MISC/12/87, Rome.

Brown D.S. 1980. *Freshwater snails of Africa, and their medical importance.* Taylor & Francis, London.

Greer G.J., Mimpfoundi R. & Malek E.A. 1990. Human schistosomiasis in Cameroon. II: Distribution of the snail hosts. *American Journal of Tropical Medicine and Hygiene* **42**: 573-580.

Imevbore A.M.A. 1987. Vector-borne disease hazards in changing agricultural practises resulting from overall development in Africa. In: FAO. *Effects of Agricultural Development on Vector-borne Diseases* (pp. 18-22). AGL/MISC/12/87, Rome.

Mather T.H. 1984. Environmental management for vector control in rice fields. *FAO Irrigation and Drainage Paper* **41**.

Mimpfundi R. & Slootweg R. (1991). Further observations on the distribution of Bulinus senegalensis Muller in Cameroon. *Journal of Molluscan Studies* **57**: 487-489.

Oomen J.M.V., Wolf J. de & Jobin W.R. 1988. Health and Irrigation. Incorporation of disease-control measures in irrigation, a multi-faceted task in design, construction, operation. Volume II. *ILRI Publications* **45**. Wageningen, the Netherlands.

Oomen J.M.V., Wolf J. de & Jobin W.R. 1990. Health and Irrigation. Incorporation of disease-control measures in irrigation, a multi-faceted task in design, construction, operation. Volume I. *ILRI Publications* **45.** Wageningen, the Netherlands.

Slootweg R. & Schooten M.L.F. van (1989). Paludisme et irrigation. Augmentation du paludisme à cause de l'introduction des cultures irriguées à Gounougou, et une estimation de la perte au niveau du ménage. *Rapports du Projet Pisciculture* **36**. MEAVSB, B.P.17, Garoua, Cameroun.

Slootweg R. 1991a. Rapport final du volet santé, Contrôle integré de la schistosomiase à Gounougou; réussites et échecs. *Rapports du Projet Pisciculture,* MEAVSB, B.P. 17, Garoua, Cameroun.

Slootweg R. 1991b. Water resources management and health: general remarks and a case study from Cameroon. *Landscape and Urban Planning* **20**: 111-114.

Slootweg, R., Rhijn, E. van, Schijndel, J.A. van, Dijkstra, M.J., Colenbrander, A.C & Kitmo, S. (in press). A longitudinal study of snail intermediate hosts of trematode parasites in the Benue valley of North Cameroon. *Journal of Medical and Applied Malacology*

Slootweg R., Kooyman M., Koning P.C. de & Schooten M.L.F. van (submitted). The assessment of schistosomiasis infection risks and village water needs in an irrigation scheme in Cameroon, by means of a water-contact study. *Irrigation and Drainage Systems*

Timmerman J. 1989. Propositions des constructions hydrauliques pour le périmètre de Gounougou. *Rapports du Projet Pisciculture:* **21**. MEAVSB, B.P. 17, Garoua, Cameroun.

Webbe G. 1988. Planning, design, and operation of rice irrigation schemes: the impact on schistosomiasis. In: PEEM, 1988. *Vector-borne Disease Control in Humans Through Rice Agroecosystems Management* (pp. 51-65). International Rice Research Institute, Los Baños, Philippines.

Welcomme R.L. 1979. *Fisheries ecology of floodplain rivers*. Longman, London and New York.

Wibaux-Charlois M., Yelnik A., Ibrahima H., Same Ekobo A. & Ripert Ch. 1982. Etude épidémiologique de la bilharziose à *S. haematobium* dans le périmètre rizicole de Yagoua (Nord-Cameroun). II: Distribution et écologie des hôtes intermédiaires. *Bulletin de la Société de Pathologie Exotique* **75**: 72-93.

PART III Chapter 8

PRIMARY HEALTH CARE AND SCHISTOSOMIASIS CONTROL

8.1 An approach to quantify the role of existing health facilities in controlling vesical schistosomiasis in rural northern Cameroon.

R. Slootweg, A.M. Polderman, J.-P. Um & C.-F. Robert. *Tropical and Geographical Medicine*, **47**: 6-11.

Attention in schistosomiasis control has in the last decade mostly been aimed at morbidity control through mass-treatment based on systematic active case-detection. Transmission is probably little interrupted by such a control strategy, but the intensity of infections can be dramatically reduced and morbidity is assumed to have improved parallel. Disadvantages of mass chemotherapy campaigns are the elevated cost per treated individual and the low compatibility with the existing health care facilities (extensively discussed by Gryseels, 1990). The high operational costs of a campaign in areas with high prevalence rates already surpasses many a countries' national health budget. For Mali, Brinkman et al. (1980) calculated that a reduction in prevalence to less than 20% would cost about DM 5,- per person annually. This amounts to 1.8 times the total government expenditure on health per capita for this region with high rates of prevalence. For regions with moderate to low prevalence rates, the cost per treated individual will be much higher since less infected individuals will be found in systematic campaigns of case detection, implying that schistosomiasis can generally not be controlled cost-effectively.

While active case detection is mostly beyond the limits of most health budgets, passive case detection and treatment by (rural) health centres may contribute significantly to the reduction in morbidity, especially in areas with moderate to low prevalence rates. In this study we have tried to quantify the role of existing health care facilities in the control of vesical schistosomiasis around the artificial reservoir of Lagdo in the Benue valley, Cameroon. The Benue valley is endemic for vesical and intestinal schistosomiasis with moderate regional prevalence rates; the geographical distribution of both types of schistosomiasis is highly focal (Ratard et al., 1990). The artificial lake of Lagdo was created in 1982 after the construction of the Lagdo dam. A large community of fishermen and peasants has settled around the lake in order to profit from the enormous fish production and availability of arable land. The fish production (12.000 metric tons per year) is traded through Lagdo, the only village with a tarmac road to the outside world, in this case the provincial capitals of Garoua and Ngaoundéré. Almost the entire lake region depends on Lagdo for imported supplies and for health facilities. Two other villages in the vicinity of the lake also posses a small health centre, but since all trade occurs through Lagdo, people also come to Lagdo for medical help. In 1991, the number of people living along the shores was estimated to exceed 50,000 (Ganzeman & Postma, pers. com.).

The severity of infection of people reporting at the Lagdo health centre is quantitatively analyzed and compared to objective data obtained from schistosomiasis surveys that have been performed in recent years. In this paper we will only consider cases of vesical schistosomiasis since intestinal schistosomiasis is rare in this area. This study tries to give an answer to three questions;

1) Assuming that morbidity from S. haematobium is reflected by the egg-count in urine samples, the first question is whether people reporting at the health centre actually have higher egg-counts than the mean egg-count in the total infected population. This is a prerequisite for effective morbidity control.

2) If the health centre indeed treats cases with heavy infections, do the records then give reliable information about the distribution of schistosomiasis in the area? Most health centres keep records of visitors, but in practise this wealth of information is hardly ever used. If these records could be used for the identification of problem areas, it is not necessary to perform large campaigns with active case detection. For this purpose the records of the Lagdo health centre have been analyzed and compared to data obtained from an area-wide schisto-survey. So independently obtained data from active case detection in a survey are compared to passive case detection at the health centre.

3) Among the persons that are ill due to schistosomiasis, do persons from different age-classes and of different sex have access to a health centre. It is often noted that women and children have limited access to health care facilities. In order to evaluate the access to health facilities, the number of people reporting at the dispensary per class of age and sex was compared with the expected number of people as derived from the survey data.

Collection of data

The organization of primary health care. The health care system consists of several layers: a provincial hospital in the provincial capital Garoua, three district hospitals in Bibemi, Pitoa and Rey Bouba. In each district several health centres are located that each serve between 10,000 and 20,000 persons. A health centre is staffed with one or more qualified health workers. The larger health centres possess a laboratory and a small ward. Visits to a health worker are free of charge; reference to a physician costs CFA 600; materials needed for laboratory analysis or medication have to be paid for, adding up from CFA 300 (approximately US$ 1,-) for stool analysis to CFA 1,500 for blood transfusion; drugs, syringes, etc. have to be bought at the pharmacy at cost price. The pharmacies in this area are regularly supplied with drugs.

Active detection. Data on schistosomiasis prevalence and intensities around lake Lagdo are taken from Robert4,5, whose 1986 survey data from Lagdo, Ouro Kessoum, Mai Djamba, Liferi, Damé and Ouro Tchaido are used. Additional surveys were carried out in Gounougou in 1989 (Robert, pers. com.), Riao in 19906, and Djiporde in 1992 (Vroeg, pers. com.). The standard method in all surveys was urine filtration (10 ml) using Nytrell® filters. Filters were analyzed the same day.

Passive detection. The records of the Lagdo health centre were used for basic information on numbers of visitors per village and numbers of presumed cases of schistosomiasis, as recognized by the health worker. From February 1988 until October 1990, sex, age and village of origin of all recognized cases of schistosomiasis were taken from the records. Per month also the total numbers of visitors were counted; a sample of four months (3,174 visitors) was analyzed to describe the geographic origin of the visitors to the health centre. If the number of visitors from one particular village constitutes less than 1% of the total number of visitors, the village in question is omitted from the analysis.

Intensity of infection in reported cases. The Lagdo health centre is staffed by two qualified health workers and two laboratory assistants. Near the health centre a permanently staffed pharmacy disposes of a regular supply of drugs; praziquantel (sold as Biltricide®) was in constant supply and sold at CFA 400 per tablet. Officially all people suspected to be infected with *Schistosoma haematobium*, usually indicated by recent haematuria, have to present a urine sample to be verified by the laboratory. In the laboratory an electric centrifuge is available for sediment analysis. In practice however, cases of haematuria were treated without laboratory verification, especially on market days when the number of visitors is high. In order to assess the severity of infection among people that actively seek medical help, all suspected cases of schistosomiasis were asked to deliver a urine sample which was stored in the refrigerator. Regularly, the samples were filtered through Nytrell® filters and counted. These quantitative results were filled in on a special data sheet; name, sex, age, village of origin, and quantity of urine filtered were also registered.

Access to health centre. The numbers of actual cases of schistosomiasis reporting at the health centre were compared to the expected numbers of visitors per age class, based on the survey data. The expected number of cases was calculated using the data on intensity of infection from the survey and from the health centre analyses. The ratio between the relative number of lightly infected cases (1-100 eggs / 10ml of urine) reporting at the health centre and this number in the survey was calculated (r_l); the same was done for heavy infections (r_h). From the survey data the fractions of light and heavy infections (f_l and f_h) were determined per age class for men and women. The expected number (N_{exp}) of persons per sex and age class to report at the health centre was calculated as follows:

$$N_{exp} = (r_l \times f_l \times N_{tot}) + (r_h \times f_h \times N_{tot})$$

where N_{tot} is the total number of infected persons in the concerning age/sex-class as measured in the survey. To permit comparison, the resulting numbers of expected cases were scaled to the recorded number of cases reporting at the health centre between February '88 and October '90. (If larger numbers of data are available, this calculation can be more detailed by distinguishing more classes of infection. The resulting formula to calculate the expected number of visitors per age-class than is:

$$N_{exp} = \sum_{1\to X}^{a} (r_a \times f_a \times N_{tot})$$

where "X" is the number of classes of infection that are distinguished.)

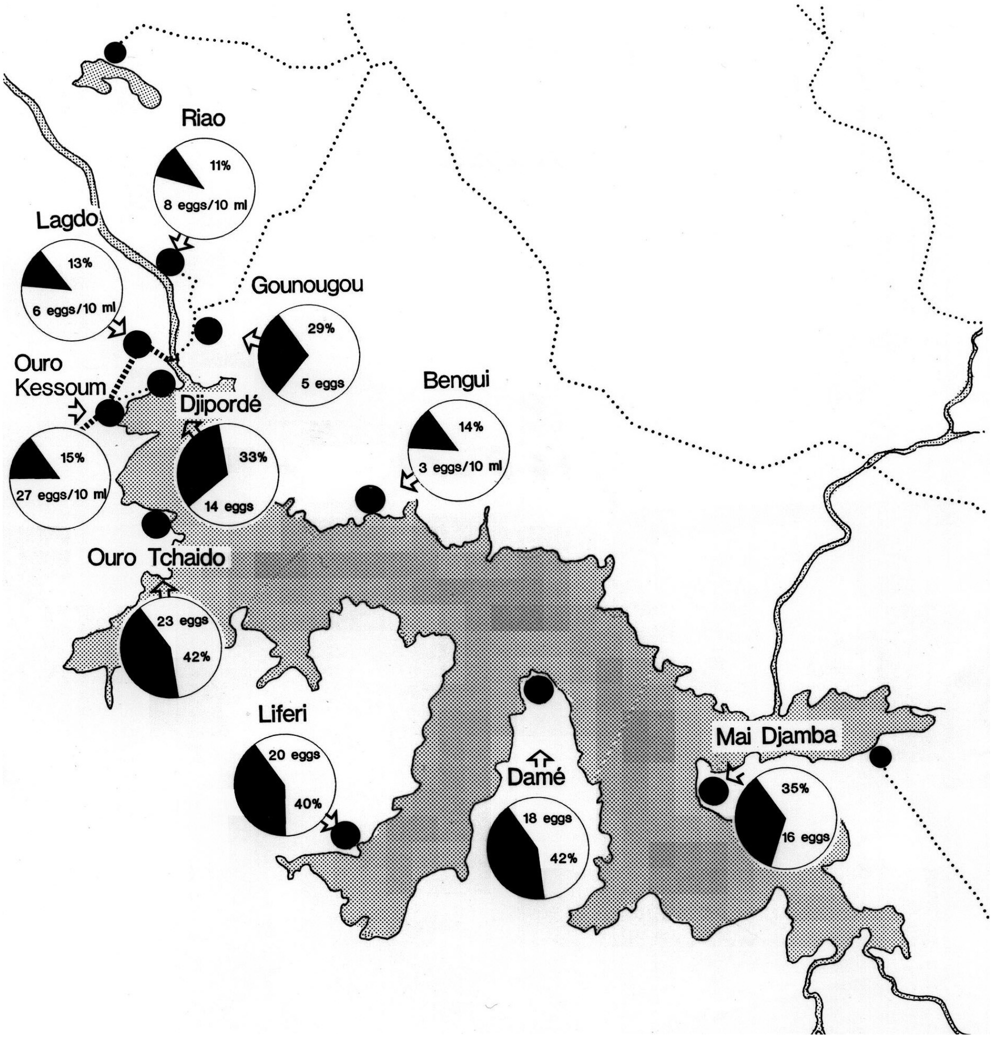

Figure 36: Results of surveys on vesical schistosomiasis around Lagdo lake; in pie charts the prevalence (percentage of total population) and intensity of infection (number of eggs per 10 ml urine).

Results

Active detection. Complete sets of data were available for 10 villages, of which 7 were situated on the shores of lake Lagdo, i.e. Djipordé, Ouro Kessoum, connected by road with the health centre, and Ouro Tchaido, Dame, Liferi, Mai Djamba and Bengui, only having access by boat. Three additional villages were situated immediately downstream of the Lagdo dam, i.e. Lagdo s.s., Gounougou and Riao. The results from several *S. haematobium* surveys in the area and the geographical location of the villages are presented in figure 36. According to Robert (1986), Slootweg (1989) and Vroeg (pers. com.) the surveys significantly reflect the sex and age structure of the population. Prevalence ranged from 11% in Riao to 42% in Damé and Ouro Tchaido. Intensity was lowest in Bengui with a geometric mean egg output of positives of 3 eggs per 10 ml urine and highest in Ouro Kessoum with 27 eggs/10 ml.

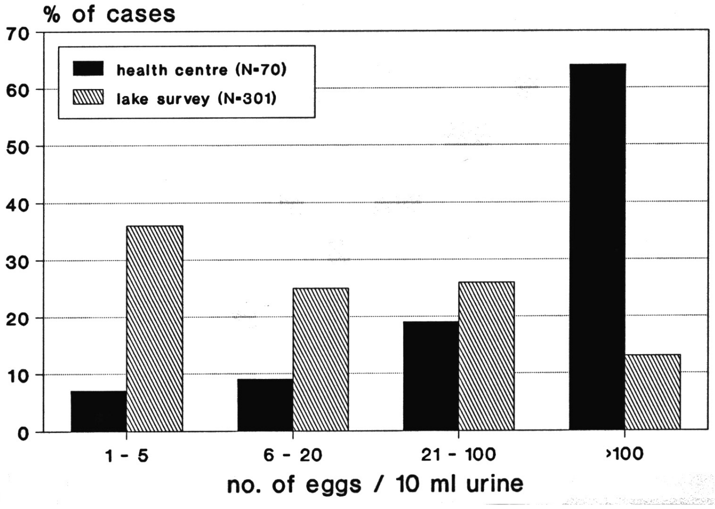

Figure 37: Comparison of egg-output between active (survey) and passive (health centre) case detection, by classes of intensity.

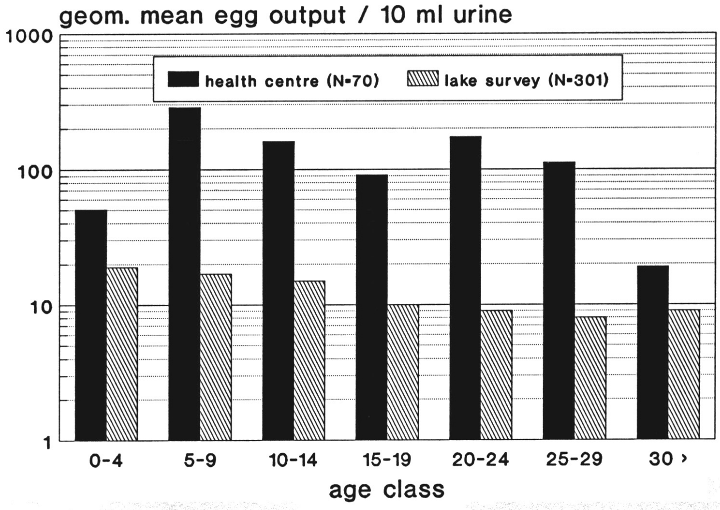

Figure 38: Comparison of geometric mean egg-output between active (survey) and passive (health centre) case detection per age-class.

Intensity of infection of cases reported at the health centre. Sofar 70 cases of vesical schistosomiasis have been quantitatively analyzed in the laboratory at the health centre. The age distribution of the tested group does not differ significantly from the overall age distribution of the schistosomiasis patients reporting at the health over the entire period (Komogorov Smirnov one sample analysis: $p=0.22$). The intensity of infection of people reporting at the health centre, the passive detection, is plotted together with the intensity of infection as measured in the survey, the active detection (figure 37). In the survey the largest numbers of infected people fall within the group of least infected people, excreting 1-5 eggs per 10 ml urine (36% of all infected persons). In the health centre, however, this group only constitutes 7% of the reported cases. The people with heavy infections (over 100 eggs per 10 ml urine) by far make up the majority of patients at the health centre (64%), whereas heavily infected people only represent 13% of the total number of infected people in the survey. In the reported cases that were quantitatively analyzed, more heavy infections were found than in the entire lake survey, i.e. 43 out of 70 persons examined vs. 40 out of 1154 respectively. This implies that passive case detection by the existing health facilities is highly selective for heavily infected individuals.

When analyzing the data per age-class (figure 38), a similar conclusion as above can be drawn; i.e. that people who actively seek medical help are on average more heavily infected than the average infected person detected in the general survey, with an extreme 20 fold difference in the 20-24 years age-class.

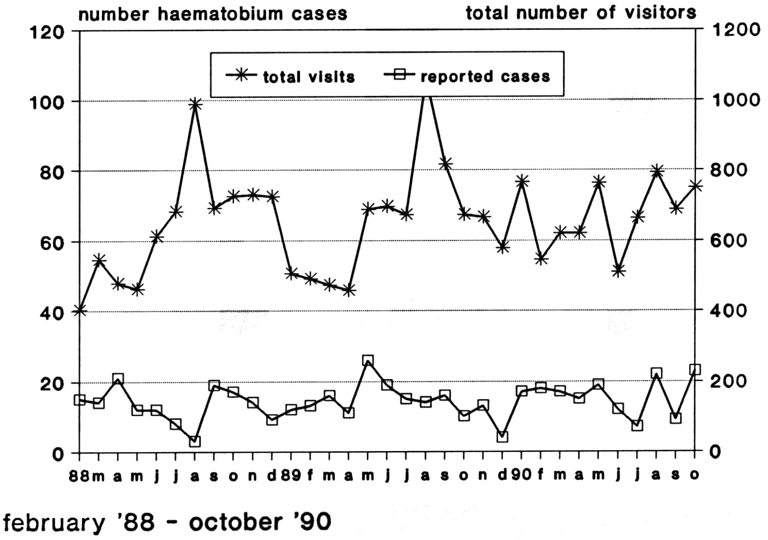

Figure 39: Total number of visitors and number of reported cases of vesical schistosomiasis in the Lagdo health centre between February 1988 and October 1990.

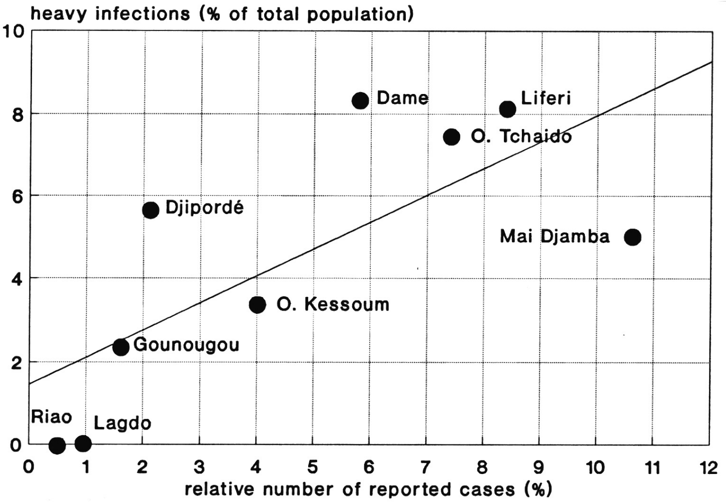

Figure 40: Relation between the relative number of reported cases per village and the prevalence of heavy infection per village.

Analyses of the health centres' records. The total number of visitors and the number of reported cases of vesical schistosomiasis at the Lagdo health centre between February 1988 and October 1990 is graphically represented in figure 39. It is not possible to recognize any seasonality in the numbers of visitors and the number of schistosomiasis cases. Over the entire 30 months period 2.2% of the total number of visitors was reported to have vesical schistosomiasis, with a monthly range between 0.3% (August '88) and 4.4% (April '88). In the rainy season the numbers of visitors is strongly influenced by weather conditions on the lake; also the availability of cash money is said to be of influence. According to the health centre's staff, people only seek medical help if they have money to buy medicines.

The number of people from a particular village reporting at the Lagdo health centre with vesical schistosomiasis, expressed as the percentage of the total number of visitors from that village, i.e. the relative number of reported cases per village, shows a significant correlation with the measured prevalence of heavy infections per village (figure 40). This implies that proportionally more people report with schistosomiasis at the health centre from villages with higher rates of heavy infections. These results corroborate with the finding that passive case detection at the health centre is selective for heavy infections, and suggest that the dispensaries' records give important information about the actual morbidity due to the parasite in the region.

Table 1: Necessary data to determine the access of patients with vesical schistosomiasis to the Lagdo health centre. The data for males and females are separated. The total number of visitors per class and the recognized number of cases are based on the health centres' records. The fractions fl and fh and the number of infected persons per class Ntot are taken from the lake-wide survey. Between brackets the calculated Nexp before scaling.

MALES age-class	total no. of males at PHC	fraction of light infections in survey (f_l)	fraction of heavy infections in survey (f_h)	number of infected males in survey (N_{tot})	no. of infected males expected at PHC (N_{exp})	no. of infected males recognized at PHC
0 - 4	262	0.77	0.23	13	30 (18.7)	36
5 - 9	106	0.89	0.11	72	104 (64.4)	97
10-14	126	0.88	0.12	25	38 (23.5)	52
15-19	88	0.86	0.14	22	37 (22.7)	32
20-24	78	1	0	4	3 (1.6)	32
25-29	67	1	0	12	8 (4.8)	20
30-34	97	1	0	8	5 (3.2)	12
35-39	69	1	0	5	3 (2)	10
40-44	58	0.8	0.2	5	11 (6.6)	7
45-49	30	1	0	2	1 (0.8)	5
50-54	25	0	0	0	0 (0)	2
55 >	32	1	0	4	3 (1.6)	4

Access to the health centre. The age-class and sex distribution of the recognized cases of vesical schistosomiasis at the health centre (table 1) is significantly different from the total numbers of visitors per class of age and sex (Komogorov Smirnov: $p=0.009$ for males and females), indicating that the cases of schistosomiasis are not randomly encountered among the visitors. The expected number of cases is calculated with the formula $N_{exp} = r_l \times f_l \times n_{tot} + r_h \times f_h \times N_{tot}$ as explained above. The ratio's r_l and r_h, derived from figure 37, are 0.4 (35% : 87%) and 4.9 (64% : 13%) for light and heavy infections respectively. These values indicate that the proportion of heavy infections at the health centre is 4.9 times that in the lake survey; the proportion of light infections is 0.4 times that in the lake survey. The fractions f_l and f_h are calculated from the survey data from the villages indicated in figure 36. To allow comparison, the resulting N_{exp} is scaled to the total number of recognized cases at the health centre.

The number of recognized cases does not differ significantly from the distribution of expected cases as calculated from the survey data ($p=0.52$ for males and females). The graphical representation in Fig. 41 shows that, although both men, women and children do visit the health centre, women are underrepresented, especially girls in the 5-9 years age-class and women between 25 and 29 years of age.

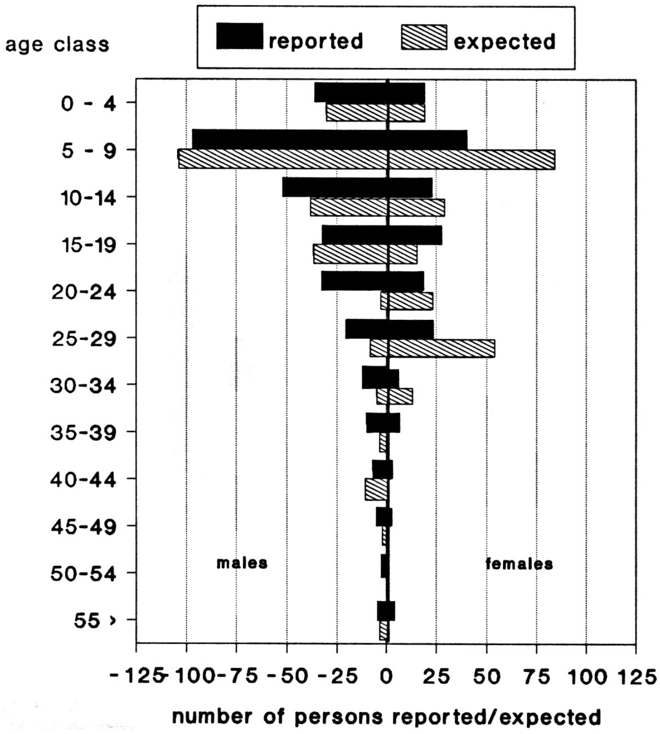

Figure 41: Numbers of recorded cases of vesical schistosomiasis at the Lagdo health centre per class of age and sexe, and the expected number of cases as derived from the survey around Lagdo lake.

Discussion and conclusions

The results of this study can be summarized in four statements:

1) Villages around the artificial reservoir of Lagdo have low to moderate infections with *S. haematobium*.
2) Passive case detection at the health centre is highly selective for heavy infections in all age-classes.
3) Severity of infection per village, represented as the prevalence of heavy infections, significantly relates to the proportion of visitors from this particular village reporting with medical complaints caused by schistosomiasis. A high number of heavy infections leads to a higher percentage of reported cases per village. Consequently, the records of a health centre can give detailed regional information on morbidity due to vesical schistosomiasis.
4) Men, women and children have access to the health centre, although men are overrepresented. Especially girls between 5 and 10 years of age have restricted access.

Several problems were encountered that interfere with the interpretation of data:
- Comparison of data retrieved from the records with demographic data was impossible because reliable demographic data were virtually absent in this area characterized by a high migration rate. Without the total number of inhabitants it is impossible to quantify the total number of heavily infected persons living in the area. It is thus difficult to see what percentage of the heavily infected population is reached by the system of passive case detection.
- Problems arose with the collection of quantitative data on intensity of infection at the health centre. Many supposed cases of schistosomiasis were treated with biltricide without laboratory verification,

and the laboratory worker failed to record negative examinations. As a result there will be false positive and unnoticed negative cases and consequently the reliability of the research data decreases.
- We assumed that schistosomiasis prevalence rates did not change dramatically in time. The surveys were performed over a six year period, while the record analyses only covers two years. In the period of study no intensive medication campaigns have been carried out.

In this paper we only try to show a possible way to assess the role of primary health care in morbidity control of schistosomiasis. In many endemic areas with low to moderate prevalence rates, morbidity control through primary health care may well be the only feasible and realistic approach. The data presented in this study showed that with relatively little effort more cases of heavy infections were found and treated at the health centre, than in the labour intensive lake-wide survey. These results give some reason for optimism concerning the effectiveness of the health centres in dealing with vesical schistosomiasis in this lightly infested region.

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References

Brinkmann UK, Werler C, Traoré M & Korte R. (1980). The costs of schistosomiasis control in a Sahelian country. *Trop Med Parasit*, **39**:175-181.

Gryseels B. (1990). The relevance of schistosomiasis for public health. *Trop Med Parasit,* **40**:134-142.

Ratard RC, Kouemeni LE, Ekani Bessala M-M, Ndamkou CN, Greer GJ, Spilsbury J & Cline BL. (1990). Human schistosomiasis in Cameroon. I. Distribution of schistosomiasis. *Am J Trop Med Hyg* , **42**:561-572.

Robert CF. (1987). Enquete sur la schistosomiase dans les populations riveraines du lac de Lagdo. Rapport intermediaire. Unité de Médecine Tropical, Geneva.

Robert CF, Bouvier S & Rougemont A. (1990). Epidemiology of schistosomiasis in the riverine population of Lagdo Lake, Northern Cameroon: mixed infection and ethnic factors. *Trop Med Parasit*, **40**:153-158.

Slootweg R. (1989). Lutte experiemntal contre la schistosomiase. Compte-rendu des activités de recherche pendant la période d'avril '88 au mois d'avril '89. *Rapports du Projet Pisciculture,* **19.** MEAVSB, Garoua, Cameroon.

Chapter 9

GENERAL DISCUSSION AND CONCLUSIONS

The chapters in this thesis all contain a section with conclusions, so it is rather unproductive to summarize these conclusions in this chapter. For that information, please refer to the summary at the end of this book. Instead, in this chapter an attempt will be made to analyse what the achievements of the research project were with respect to the expansion of scientific knowledge in general and the control of schistosomiasis in particular.

Part I: General Background

The publication in paragraph 2.1 serves a nonspecialist audience to understand the interrelation between wetland management, irrigation development and transmission of schistosomiasis. The approach of the Lagdo Fishculture Project was presented as a possible way to deal with adverse health effects of a water resources management project. This paper was written as a case study in a book on the sustainable use of tropical wetlands, aimed at persons working at the regional administrative level in wetland areas. It shows the intricate interrelationships in a wetland system and the multitude of problems that have arisen after the large-scale changes that have taken place. It is informative with respect to the general achievements of the Fishculture Project and the problems that we encountered during implementation. The description of the results of a participatory approach as applied in Gounougou gives good insight in problems that at first sight have nothing to do with the objective we deal with in this thesis, i.e. the control of schistosomiasis. Land-tenure rights, access of women to resources, relations with neighbouring villages, and last but not least the presence of a hippopotamus family, can all be seen as important obstacles to the implementation of successful measures to control snail intermediate hosts of schistosomiasis.

Part II: Descriptive research

In spite of three years of research efforts, an accurate description of the transmission dynamics of schistosomiasis in the Benue valley was still lacking in July 1991. This can be attributed to several complicating factors. The formerly sparsely populated Benue valley was flooded with immigrants in the last decade. Most of these migrants came from areas endemic to schistosomiasis. Hence, many people must have carried infections upon arrival. It is impossible to distinguish between local and imported infections, so data obtained from a schistosomiasis survey do not give reliable information on transmission in the area. Secondly, due to the recent and continuing large scale modifications in the hydrology of the valley, newly created habitats have to be colonised by populations of snail intermediate hosts. Data indicate that this colonisation and the subsequent succession of species has not reached its end yet. From the available evidence it can be deduced that in former days seasonal transmission in temporary habitats was the most important source of infection in the valley, which is reflected by high prevalence rates among school children in those villages that only possess seasonal transmission pools. Gradually, permanent transmission increases in importance because of the creation of permanent habitats in and around the irrigation scheme, as seen in Gounougou where prevalence rates are slowly increasing. Since no infected snails have been found in 36 months of sampling, it is obvious that transmission is not wide-spread. In spite of the incompleteness in the description of the transmission cycle, several new and relevant aspects are presented in the papers in part II.

Any longitudinal study on populations of snail intermediate hosts of schistosomiasis undoubtably has scientific value, as this kind of field observations is rare. The climatological and logistical conditions in West Africa do not contribute to the popularity of field research. The work is tedious and standard procedures have to be maintained under all weather conditions. This is the reason why snail sampling along the shores of lake Lagdo was not considered feasible. The sampling sites that were studied for 36 months were situated within moped- range of the laboratory facilities.

The succession of species as described for the Gounougou irrigation scheme is one of only a few longitudinal studies that confirm the succession of species in West Africa as postulated in several earlier publications. From the available evidence from other irrigation schemes, it seems probable that the succession has not reached its climax yet. This is confirmed by recent observations by Vroeg (pers. com.), who in March 1993 for the first time observed large numbers of *Biomphalaria pfeifferi* in the irrigation scheme.

As in many other studies it was difficult to find parameters that might explain the distribution of snail species. Only water temperature correlated significantly with snail densities. During prolonged periods throughout the year the water temperature exceeds the optima! temperature for three snail species. In spite of the high water temperatures, varying numbers of these snails can be found throughout the year .The distinction between different types of habitat appeared to be more effective in explaining differences in snail densities. Without exactly knowing in what parameters these habitats differ, it is possible to make a sensible distinction between three main habitat types, *i.e.* (1) large reservoirs, (2) medium- sized, semi-natural water bodies and (3) man-made, man-managed water bodies. The observation that man-made reservoirs harbour the largest numbers of intermediate hosts once again proves that schistosomiasis is, to a large extend, a man-made disease.

The construction of a species growth curve of snails collected in the field was a tricky affair. With fast growing *B. forskalii*, even intensive weekly samplings of snails could not give satisfactory results. Only a mark and recapture technique may give reliable data. The method of following size-cohorts as applied in §3.1 is a goad second choice method, if samplings are carried out more often and larger numbers of snails can be collected. It must be stressed that these field observations remain necessary in order to corroborate laboratory observations. After all, experiments in the laboratory have little resemblance with natural habitats.

B. senegalensis can easily be confused with *B. forskalii*, a species not capable of transmitting vesical schistosomiasis. The difficulty in distinguishing *B. forskalii* and *B. senegalensis* has been solved by a fruitful cooperation with Dr Mimpfoundi of the Faculty of Sciences in Yaoundé. By means of iso-enzyme detection in the Yaoundé laboratory, it was possible to prove that *B. senegalensis* is also endemic in the Soudanian zone of Cameroon. This finding can have implications for the understanding of seasonal transmission in the entire Soudanian zone. *B. forskalii* is widespread in West Africa, but since *B. senegalensis* was not known to occur South of the Sahelian zone, it might be possible that the latter species has often been overlooked in the past.

Water contact studies have often been used to explain the prevalence and intensity of infection among different groups of inhabitants. In many cases this appears to be a fruitless exercise since transmission dynamics can hardly be captured in a simple linear model of parameters derived from observations on water contacts. However, this kind of study can be helpful in differentiating various groups of people that make use of open water. By recognizing and classifying high risk activities and sites, the study in Gounougou was helpful in identifying different target groups. It became clear that these groups perform different activities and that entirely different approaches are needed to reduce the exposure to potentially infested water. The study provides tools to study the problem and develops guidelines for possible measures aimed at the reduction of health risks.

The demographic characteristics of two villages in the Benue valley that are presented in paragraph 5.1 demonstrate the complexity of an immigrant society . One village is turned into a multi-ethnic society with over 20 different ethnic groups, speaking different languages, having different religions, etc. In the neighbouring village the autochthonous Islamic Foulbé are outnumbered by a large immigrant majority belonging to a single Christian ethnic group. The daily problems arising from this mixture of peoples are plenty, ranging from pigs that belong to a Christian group entering a musulman's rice field, to the refusal by autochthones to share land with immigrants. It is remarkable that so little of the disputes between people in Gounougou and Riao get out of control, given the enormous changes which have taken place in a few years time.

The most important conclusion that can be drawn from the epidemiological data is that in the year the surveys were carried out, schistosomiasis was not a major health problem in these villages. Recent information, however, indicates that transmission of schistosomiasis in Gounougou is increasing; *S. haematobium* prevalence has increased from 21% in 1986 to 43% in January 1993 (Brussel & Contant, pers. com.).

Part III: Experimental control

The general failure of *Astatoreochromis alluaudi* in snail control will not really astonish schistosomiasis experts with field experience. Seasonal streams, seepage pools in irrigation schemes, and shallow water borders with dense stands of vegetation are notorious sites for schistosomiasis transmission. The physical characteristics of these transmission habitats are such that fish cannot control snail populations because they are hardly be able to reach these snails. In fact, fish may not even be able to survive in these surroundings. The only realistic option for biological snail control with fish that remained was fish culture, also because molluscicides are toxic to fish. The evidence given in §6.3 and §6.4 dashes ail hopes on effective control in fishculture ponds. The availability of food, a prerequisite for fish culture, seems to stimulate growth and reproduction of snails but simultaneously reduces the fish's "appetite" for snails. The resulting reduction in the pharyngeal jaw apparatus of the fish does not make the fish incapable of eating snails, but reduces the benefit obtained from eating snails.

The need for biological control efforts has often been stressed by many authors, but for a long period necessary field evidence was lacking. It is hoped that the evidence accumulated by this research and the review on the role of fish in biological snail control, win help to fin this gap. The hope to find the perfect snail predator among fish is very dim. Therefore, the review ends with a recommendation that future experiments in snail control should concentrate on the field of integrated vector control. In integrated water and habitat management efforts, fish can possibly have an additional role as a snail predator in a surrounding where snails are already under high pressure.

An important conclusion that can be drawn from this study is that fishculture inevitably increases the risk of schistosomiasis transmission. It is highly probable that snail hosts will establish themselves in fish ponds. Therefore it should be strongly discouraged to propagate communal fish ponds near village compounds in schistosomiasis endemic areas, unless these ponds can be fenced in some way or another.

As stated before, good irrigation practise is the backbone of the control of disease transmitting organisms. The design of the irrigation scheme of Gounougou illustrates the ignorance often encountered among irrigation designers. The increased health risks that were created near the village by the absence of a functional drainage system, could be prevented if the scheme had been proper I y constructed. Our alternative approach to the drainage problem showed that successful vector control can be combined with economic activities. More important, it also showed that the inhabitants of Gounougou were very interested in utilising this opportunity by establishing vegetable gardens near the reconstructed drainage canal. Unfortunately, the hippopotamus family was also very interested in these gardens which they appreciated as grazing grounds. It was impossible to divert the animals to the alternative grazing area that was created nearby. According to recent information from Cameroon, many gardens have been abandoned. The only solution to this problem is an investment in the planting of thorn trees around garden plots, which will only be possible after the village has solved its land ownership problems between autochthones and immigrants.

The relatively restricted number of people that actually develop illness due to infection puts a constraint on large scale schistosomiasis control campaigns with active case detection in areas with moderate to low prevalence rates. The cost per treated individual will be very high. .Treatment of ill people at a health care facility is the only feasible alternative to such campaigns. The Lagdo area reflects the present day situation in many rural areas of Africa, where the passive case detection at health centres is the only available instrument in disease control.

The method of evaluating the efficacy of the health care facilities that is presented in chapter 8 urgently needs to be refined. Many methodological obstacles remain which are subject of study at present. Furthermore it seems useful to invite epidemiologists into this research, to analyse health care records and to evaluate the reliability of conclusions derived from this analysis. It should be possible to develop a standardized protocol for the evaluation of health statistics with guidelines on how to deal with a schistosomiasis problem at regional level. With this approach the need for active case detection is reduced and the available resources can be focused on problem areas that have been identified by the analysis of the health statistics.

The data presented in chapter 8 indicate that a considerable number of heavily infected persons indeed visit the Lagdo health centre with complaints related to schistosomiasis. These persons receive treatment on the spot. By treating 70 persons, the total reduction in egg-output achieved by the health centre probably is larger than that achieved by the lake-wide survey in 1986 among approximately 1,000 inhabitants, and this was achieved at much lower costs. The reduction of egg-output is one of the means that can contribute to a reduction in transmission. It is an important observation that, compared to a vertically organized campaign with active case detection, the Lagdo health centre is achieving better results at lower costs, as well in treating people with high intensities of infection, as in the total reduction of egg-output.

The last question to be answered is whether all these activities have contributed to a reduction in the number of people becoming ill. Clearly, this question cannot be answered. The hydrological changes in the area are still continuing. Not all of the numerous potential snail breeding sites have been colonized by intermediate hosts yet. The activities of the fishculture project were aimed at reduction in the risk of infection in the Gounougou drainage system. The effects of such actions can only be evaluated after a prolonged period, because morbidity due to infection only develops slowly. Consequently, the effect of reduced infection will only become visible after several years. Given the large number of other potential transmission sites it is doubtful whether the effect of the reconstruction of the Gounougou drainage system will ever be visible.

Several achievements of this research project can be applied to schistosomiasis control elsewhere:

- The achievement of the experiments on biological control is, that for the first time a comprehensive study has been dedicated to lacustrine snail-eating cichlid fishes (chapter 6). The results convincingly show the failure of the use of fish in snail control, and a scientifically valid explanation for this failure is given.
- In the approach to drainage management (chapter 7) it is shown that an economic incentive can enhance the active participation of a local community in resolving a drainage problem and reducing the health risks.
- The assessment of the role of health care facilities in the control of morbidity due to schistosomiasis infection (chapter 8) points towards a new direction of research that may eventually lead to the formulation of an effective strategy for schistosomiasis control in areas with moderate to low prevalences.

It is my hope that this thesis has shown that promising directions in schistosomiasis research, applicable under field conditions in the less-developed parts of the world, are still existing. Even in areas with low standards of living and little money available, there is still some room for progress in the control of morbidity due to schistosomiasis.

SUMMARY

In the planning and construction process of hydraulic projects, such as dams and irrigation systems, health aspects are often neglected. This oversight can be dangerous because newly created freshwater habitats often serve as breeding sites for organisms that transmit parasitical diseases such as schistosomiasis and malaria. In 1982 a dam was constructed in the Benue river near Lagdo, North Cameroon. The dam was designed for the production of hydro-electricity and large scale irrigated agriculture in the former floodplains downstream from the dam. Because of the dam, yearly flooding was greatly reduced thus diminishing the traditional uses of the floodplains. Especially fish production suffered dramatic losses.

Moreover, the construction of an irrigation scheme in 1987 has increased the risk of transmission of various forms of schistosomiasis, a parasitic disease that was already present in the area. In order to compensate for the losses in fisheries production and to tackle the predictable health problems, the Cameroonian government asked The Netherlands to finance the Projet Pisciculture Lagdo (Lagdo Fishculture Project). The purpose of this project was (1) the restoration of floodplain fishery by means of water management and the introduction of fingerlings, and (2) the control of schistosomiasis in just downstream from the Lagdo dam.

This thesis describes the research and control experiments on schistosomiasis which have been performed within the framework of this project. The research has been subdivided in a descriptive section and a section that deals with the various forms of control activities. Both sections are structured according to the schistosomiasis transmission cycle. The parasite's transmission cycle has been divided in three distinct phases: (I) the snail intermediate hosts, (2) the man-water interface, and (3) the adult worm in the human body.

Descriptive research

The snail intermediate hosts of schistosomiasis: succession and population dynamics of snails. For 36 months a monthly sampling program was carried out at various sites around the village of Gounougou, in order to obtain data on the population dynamics throughout the year .In addition the succession of species in the Gounougou irrigation scheme was studied. Sampling started at the end of the first year of operation of the irrigation scheme. At several sampling sites bi-hourly temperature and oxygen measurements were taken, in order to assess the fluctuations throughout the day. In the Gounougou fishculture station weekly temperature measurements were taken at a fixed hour in order to record seasonal fluctuations. Based on these measurements, three main habitat types could be distinguished: (I) large reservoirs with constant water temperature and oxygen concentration, (2) stagnant water in semi-natural reservoirs with low oxygen contents and rapidly increasing water temperature in morning hours, and (3) man- made, man-managed reservoirs with large fluctuations in water temperature and oxygen contents during the day. In the first habitat type only occasionally populations of *Biomphalaria pfeifferi* and *Bulinus truncatus* were found. In the other two habitat types temporary as well as permanent populations of *Bulinus forskalii*, *B. truncatus*, *B. globosus*, and *Lymnaea natalensis* were found. The largest numbers of snails were found in man-managed reservoirs, i.e. in fish ponds and in the irrigation scheme.

In the irrigation scheme a succession of species was observed that is typical for this climatic zone. *B. forskalii*, a pioneering species that invaded the newly created scheme immediately after it was put into operation, was followed after two years by *B. truncatus* and *L. natalensis*. *Biom. pfeifferi* and *B. globosus* were also present in the study area but these species did not establish themselves in the irrigation scheme (yet?). In temporary pools and streams that only fill up in the rainy season, *Bulinus senegalensis* was found; this is the southernmost site where this typical Sahelian species has ever been recorded. Probably this phenomenon can be explained by the existence of the Mayo Kebi, a waterway connecting the Benue valley and the more northern Logone valley. In table 13, a summary is given of the parasites that are transmitted by the different snail species.

Two yearly peaks in snail reproduction can be recognized, coinciding with periods of lower temperatures. The cool dry season between December and February is the most important reproduction period for all species except *B. senegalensis*. In the middle of the rainy period, July/August, a second reproduction peak has been observed. This is the only period in which *B. senegalensis* is found. The numbers of *Biom. pfeifferi* were too low to be able to define reproduction seasons.

It is remarkable that during the entire sampling programme, no infected snails have been found, indicating that transmission was erratic and focal. From these data and from the epidemiological studies it can be concluded that seasonal transmission by *B. senegalensis* and *B. globosus* in streams and pools still is the main source of schistosomiasis infection. The recent establishment of populations of *B. truncatus* in the irrigation scheme gives reason to expect that transmission in the scheme will become more important in the near future. Based on experience in similar schemes elsewhere it is expected that *Biom. pfeifferi* will establish itself in the scheme. It is expected, therefore, that the prevalence of intestinal schistosomiasis will rise in due course.

Table 13: Parasites that can be transmitted by freshwater snails of the Benue valley.

Intermediate host	*Parasite*
Biomphalaria pfeifferi	*Schistosoma mansoni*; intestinal schistosomiasis
Bulinus truncatus	*S. haematobium*; vesical schistosomiasis
Bulinus globosus	idem
Bulinus senegalensis	idem
Bulinus forskalii	in this region no parasites
Lymnaea natalensis	*Fasciola* spp. ; blood flukes in cattle

The man-water interface: water contact study. The behaviour of humans in relation to water has been observed and quantified during 49 days of observation over an eight month period. With the help of scaling techniques an index has been calculated that categorizes the exposure to water for different activities and sites. Three main types of water contact can be recognized: domestic, occupational and recreational. Within these categories, several activities of high infection risk could be recognized: (I) bathing and washing of dishes and clothes, (2) working on rice fields and fishing without boat, (3) playing and swimming. The observations have led to the conclusion that the introduction of irrigated agriculture has added new infection risks to the already existing risks. It is also concluded that in the design of measures to reduce tbe infection risk, a distinction bas to be made between the different categories of activities.

Water contacts through domestic activities can be reduced by providing reliable water. The availability of relatively safe irrigation water offers a possibility to create safer washing sites. The analysis of the present water supply shows that certain village quarters have a chronic shortage of water, which forces the inhabitants to use potentially infected water bodies nearby.

Unlike domestic water contact, fishery and work on irrigated fields inevitably bring along infection risks, because people are forced to actually enter the water. Prevention of infection can only be achieved by snail control; health care facilities are essential in detecting and curing infected persons.

Recreational water contact, mainly a children’s' activity, is hard to prohibit. By regularly searching for snails, it is possible to determine which sites are safe to swim and which are not. At school, children may be instructed where to swim.

All measures described above cannot eliminate but can only reduce the risk of infection. After people become infected, the primary health care facilities play a major role in the control of morbidity due to schistosomiasis.

Man and the adult parasite: epidemiology of schistosomiasis. Riao and Gounougou, two villages situated in the study area, are characterized by large numbers of immigrants from the overpopulated Extreme Northern Province of Cameroon. The national government stimulates migration towards areas where arable land still is available. Between 1974 and 1988 the number of families in Gounougou has increased from 15 to 425, distributed over some 20 ethnic groups. In Riao the number of families has increased from 35 to 147, distributed over only two ethnic groups. The prevalence rate of vesical schistosomiasis in 1989 was 29% for Gounougou and 11% for Riao; rates for intestinal schistosomiasis were 12 % and 4% respectively. Since both forms of schistosomiasis are also endemic to the region of origin of most migrants, it is difficult to indicate what proportion of the population is infected in the Benue valley itself. It is certain, however, that transmission is taking place in the valley, because small children who never have left the village are found to be infected. The fact that Gounougou has a higher prevalence than Riao cannot entirely be attributed to the presence of an irrigation scheme near Gounougou. Among pupils of the Gounougou primary school it was observed that children with highest prevalence came from distant villages. This indicates that transmission dynamics of schistosomiasis are quite complex in the study area. In spite of this complexity it is justified, however, to conclude that schistosomiasis transmission has not explosively increased in the villages, but that there is a real danger of an increase in transmission in and around the newly created irrigation schemes.

Control

The intermediate host: biological control by means of snail eating fish. Some examples of snail control by snail eating fish have been described in the scientific literature. Usually these descriptions deal with experiments that have been performed in the margin of projects related to aquaculture or water supply. Few of these publications describe experiments that were designed explicitly to test the ability of snail-eating fish to control snails. Nevertheless, several experiments appeared to be successful, although there is no definite proof yet. The experiments in Africa always involved members of the cichlid family (Cichlidae), and particularly a snail eating cichlid from Lake Victoria, *Astatoreochromis alluaudi.*

To put an end to all speculation about the potential use of this species in snail control, an elaborate research program with laboratory and field experiments was launched. In the laboratory , observations were made on prey selection on several species of snail eating fish. The experiments revealed that the prey choice of these species could to a large extend be explained by a simple foraging model, in which the choice is determined by the yield in prey mass per unit of time invested. Different prey types can be arranged according to their yield per second handling time (the time required for searching, processing and ingestion of a prey). When offered an excess of prey the fish chose the prey-type with highest yield per second.

Among the snail eating cichlids, the best known and well described species *Astatoreochromis alluaudi* was selected for field trials in Cameroon. Before introducing the fish into the Benue valley of Cameroon, the possible risks of introducing this exotic species were assessed. No reasons against the introduction could be found. A number of fish were transported from the Leiden laboratory to the fishculture station of Gounougou in Northern Cameroon. There, fish could be reproduced and introduced into trials together with fish that were cultured for human consumption. On some occasions fish have also been used in controlled field experiments outside the fishculture station.

In order to be effective in snail control, the fish had to meet two criteria:

1. It should be possible to produce sufficient numbers of juveniles for large scale introduction of fish in natural and artificial habitats.

2. To be really effective against schistosomiasis transmission, snail populations needed to be virtually eradicated. In general it is assumed that only a few snails are already capable of maintaining a certain level of transmission.

Pond trials during several seasons have shown that the reproduction of *A. alluaudi* is low, and the numbers of juveniles are totally insufficient. Probably the adult fish only produce one or two brood per year and cannibalism may explain the disappearance of large numbers of juveniles. Even more serious is the observation that the fish did not achieve any significant reduction in the number of snails in fish ponds. Experiments in fish ponds led to the conclusion that the permanent availability of food in these production ponds enhances the growth of snail populations and reduces the fishes' interest in eating snails. Based on the earlier mentioned foraging model and with additional evidence from laboratory observations it became clear that snails were not the prey type with highest yield per second. Consequently the fish will not search for snails if more profitable food items are available. The few field experiments that were carried out in addition to the pond experiments, further corroborate the conclusion that the fish were not capable of controlling snail populations.

A third reason for the failure of *A. alluaudi* in snail control can be found in the phenotypic plasticity of the pharyngeal jaw apparatus and muscles that are used to crush snail shells. Fish raised in the fishculture station showed a reduction in the size of the jaw and the muscles that operate on the pharyngeal jaw, as compared to fish that were caught in Lake Victoria. Due to the absence of competition such as can be found in Lake Victoria, the pond-raised fish were not forced to eat snails and consequently did not develop their jaw apparatus. The result is that snails are becoming less profitable and fish will be even less inclined to eat snails.

The conclusion of these trials is that it has no use to invest much more energy in experiments with lacustrine cichlids from Lake Victoria in snail control. The reasons for the failure of *A. alluaudi* as described above will most certainly also apply to other related cichlids. In snail control more attention should be paid to an integrated approach in which habitat management can alter the living conditions for snails so that natural predators or competitors can put more pressure on snail populations. Snail eating fish species that may be useful in such an approach are *Serranochromis mellandi*, *Lepomis microlophus*, *Mylopharyngodon piceus* and *Trematocranus placodon*, possibly assisted by the herbivorous *Ctenopharyngodon idella*. Unfortunately, in most schistosomiasis endemic areas this approach will be difficult to implement because the knowledge for such an integrated approach is entirely lacking.

The man-water interface: water and habitat management. The observations of snail populations and number of contacts of humans with water revealed that the depression alongside the village of Gounougou has become a potential transmission site of schistosomiasis since the depression has been put into use as a drainage area for the irrigation scheme. The depression has turned into a permanent marsh where snails, but also mosquitoes, find a good place to breed. The area is useless for agricultural purposes because the water level is unpredictable and fully depends on the timetable used for the irrigation scheme. However, the villagers do use the water for domestic purposes. The number of water contacts further increases because people have to wade through the depression to reach their fields on the other side. In order to reduce the risk of infection and to increase the possibilities to produce fish and vegetables, the depression was reconstructed in consultation with the villagers. The entire depression bas now been canalised and a cofferdam with removable valves enables the villagers to regulate the water level in the canal. This project had several beneficial consequences:

- the marshes were reclaimed and a considerable surface of arable land became available;
- the water level can be regulated, enabling the villagers to grow vegetables in the dry season;
- by opening the valves in the cofferdam at the end of the dry season, the depression can be drained and fish can be caught;
- all these activities have resulted in a strong decline in numbers of snails;
- the frequency of water contact decreased because a bridge for pedestrians and the dam itself now allow people to cross the depression without having to wade.

The benefits derived from vegetable and fish production highly motivates the villagers to manage the depression properly, which in turn has the beneficial side- effect of reducing the risk of infection because snail populations are kept at a minimal level. It is obvious that the proper management of the depression depends on the willingness of the villagers to cooperate. For the time being, problems persist between immigrants and autochthones with respect to the allocation of land. The national government has promised that all immigrants would have the right to possess land, but the autochthones appear to be very reluctant to give up their traditional rights.

Man and parasite: morbidity control by the health centres. The ultimate goal in the control of schistosomiasis is the prevention of transmission of the parasite. It has gradually become clear that in less wealthy parts of the world this goal cannot be achieved. Therefore the goal had to be adjusted to the prevention of illness due to schistosomiasis. The drug currently available, praziquantel, not only kills the parasite but also partly heals physical damage to the intestines. Formerly it was thought that this damage was irreversible. Morbidity control can be achieved by active detection and treatment of infected persons, thus preventing the development of serious disease resulting from prolonged infection. The costs of such an approach are high. It is also possible to treat people that actually feel ill at the health centres. This approach is based on passive case detection, which entirely depends on the motivation and available financial means of the affected persons. In most areas where schistosomiasis is endemic, this primary health care approach appears to be the only feasible way to control schistosomiasis. Hardly any quantitative data exist on the effectiveness of this approach.

In this thesis a first at tempt is made to quantify the role of the existing health care facilities in controlling morbidity due to schistosomiasis. The records of health centres provided data on the number of recorded cases of schistosomiasis, and the sex, age, and village of origin of the victims. These data were compared with the results of an independent schistosomiasis survey that was carried out in the same region. Finally, the intensity of infection was determined in people that visited the health centre. This comparison revealed that the passive case detection as applied in the health centres' policy, is highly selective in discovering cases of heavy infection. This implies that people who actually feel ill are willing to let themselves be treated against the disease. Both men, women and children have access to the health facilities, although women and especially girls between 5 and 10 years of age report in smaller numbers than would be expected from the survey data. From the health centre's records it was possible to identify villages with high numbers of heavily infected people. If morbidity control is the objective in schistosomiasis control, than these preliminary results indicate that the existing health facilities play a major role in this approach. There is a high probability that using the health care facilities to combat morbidity may be an effective method in areas with low to moderate prevalence rates.

Although this new direction of research on morbidity control is promising, there are still plenty of methodological problems that need to be overcome. The presented research approach still has to be verified with data from a larger number of health centres. This is an important task for the new project team that is working in Cameroon at the moment of writing.

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RÉSUMÉ

Les aspects de santé sont souvent négligés dans la planification et la réalisation d'aménagements hydro-agricoles tels que les barrages et les périmetres d'irrigation. Des gites d ' eau douce nouveIlement créés servent souvent de sites de reproduction aux organismes qui transmettent des maladies parasitaires comme Ie paludisme et la schistosomiase. En 1982, un barrage fut construit sur Ie fleuve Bénoué, pres de Lagdo {province du Nord, Cameroun). Ce barrage est destin é a produire de l'électricité et a approvisionner en eau de nouveaux périmetres d'irrigation aménagés dans les anciens plaines d'inondation, en aval du barrage. La disparition des inondations annuelles a entrainé une baisse de 1 'utilisation traditionnelle des ces plaines. La pêche, en particulier, a enregistré d'importantes pertes. La mise en place, en 1987, d'un systeme d'irrigation a accru Ie risque de transmission de plusieurs especes de schistosomiases déja présentes dans la région. Afin de restaurer la production piscicole et pour prévenir les probIemes de santé potentiels qui avaient été identifiés au préalable, Ie gouvernement Camerounais a demandé au gouvernement Néerlandais de financer Ie Projet Pisciculture Lagdo. Ce projet vise, au moyen d'une meilleure gestion de l'eau et de l'introduction d'alevins, a (1) restaurer Ia production piscicole dans les plaines d'inondation et (2) luter contre la schistosomiase dans la zone du projet, en aval du barrage de Lagdo.

Les expériences de Iutte contre Ia schistosomiase, effectuées dans Ie cadre du projet sont présentées dans cette these. Cet ouvrage comporte deux sections, Ia premiere décrivant Ie cycle de transmission tandis que Ia deuxieme présente les différentes expériences de Iutte. Ces deux sections sont structurées selon Ie cycle de transmission du parasite, qui comporte trois phases distinctes: (1) Ie mollusque en tant qu'hôte intermédiaire, (2) Ia phase homme-eau, et (3) Ie ver adulte dans Ie corps humain.

Partie descriptive

Le mollusque hôte intermédiaire de la schistosomiase: succession et dynamisme des populations de mollusques. Un échantillonnage mensuel a été effectué autour du village de Gounougou pendant 36 mois, afin d'étudier Ie dynamisme des populations de mollusques au cours de l'année. De plus, la succession des especes a été suivie dans Ie systeme d'irrigation. L 'échantillonnage débuta a la fin de la premiere année d'opération du périmetre irrigué. La température et la teneur en oxygene de l'eau ont été mesurées toutes les deux heures sur quelques sites d'échantillonnage. Les variations saisonnieres ont été observées dans les étangs du Centre de Pisciculture de Gounougou ou des mesures hebdomadaires ont été effectuées à heure fixe. Sur la base des données ainsi obtenu, trois grands types de gites peuvent être distingués: (1) les grands réservoirs d'eau ou la température et la teneur en oxygene sont constantes, (2) les eaux stagnantes des réservoirs semi-naturels ou la teneur en oxygene est faible et la température s'éleve rapidement pendant la matinée, et (3) les réservoirs construits et gérés par l'homme qui se caractérisent par de grandes fluctuations de température et de teneur en oxygene pendant la journée. Des population incidentelIes de *Biomphalaria pfeifferi* et de *Bulinus truncatus* ont été trouvés dans le premier type de gites. Des populations temporaires et permanentes de *Bulinus forskalii*, *B. truncatus, B. globosus* et *Lymnaea natalensis* ont été observées dans les deux autres types de gites. Le nombre de mollusques Ie plus élevé a été enregistré dans les gites géré par l'homme, c'est-á-dire dans les étangs de pisciculture et Ie systeme d'irrigation.

Dans Ie systeme d'irrigation, la succession des especes est typique de cette zone climatique. L' espece pionniere, *B. forskalii*, envahit les nouveaux périmetres irrigués jusqu'apres leur mise en service. Ell fut suivie, deux ans plus tard, par *B. truncatus* et *L. natalensis*. *Biom. pfeifferi* et *B. globosus* sont présents dans la zone d'étude maïs ne se sont pas (encore?) établis dans le systeme d'irrigation. *Bulinus senegalensis* a été observé dans les cours d'eau et les flaques d'eau temporaïres qui se remplissent seulement pendant la saïson des pluies; la zone du projet constitue la région la plus méridionale dans laquelle cette espece Sahélienne a été rencontrée. Ce phénomene s'explique probablement par l'existence au Nord d'une communication entre la vallée de la Bénoué et la vallée du Logone: le fleuve Mayo Kebi. Le tableau 12 indique les parasites transmis par les mollusques de la vallée de la Bénoué.

Aucun mollusque infecté par des schistosomes n'a pu être trouvé pendant toute la période d'échantillonnage, ce qui constitue un fait remarquable. A partir de ces donnés et des études épidémiologiques, on peut conclure que la transmission saisonniere par *B. senegalensis* et *B. globosus* demeure la source d'infection la plus importante. Néanmoins, l'établissement de *B. truncatus* dans Ie systeme d'irrigation est inquiétant et il faut s'attendre, dans un proche avenir, a une transmission plus importante dans les systemes d'irrigation. Sur la base d'expériences effectuées dans des systemes comparables, il est aussi à prévoir que *Biom. pfeifferi* s'établira dans le systeme de Gounougou; en conséquence, la prévalence de la schistosomiase intestinale augmentera.

Tableau 1: Parasites transmis par les mollusques d'eau douce dans la vallée de la Bénoué.

Hote intermédiaire	***Parasite***
Biomphalaria pfeifferi	*Schistosoma mansoni* (schistosomiase intestinale)
Bulinus truncatus	*S. haematobium* (schistosomiase vésicale)
Bulinus globosus	Idem
Bulinus senegalensis	Idem
Bulinus forskalii	dans cette région pas de parasites
Lymnaea natalensis	*Fasciola* spp. (grande douve du bétail)

La phase homme-eau: I'étude des contacts homme-eau. Le comportement humain par rapport a l'eau a été observé et quantifié pendant 49 jours repartis sur une période de 8 mois. Un index d'exposition a l'eau a été calculé pour les différentes activités et les différents sites selon des méthodes de calcul adaptées. Trois grandes catégories de contacts homme-eau ont été identifiées: (1) les contacts liées aux activités domestiques, (2) les contacts liées aux activités professionnelles, et (3) les contacts liées aux loisirs. A I'intérieur de ces catégories des activités a haute risque ont été identifiées: (1) Ia baignade/toilette, le lavage de la vaisselle et la lessive, (2) Ie travaïl dans les rizieres et la pêche sans pirogue, et (3) la nage et les jeux. Les observations montrent que l'introduction de l'agriculture irriguée s'est traduite par une augmentation du risque d'infection maïs qu'il existe aussi d'autres sources d'infection. Il était aussi évident qu'une distinction doit être faite entre les différents catégories d'activités lors d'élaboration de mesures prophylactiques.

Il est possible de réduire le nombre de contacts liées aux activités domestiques par l'adduction d'eau non-contaminée. La présence d'une source d'eau assez fiable, c'-est-à-dire l'eau d'irrigation, donne la possibilité de créer des lavoirs offrant peu de dangers. Une analyse de la disponibilité d'eau dans Ie village de Gounougou montre que certains quartiers souffrent d'un manque d'eau permanent, ce qui force les gens a utiliser les réservoirs potentiellement infectés a coté du village.

Contrairement au contacts liées aux activités domestiques, la pêche et le travail dans les rizieres comporte inévitablement un risque d'infection puisque les gens sont obligés d'entrer dans I'eau. La prévention de l'infection peut se faire seulement par l'éradication des mollusques; le service de santé est essentiel en matiere de détection et de traitement des individus infectés.

Les cantacts liées aux loisirs, il s'agit ici natamment d'enfants, sont tres difficiles à interdire. L'échantillannage régulier dans les lieux de baignade permet d'identifier les sites dépourvus de danger, c'est-à-dire de mollusques. Les endroits ou la baignade est autorisée peuvent être indiqués aux jeunes par le biais de l'école.

Les mesures décrites ci-dessus visent seulement à réduire le risque d'infection. Le service de santé primaire joue le róle principale dans le contróle de la morbidité causée par la schistosomiase dès lors que les gens sont infectés.

L'homme et le parasite adulte: épidémiologie de la schistosomiase. Riao et Gounougou, deux villages dans la zone du projet, se caractérisent par un grand nombre d'immigrés provenant de la province de l'Extrême Nord. Le gouvernement national encourage cette migration vers les zones ou des terres cultivables sont encore dispooibles. Entre 1974 et 1988 la population de Gounougou est passée de 15 a 425 familles, réparties en plus de 20 ethoies. A Riao le nombre de familles est passé de 35 a 147, reparties en seulement deux ethnies. En 1989, la prévalence de la schistosomiase vésicale était de 29% a Gounougou et 11 % a Riao; la prévalence de la schistosomiase intestinale était de 12% et 4% respectivement. Ces deux formes de schistosomiase étant aussi endémiques dans la zone de provenance des immigrés, il est difficile d'indiquer quelle partie de la population a été infectée dans la vallée de la Bénoué même. Il est néanmoins certain que la transmission a lieu dans la vallée puisque l'infection a été observée chez des petits enfants qui n'ont jamais quitté leur village. Le fait que Gounougou ait une prévalence plus élevée que Riao ne peut pas être attribué entierement a la présence d'un périmetre irrigué a Gounougou. Parmi les éleves de l'école primaire de Gounougou, l'intensité d'infection la plus élevée, est observé chez des enfants provenant des villages éloignés. Le dynamisme de transmission de la schistosomiase dans la zone d'étude est donc tres complexe. Malgré cette complexité, il est justifié de conclure que la schistosomiase n'a pas augmenté de maniere explosive dans les villages, mais qu'il y a un véritable risque d'intensitication de transmission autour des périmetres irrigués.

Lutte expérimental

L'hote intermédiaire: lutte biologique contre les mollusques au moyen de poissons malacophages. Les publications scientifiques donnent quelques exemples de lutte hiologique grâce à l'utilisation de poissons malacophages. En général, ces descriptions concernent des expériences réa!isées en marge de projets d ' aquaculture ou d'approvisionnement en eau. Seules quelques unes de ces expériences ont été effectuées dans le but explicite de tester les poissons en matiere de lutte contre les mollusques. Néanmoins, quelques expériences semblaient être des réussites, bien que la preuve définitive n'ait pas été fourni. Toutes les especes de poissons utilisées dans les expériences effectuées en Afrique, appartenaient a la famille des Cichlidae, en particulier une espece malacophage du Lac Victoria: *Astatoreochromis alluaudi*.

Afin de mettre fin à toutes les spéculations sur l'utilisation potentielle de cette espece dans la lutte contre les mollusques, un vaste programme de recherches a été mis en place avec des expériences en laboratoire et sur le terrain. En laboratoire, des observations ont été faites sur le choix des proies par différentes especes de poissons. Ces observations ont relevé que ce choix pouvait être expliqué en grande partie par une modele simple. Ce modele prédit le choix sur Ie base du quantité de nourriture ingurgitée par unité de temps. Les différents types de proies peuvent être classifiés en fonction de leur rendement par seconde de traitement (c'est-à-dire le temps nécessaire pour chercher, manipuler et consommer la proie). Dans une situation d 'abondance, les poissons choisissent la proie qui fournit le rendement le plus élevé.

Parmi les cichlides malacophages, l'espece la plus connue, *Astatoreochromis alluaudi*, a été choisie pour des essais sur le terrain au Cameroun. Avant d'introduire les poissons dans la vallée de la Bénoué, les risques potentiels liées à l'introduction d'une espece exotique ont été évalués. Cette évaluation n'a pas donné d'avis négatif sur l'introduction. Une quantité de poissons a été transportée du laboratoire de Leyde au centre de pisciculture a Gounougou. Les poissons purent se reproduire au centre de pisciculture et être introduits dans les étangs expérimentaux avec des poissons destinés à la consommation. Dans quelques cas, les poissons ont été introduits dans des sites expérimentaux sur le terrain, hors du centre de pisciculture.

Afin d'être un moyen efficace de lutte contre les mollusques, le poisson sélectionné devait satisfaire a deux criteres:

(1) La production des alevins doit être suffisante afin de permettre une introduction a grande échelle dans les gites naturels ou artificiels.

(2) Pour réduire la transmission de la schistosomiase, les populations de mollusques doivent être pratiquement éliminées. On suppose généralement que quelques individus sont en mesure de maintenir la transmission.

Les essais réalisés dans les étangs ont montré que la reproduction d' *Astatoreochromis alluaudi* est faible et que le nombre d'alevins est insuffisant. Cette espece ne compte qu'un seul frai par an et le cannibalisme peut probablement expliquer la disparition d'un grand nombre d'alevins. Il a de plus été constaté que les poissons ne sont pas du tout en mesure de réduire les populations de mollusques, ce qui est plus grave. Les résultats des essais en étang nous amènent a conclure que la présence permanente de nourriture stimule la croissance des populations de mollusques et réduit en même temps la disposition des poissons a se nourrir de mollusques. Sur la base du modele de choix de proies (voir ci-avant), et les preuves supplémentaires apportées par des observations faites au laboratoire, il est clair que les mollusques ne constituent pas la proie fouroissant de plus haut rendement. Pour cette raison, les mollusques ne constituent pas la proie préférée; par conséquent, les poissons se détoument des mollusques lorsque d'autres types de nourriture pl:us rentables sont dispooibles. Les quelques essais réalisés sur Ie terrain ont démontrés, eux aussi, que les poissons ne sont pas en mesure de réduire la taille des populations de mollusques.

Une troisième cause de l'échec des poissons est liée à la plasticité phénotypique de leurs mâchoires pharyngales et les muscles qui y sont rattachés, c- est-à dire l'ensemble constituant l'appareil qui permet au poisson de casser les coquilles des mollusques. L 'analyse des poissons produits par le centre de pisciculture montre que ces animaux ont des mâchoires et des muscles plus petits que ceux des poissons du Lac Victoria. La compétition entre les différents especes de poisson étant moins forte que dans le Lac Victoria, les poissons du centre de pisciculture à Gounougou ne sont pas obligés de se nourrir de mollusques; en conséquence, leurs mâchoires ne se développent pas. Ce phénomene rend les mollosques encore moins "rentable" et les poissons sont encore moins inclinés a inclure les mollusques dans leur menu.

En résumant, on peut conclure qu'il est inutile de poursuivre les travaux de recherche sur la lutte biologique contre les mollusques avec les cichlides lacustres du Lac Victoria. Les raisons données ci-avant pour expliquer l'échec d' *Astatoreochromis alluaudi*, sont surement aussi valable pour les cichlides apparent és a cette espece. La démarche la plus digne d'attention en matiere de lutte contre les mollusques est la démarche intégrée. Selon cette démarche, la modification des gites rendent les conditions de vie des mollusques plus difficiles et leurs ennemis naturels sont mieux en mesure d'exercer une pression soutenu sur les populations de mollusques. Dans le cadre d'une telle démarche, les poissons malacophages suivants méritent une plus grande attention: *Serranachramis mellandi*, *Lepomis microlophus, Mylopharyngodon piceus*, et *Trematocranus placodon*. Ces poissons pourraient éventuellement être complétés par une espece herbivore telle que *Ctenopharyngodon idella*. Malheureusement, il est souvent difficile de suivre une telle démarche parce que dans la majorité des régions ou la schistosomiase est endémique, les connaissances pertinentes a une telle démarche sont inexistantes.

La phase homme-eau: gestion de l'eau et modification des gîtes. Les études décrivant les populations de mollusques et les observations relatives a l'utilisation de l'eau ont montré que, depuis qu'elle est utilisée comme drain principal du périmètre irrigué, la dépression longeant le village de Gounougou est devenue un site potentiel de transmission de la schistosomiase. Cette dépression a été transformée en zone marécageuse ou les mollusques et les moustiques peuvent se reproduire. La zone est devenue inutile pour l'agriculture parce-que le niveau d'eau dans la dépression étant dépendant de la gestion du périmètre irrigué, ses fluctuations sont imprévisibles et cette zone est inutilisable a des fins agricoles. Cependant, la population utilise l'eau, en grandes quantités, pour des activités domestiques. En outre, les agriculteurs sont obligés de traverser le marais pour atteindre leurs champs situés de l'autre coté de la dépression. Afin de diminuer les risques de transmission et d'accroitre la production maraichere et la production piscicole, la dépression a été modifiée en consultation avec la population locale et avec sa coopération. La dépression a été canalisée et munie d'une vanne. Cette intervention a eu les effets favorables suivants:

- le marais a été drainé et une superficie considérable de terre cultivable est maintenant disponible;
- les cultivateurs peuvent régulariser le niveau de l'eau dans le canal, ce qui permet la culture maraichère pendant la saison sèche;
- l'ouverture de la vanne à la fin de la saison seche donne la possibilité de pêcher tous les poissons présents dans cette zone;
- l'ensemble des interventions a abouti à une forte réduction du nombre de mollusques;
- la possibilité de traverser la dépression grace a un pont piétonnier et a la vanne a fortement diminué les contacts homme-eau.

Les bénéfices provenant de la culture maraichere et de la production piscicole stimulent la population a mieux gérer la dépression. Ceci a pour effet favorable de maintenir les risques de transmission a un niveau bas en raison de Ia lutte contre les populations de mollusques. II est devenu clair, cependant, qu'une gestion efficace de la dépression requiert une coopération étroite entre les villageois. Actuellement les probiemes entre autochtones et immigrants concernant la répartition des parcelles autour du canal dans la dépression constituent une entrave a une telle coopération. Le gouvernement Camerounais a promis des parcelles aux immigrants, mais les autochtones sont réticents en ce qui concerne l'abandon de leurs droits traditionnels.

L'homme et le parasite adulte: lutte contre la morbidité par service de santé. L' objectif final de la lutte contre la schistosomiase est la prévention de la transmission. Au cours des années, il est devenu clair que dans les régions les moins riches du monde, il est impossible d'atteindre cet objectif; l'option la plus réaliste est donc la prévention de la morbidité causée par le parasite. Le médicament disponible, Praziquantel, est efficace dans la lutte contre le parasite. De plus, ce médicament annule les dommages physiques autrefois considérés comme irréversibles. On peut lutter contre la morbidité grace a un dépistage actif de toutes les personnes infectées qui sont traitées sur place. La morbidité causé par une infection de longue durée peut être prévenue en grande partie de cette manière, mais le cout d'une telle prévention est élevé. On peut aussi traiter les malades dans les centres de santé locaux. Ce dépistage passif dépend entierement de la motivation et des moyens financiers des patients. Dans la pratique, cette méthode de lutte contre la schistosomiase est la seule méthode faisable dans la plupart des régions endémiques, bienqu'il n'existe presque pas d'informations sur son efficacité.

Cette these constitue un premier effort en matière de quantification du role joué par le service de santé existant dans la lutte contre la morbidité causé par la schistosomiase. Les registres des centres de santé fournissent des informations sur l'age, le sexe et le village de provenance des personnes atteintes de schistosomiase. Ces données furent comparées avec celles fournies par une enquête dans la région. De plus, l'intensité de l'infection fut déterminée pour tous les cas de schistosomiase enregistrés au centre de santé. Ces données montrent que le dépistage passif, qui résulte de la politique des centres de santé, est tres sélectif pour les infections graves. Ceci indique que les gens qui se sentent malade du fait de l'infection, cherchent effectivement a se faire traiter. Les hommes, les femmes et les enfants ont acces au service de santé, bien que les femmes, et en particulier les filles entre 5 et 10 ans, se rendent moins au dispensaires qu'il n'avait été prévu en tenant compte de la prévalence mesurée dans le cadre de l'enquête. Les registres des dispensaires permirent aussi d'identifier les villages ou la prévalence des cas graves est grande. Si l'on considere la lutte contre la morbidité comme l'objectif principal, les données provisoires présentées dans cette these montrent que le service de santé existant joue un role important dans les efforts visant a atteindre cet objectif. Cette approche peut s'avérer suffisante en matiere de lutte contre la morbidité dans les zones de ou la prévalence est faible ou moyenne.

Pour l'instant, des probiemes méthodoiogiques jouent un roie principal dans cette recherche. L 'approche proposée ci-avant devra être mise a l'épreuve en faisant usage de données provenant d'autres centres de santé. Ceci constitue une tâche importante pour l'équipe travaillant actuellement au Cameroun.

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