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.

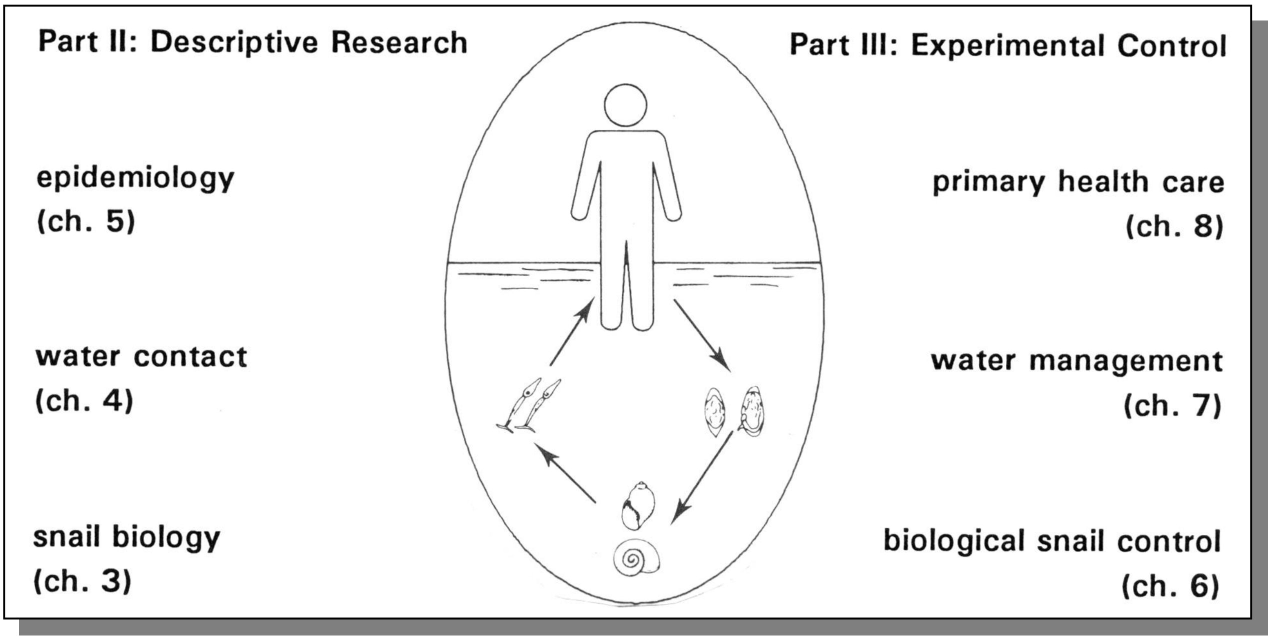

Fig. 1: The contents of this thesis in relation to the transmission cycle of schistosomiasis.

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.