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Schistosomiasis in Lake Malaŵi and the Potential Use of Indigenous Fish for Biological Control

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1. Introduction

Schistosomiasis is a parasitic disease of major public health importance in many countries in Africa, Asia, and South America, with an estimated 200 million people infected worldwide (World Health Organization, 2002). The disease is caused by trematodes of the genus *Schistosoma* that require specific freshwater snail species to complete their life cycles (Fig. 1). People contract schistosomiasis when they come in contact with water containing the infective larval stage (cercariae) of the trematode.

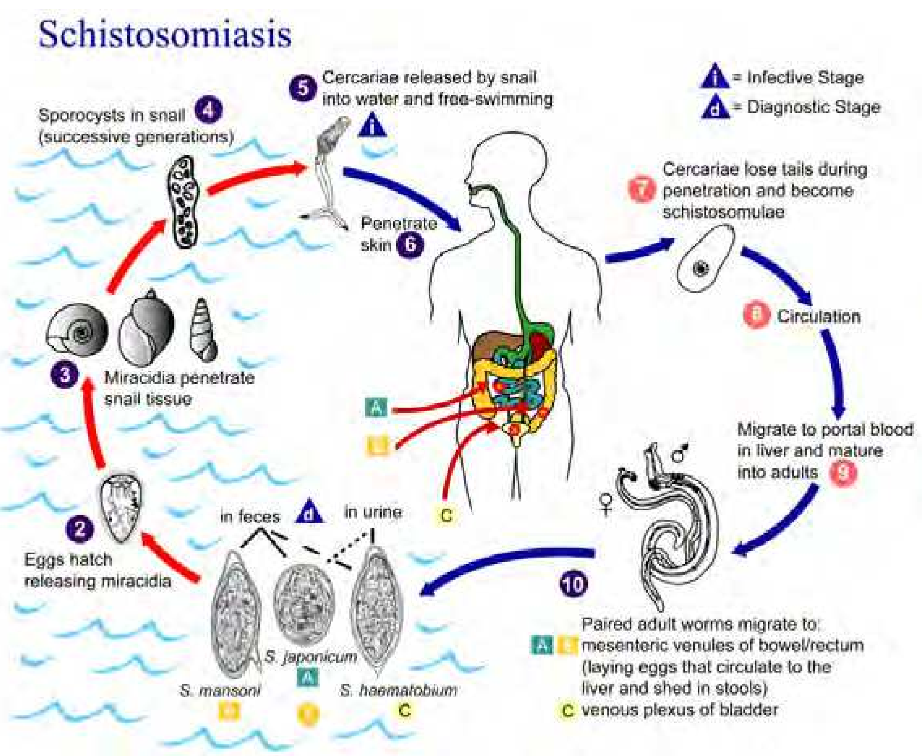

Fig. 1. Life cycle of schistosomes (Source: CDC/Alexander J. da Silva, PhD/Melanie Moser)

Schistosome transmission, *Schistosoma haematobium*, is a major public health concern in the Cape Maclear area of Lake Malaŵi (Fig. 2), because the disease poses a great problem for local people and reduces revenue from tourism. Until the mid-1980's, the open shores of Lake Malaŵi were considered free from human schistosomes (Evans, 1975; Stauffer et al., 1997); thus, only within relatively protected areas of the lake or tributaries would transmission take place. These areas were suitable habitat of intermediate host snail, *Bulinus globosus*. During mid-1980's, reports indicated that transmission also occurred along open shorelines. It is now evident that in the southern part of the lake, especially Cape Maclear on Nankumba Peninsula, transmission occurs along exposed shorelines with sandy sediment devoid of aquatic plants via another intermediate host, *Bulinus nyassanus* (Madsen et al., 2001, 2004). This species is endemic to Lake Malaŵi and is a diploid (2n=36) member of the *tropicus/truncatus* group of *Bulinus* where also the most important hosts of *S. haematobium* in North Africa belong, i.e., *B. truncatus* (4n=72). The changes in transmission pattern could be related in part to over-fishing which clearly has resulted in decline in density of several cichlid fish species (Stauffer et al., 1997), some of which are important predators of snails or a new strain of *Schistosoma haematobium* capable of exploiting *B. nyassanus* as host. Another diploid species of this group, *Bulinus succinoides* has not been shown to be a host. Stauffer et al. (1997) suggested that a lake-wide strategy for controlling schistosome intermediate hosts using fishes should be initiated to reduce the prevalence of this disease. Preliminary studies indicated that the facultative molluscivore and popular food fish, *Trematocranus placodon*, is effective at controlling schistosome intermediate host snails in fishponds (Chiotha et al., 1991a, b).

Although all types of fishing are prohibited within a 100-m zone along the shoreline within Lake Malaŵi National Park, this clearly is not respected. Seine-net fishing from the shoreline is often observed and gill-nets are often found within this sanctuary zone (pers. obs.). Beach seining, however, is the most damaging form of fishing, since nets are often very fine meshed (sometimes lined with mosquito nets) and since the near-shore zone of the lake is where juvenile fishes reside; thus, recruitment of fish populations is seriously affected. It is evident that densities of some cichlid species, including molluscivorous species, have declined markedly in shallow waters compared to densities during the early 1980s (Stauffer et al., 2006). Here we summarize the results of a six year study of the interactions among fish abundance, snail intermediate hosts for *Schistosoma haematobium*, and prevalence of human infections.

2. Study area

Lake Malaŵi (Fig. 2), the most southerly lake in the East African Rift Valley system, is over 600 km long (Beadle, 1974) and is 75 km wide at its widest point; its total surface area is approximately 29,600 km². As such, it is the third largest lake in the world by volume and the ninth largest by surface area. The lake is bordered by western Mozambique, eastern Malaŵi, and Tanzania. Its largest tributary is the Ruhuhu River and its outlet is the Shire River, a tributary of the Zambezi. The largest part of the lake is in Malaŵi, while about a quarter of the lake area is under the jurisdiction of Mozambique; this includes the area surrounding the Malaŵian islands of Likoma and Chizumulu, which are the lake's only two inhabited islands. It is bordered by Malaŵi, Mozambique, and Tanzania. It is also the second deepest lake in Africa. The lake harbors more fish species than any other lake on Earth.

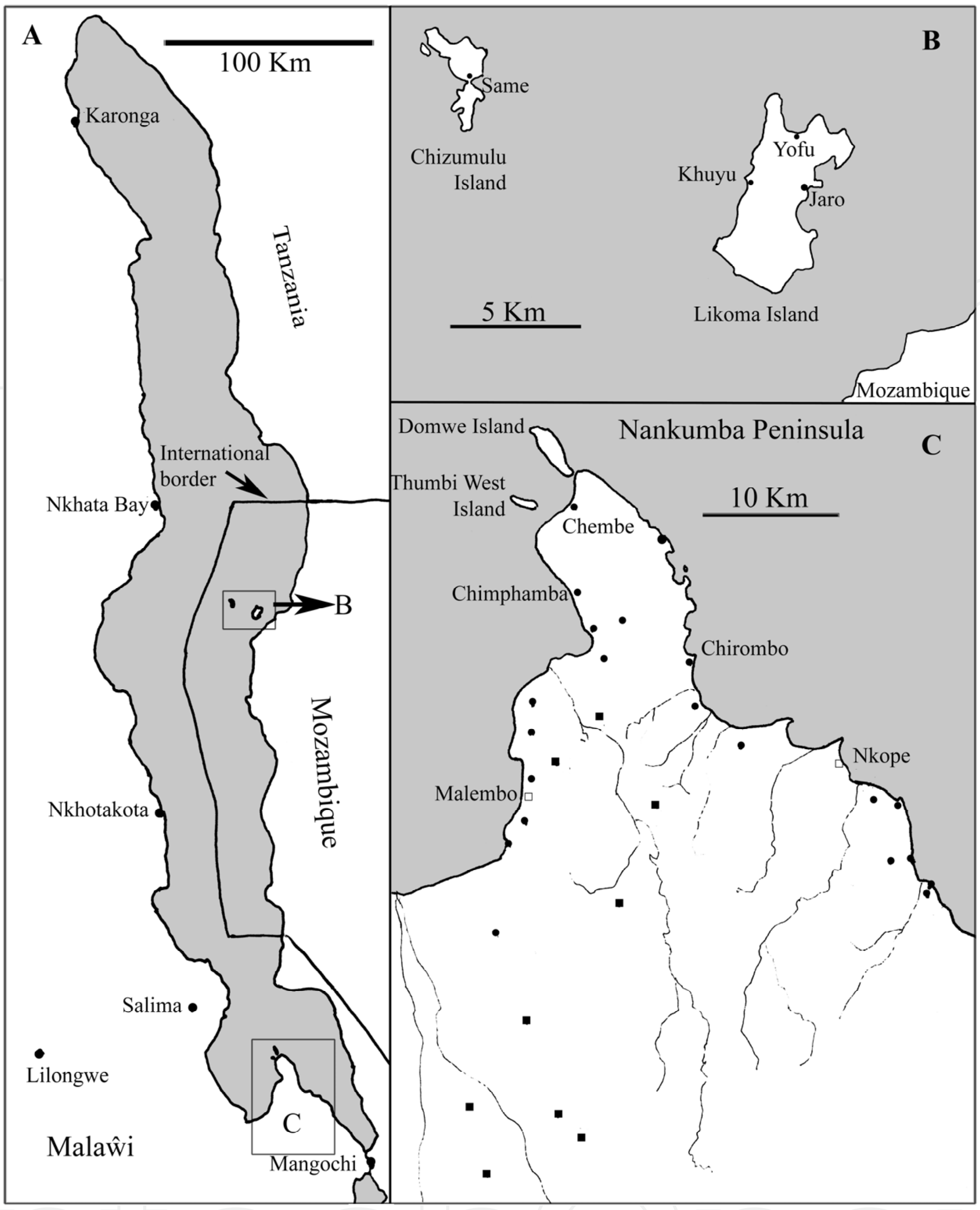

Fig. 2. Lake Malaŵi and some of our sampling sites (Source: Madsen et al. in press).

The climate is generally tropical with a rainy season from November to April. There is little to no rainfall throughout much of the country from May to October. It is hot and humid from September to April along the lake, with average daytime maxima of 27- 29°C. From June through August, the daytime maxima are around 23°C. During the cold months the prevailing wind is southerly.

Fishes from Lake Malaŵi are the major food source to the residents of Malaŵi. The Malaŵians prefer chambo, which consists of any one of four species of the cichlid genus *Oreochromis*, as well as the kampango, a large catfish (*Bagrus meridionalis*).

The water in Lake Malaŵi is typically alkaline with a pH of 7.7-8.6, a carbonate hardness of 107-142 mg l^{-1} and a conductivity of 210-285 μS cm-1. The lake water is generally warm, having a surface temperature that ranges from 24-29°C and a deep level temperature of 22°C.

Lake Malaŵi National Park, a World Heritage site since 1984 and the World's first freshwater underwater park, is located on and around the Nankumba Peninsula. The park includes some islands, the separate Mwenya Hills, Nkhudzi Hills and Nkhudzi Point at the eastern base of the peninsula, and an aquatic zone extending 100 m offshore of all these areas. Its aim is to protect portions of Lake Malaŵi's aquatic communities so the steep hills immediately behind the shoreline are protected to prevent eroded sediments polluting the lake. A managed fishing zone is designated just offshore incorporating some islands within the park, but trawling is prohibited. Other fishing methods such as gill netting, long line, and trapping are prohibited within the 100m aquatic zone of the reserve.

Much of the lakeshore is heavily populated. Five shoreline villages, Chembe, Chimphamba, Mvunguti, Zambo and Chidzale, are included within enclaves in the park. As the soil of the peninsula is poor and crops fail about 50% of the time, local people are dependent on fishing for a livelihood. Some 40,000 people make a living directly from the lake in offshore fisheries, providing most of the country's animal protein intake.

2.1 Study sites

In the following we will refer to specific villages and these are briefly described below. On Nankumba Peninsula, detailed studies were done in 4 villages, i.e. Chembe, Chimphamba, Mvunguti, and Chirombo Bay.

Chembe is a fishing village with a population of roughly 8,000-10,000. Chembe (Fig. 3) is located on an open bay on the northern part of the Monkey Bay peninsula. It is well protected from the strong winds which blow in the southern and eastern sections of Lake

Fig. 3. Sampling sites in Chembe Village area. Green labeled symbols show transect sampling sites and red numbered symbols scooping sites. Red circles show inland sampling sites.

Malaŵi. People live primarily along an approximately 3000 m stretch of shoreline to a distance of about 250-300 m from the shore. The shoreline is facing northwest and the inland area is rather low and traversed by a number of streams and rivers, which are potential habitats for *Bulinus globosus*, an intermediate host for the urinary schistosome, *Schistosoma haematobium*. In the upland areas, some agricultural activities take place.

Chimphamba, with a population of about 2000 people, is located along an approximately 1.2 km shoreline facing southwest. The village area is surrounded by mountains and a few short streams cross the village area. To the south, there is a valley with one major in-flowing stream. The lake bottom outside the village is heavily polluted with various debris.

Mvunguti is located along an approximately 400 m sandy shoreline facing north and the village area extending up to about 300 m from the shore is surrounded by mountains. At each end of the village a small stream flows through the village area. Both streams are habitats for *B. globosus*. The lake bottom slopes steeply.

Chirombo Bay is located along an approximately 1700 m stretch of sandy shoreline facing east. Most people live along the southernmost 1000 m of this shoreline. The upland is flat and the lake bottom slopes gently, so the maximum depth sampled within 200 m from the shoreline was 4.5 m. Population density is not high. The upland areas contain a number of streams that can harbor *B. globosus*.

Kasankha is located along an approximately 1800 m stretch of sandy shoreline facing northwest. Houses are primarily found less than 400 m from the shoreline. The bottom slope is relatively gentle and the shoreline well protected. Close to the southern end of the beach, a river flows into the lake forming a swampy area, which is habitat for *B. globosus*. At the northern end of the beach, a small seasonal stream joins the lake. Crocodile and hippopotamuses are often seen in the bay and therefore this site was excluded from regular sampling. *Bulinus nyassanus* is abundant in the lake at this site.

Matola village is located along an open shoreline with gentle slope and the maximum depth that could be sampled within 200 m from shore was 4.5 m. *Bulinus nyassanus* was often found at high densities in relatively shallow water, but inland sites were not checked at this location. Also, *B. succinoides* was generally abundant in *Vallisneria* beds.

Finally, a number of sites were sampled along the Malaŵian shoreline in the northern part of the lake and most of these sites had relatively exposed sandy shorelines and generally density of *B. nyassanus* was low. Often inland sites, however, are important habitats for *B. globosus*. Some of these sites were close to the shore and kept flooded from wave action in the lake. Two sites were selected on the islands, i.e. Same Bay on Chizumulu Island and Yofu on Likoma Island. Same Bay is a protected bay with a stretch of sandy beach and a large area with very shallow water with stones and/or grass. Within this area, rice is cultivated and the area contains a dense population of *B. globosus*. The lake outside the sandy beach harbors *B. nyassanus* at relatively low density. Yofu is located along a sandy beach which is quite exposed to wave action.

Along the Tanzanian coast the lake bottom slopes very steeply at most sites and is therefore unsuitable for *Bulinus* snails. Only at Liuli did we find *B. nyassanus*. In one pool next to the lake, we found *Biomphalaria pfeifferi* infected with *Schistosoma mansoni*.

3. Schistosomiasis in people at Lake Malaŵi

Malaŵi is one of the countries where both urinary and intestinal schistosomiasis is endemic (Teesdale et al. 1986); around the lake, however, the urinary form caused by *S. haematobium* is dominant. Although schistosomiasis has been a major public health problem for many years in many lakeshore communities of Lake Malaŵi, there is evidence that transmission has increased in certain areas within the last 20 years (Stauffer et al. 2006). In addition to causing a major health problem for local people, the disease also affects an important source of income for the country, namely tourism. The area around Cape Maclear is a World Heritage Site and is visited by many tourists every year. Unfortunately, many visitors become infected with schistosomes and some health organizations such the United States Centers for Disease Control and Prevention (CDC) warn against visiting Lake Malaŵi (Centers for Disease Control, 2005).

On Nankumba Peninsula, in the southern part of the lake overall prevalence of *S. haematobium* infection in 1998/1999 ranged from 10.2% to 26.4% in inland villages and from 21.0% to 72.7% in lakeshore villages; for school children prevalence of infection ranged from 15.3% to 57.1% in inland schools and from 56.2% to 94.0% in lakeshore schools (see Madsen et al., in press). Inhabitants on the islands, Chizumulu and Likoma, also had lower prevalence of infection than those living in lakeshore villages on Nankumba Peninsula. This increased prevalence in lake shore villages is not necessarily linked to transmission taking place in the lake itself, but could also be due to the presence of more numerous typical transmission (back waters and inland sites such as streams, ponds) being close to the lake. Re-infection after treatment of school children in some villages, Chembe and Chimphamba) on Nankumba Peninsula is as high as 40% using parasitological examination, but using more sensitive serological tests reinfection rates are considerably higher (70%)(Madsen et al., in press).

3.1 Schistosome transmission

Two snail species are involved in transmission on the Nankumba Peninsula, i.e. *B. globosus* and *B. nyassanus*. *Bulinus globosus* (Morelet, 1866) is found in most of the sub-Saharan Africa in various freshwater habitats including streams, rivers, seasonal pools, and lakes (Brown, 1994; Mandahl-Barth, 1972; Cantrell, 1981; Madsen et al., 1987; Ndifon & Ukoli, 1989). *Bulinus nyassanus* (Smith, 1877) is a member of the *B. truncatus/tropicus* group and is endemic to Lake Malaŵi; it is found on open sandy areas and has a preference for habitats devoid of vegetation and with substratum consisting of coarse and, to a smaller extent, fine sand, where it is normally found in the upper 2-3 cm of the substratum (Wright et al., 1967; Phiri et al., 2001; Madsen et al., 2004). Its status as intermediate host was not recognized prior to these studies (Madsen et al., 2001) and an alternative explanation for the changed transmission pattern was that another strain of *S. haematobium,* capable of using *B. nyassanus* as host, had been introduced on Nankumba Peninsula. Molecular data, however, do not suggest existence of two *S. haematobium* strains and *S. haematobium* from Likoma Island can infect *B. nyassanus* from Nankumba (Stauffer et al., 2008).

Transmission in the lake takes place both in back waters and in the lake proper and also in further inland habitats. Transmission in inland sites and back waters is through *B. globosus* and starts towards the end of the rainy season or early dry season in March/April and continues until sites dry; which could be as early as June/ July or 1-2 months later (Madsen et al., in press). A few sites may, however, persist for longer but *B. globosus* populations often disappear before sites dry. Usually several of such sites exist in village areas at the lake shore and these clearly contribute to the higher infection levels in lake shore communities. Many of these inland water bodies (Fig. 4) are actually streams that after rains become isolated from the lake (Madsen et al., 2004). Inland transmission can be found throughout the lake's upland. Especially, in the northern part of the lake such sites may be kept under water due to wave action. Some of the inland sites may support *Biomphalaria pfeifferi* and *S. mansoni* transmission (Fig. 5).

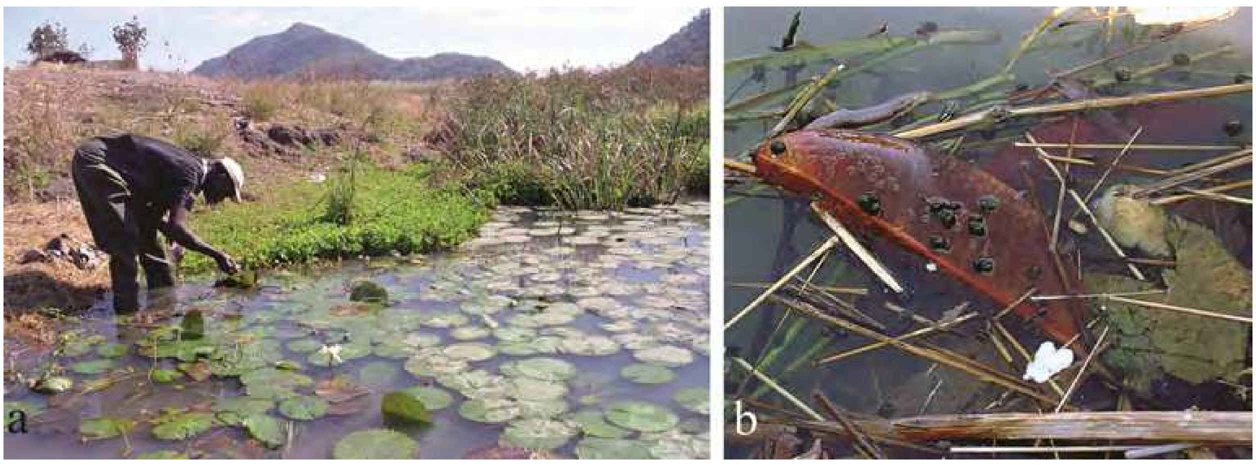

Fig. 4. Typical inland transmission site (a) with high density of *Bulinus globosus* (b).

Fig. 5. A "stream" site (a) along the foothill harbouring *Biomphalaria pfeifferi* that shed cercariae of *Schistosoma mansoni* (b).

Transmission in the lake can be either by *B. globosus* along protected shorelines often with aquatic vegetation or presence of boulders in the water (Fig. 6) and/or through *B. nyassanus* along open sandy shorelines (Fig. 7) on the Nankumba peninsula (Madsen et al., 2004).
Transmission by *B. globosus* within the lake or backwaters may commence towards the end of the rainy season or shortly after and may continue through October/November which is much longer than transmission in sites further inland (Madsen et al., in press). Transmission through *B. nyassanus* will start May/July when populations increase in shallow water and persist into November/December depending on weather conditions, i.e. storms coming

Fig. 6. Protected harbour site at Same Bay with transmission through *Bulinus globosus.*

Fig. 7. Open beach at Chembe (a) where transmission of *Schistosoma haematobium* occurs with *Bulinus nyassanus* as intermediate host. This is the shoreline where many tourists (b) get infected.

from a northerly direction which can cause high mortality in *B. nyassanus* populations (Madsen et al., in press). *Schistosoma haematobium* transmission through *B. nyassanus* is limited to sites where snail occurs in shallow water close to shore. Infected *B. nyassanus* have been found only on Nankumba Peninsula. Density of *B. nyassanus* is generally higher in the southern part, especially in shallow water, of the Lake (Nankumba and Matola) than in the northern part. Density of *B. nyassanus* is partly governed by sediment composition (Genner & Michel, 2003; Madsen & Stauffer, in press) and further there is a negative association between density of *B. nyassanus* and density of *T. placodon* (Madsen & Stauffer, in press).

4. Snail fauna

Lake Malaŵi has an impressive snail fauna (Fig. 8), though the snail fauna is less diverse than Lake Tanganyika's (Brown, 1994). For many years, the molluscs of Lake Malaŵi continued to be known almost entirely from empty shells (Crowley et al., 1964). Later, collections of living specimens allowed substantial revision (Mandahl-Barth, 1972, Wright et al., 1967). A total of 28 gastropod species is recognized to live within the lake and on the swampy parts of its shores (Brown, 1994) of which 16 are endemic. Amongst these are the medically important species.

The prosobranch gastropods are dominated by *Melanoides* spp. (Oliver, 1804). Their shell is medium to large (max shell height 27 mm), slender and dextral. It is the most abundant snail genus in Lake Malaŵi and distinction between species is an ongoing debate (Eldblom & Kristensen, 2003; Sørensen et al., 2005). *Gabbiella stanleyi* (Smith, 1877) is a small (max size: 5.3 mm) snail with a thick-walled dextral shell and is endemic to Lake Malaŵi (Brown, 1994). Four species of *Lanistes* (Montfort, 1810) are found in Lake Malaŵi; they have a sinistral shell with a max height of 75 mm. *Lanistes nyassanus* (Dohrn, 1865) and *L. solidus* (Smith, 1877) are both endemic to Lake Malaŵi and found in shallow water and most common on sand among weedbeds (Louda et al., 1984; Brown, 1994). Several species *Bellamya* are known from Lake Malaŵi.

4.1 *Bulinus globosus*

Bulinus globosus (Morelet, 1866) belongs to the *Bulinus africanus* group and reaches a maximum of 22.5 mm in shell height (Brown, 1994). The globose shell has a blunted spire. *Bulinus globosus* is found in sub-Saharan Africa in various freshwater habitats including streams, rivers, seasonal pools, and lakes (Mandahl-Barth, 1972; Cantrell, 1981, Madsen et al., 1987, Ndifon & Ukoli, 1989). The snail lives in shallow water, where it may occur on bare substrata, but is more common among aquatic plants (Thomas & Tait, 1984). *Bulinus globosus* may be flushed into Lake Malaŵi during the rainy season, when lagoons and ponds adjacent to the lake overflow or are captured by the rising lake (Phiri et al., 2001). *Bulinus globosus* has been reported at several sites in Lake Malaŵi, especially in sheltered corners and near inflowing streams (Fryer, 1959; Madsen et al., 2004).

Bulinus globosus is the most widespread and probably the most important intermediate host for *Schistosoma haematobium* in Tropical Africa (Brown, 1994) and was until recently the only confirmed intermediate host for *Schistosoma haematobium* in Malaŵi (Teesdale et al., 1986, Brown, 1994, Msukwa & Ribbink, 1997). Stauffer et al. (1997) and Msukwa & Ribbink (1997) suggested that other *Bulinus* species, apart from *Bulinus globosus*, may also act as intermediate host for *S. haematobium*.

4.2 *Bulinus nyassanus*

Bulinus nyassanus (Smith, 1877) is a member of the *B. truncatus/tropicus* group and has a more thick-walled shell with a more pointed apex (barely projecting above the last whorl) compared to *B. globosus*. The maximum shell height of *B. nyassanus* is 13.6 mm (Brown, 1994). *Bulinus nyassanus* is endemic to Lake Malaŵi and is found on open sandy areas and has a preference for habitats devoid of vegetation and with substratum consisting of coarse and, to a smaller extent, fine sand, where it is normally found in the upper 2-3 cm of the substratum (Wright et al., 1967; Louda et al., 1983; Phiri et al., 2001; Madsen et al., 2004). *Bulinus succinoides* (Smith, 1877) is in the same group as *B. nyassanus* but smaller (maximum size: 6 mm), more slender, and with a thinner shell living upon *Vallisneria* plants (Wright et al., 1967; Brown 1994).

Fig. 8. Snail shells from Lake Malaŵi.

4.3 *Biomphalaria pfeifferi*

This genus comprises most of the larger planorbid snails in Africa and with a few exceptions these are of medical importance as intermediate hosts of *Schistosoma mansoni* (Danish Bilharziasis Laboratory, 1977). Eleven species are known from Africa and four of these are found in South-east Africa. The shell is discoid of medium size up 12-15 mm in diameter. Both in size and shell shape *Biomphalaria pfeifferi* (Fig. 9) is very variable and many local forms have been described as distinct species, but it is impossible to regard them even as subspecies. It is common throughout tropical Africa and the most important intermediate host of *S. mansoni*. In South-east Africa it is widely distributed, but rare or absent in the coastal area and in the great lakes.

Fig. 9. *Biompalaria pfeifferi*

5. Fish and fishing in Lake Malaŵi

Lake Malaŵi harbors the most diverse ichthyofauna of any freshwater lake in the world, with as many as 850 species occurring (Konings, 2001). Lake Malaŵi cichlids exhibit spectacular diversity in trophic morphology, including specialist algal scrapers, planktivores, insectivores, piscivores, paedophages, snail crushers, and fin biters (Stauffer et al., 1995).

The rich fauna of this lake is primarily attributable to the explosive adaptive radiation and speciation of the haplochromine cichlids (Regan, 1922; Trewavas, 1935; Greenwood, 1979). As early as 1893, the diversity of the fishes inhabiting Lake Malaŵi was recognized by Günther (Eccles &Trewavas, 1989). Regan's (1922) revision of the fishes of Lake Malaŵi encouraged several collecting expeditions, which provided the material for Trewavas' (1935) classic synopsis of the fauna. The cichlids of Lake Malaŵi are characterized, in part, by both their inter- and intra-lake endemicity. The status of many of the groups described as genera, however, remain questionable as precise locality information is lacking for 32 of the 38 type species used to define these genera. In some cases, the validity of the type species of the genus is questioned. For example, the type species of *Ctenopharynx* is *Ctenopharynx intermedius* (Günther), and the type collection of *C. intermedius* consists only of the holotype, which is a relaxed skin with broken fins (Eccles & Trewavas, 1989). Surveys have been undertaken of the cichlids in Lake Malaŵi (Ribbink et al., 1983; Lewis et al., 1986; Konings, 1990; Turner 1996), and, although these surveys resulted in new facts and speculation of the different forms, they did not result in comprehensive and formal descriptions of new taxa. The rapid speciation within these fishes has resulted in a paucity of characters needed to distinguish among taxa. This dearth of information about unique characters is at odds with the need to be able to delimit species for the conservation and utilization of these fishes for food, tourism, disease control, and scientific investigations. Certainly, there is an inherent obligation for all the species in a World Heritage Site, such as Lake Malaŵi, to be documented and recognized.

5.1 Diversity of Lake Malaŵi cichlids

Cichlids are one of the most speciose families of vertebrates, with conservative estimates quoting more than 2000 extant species. Although native to tropical areas of the world, with the exception of Australia, some 70-80% of cichlids are found in Africa, with the greatest diversity found in the Great Lakes (lakes Victoria, Tanganyika, and Malaŵi). Their highly integrated pharyngeal jaw apparatus permits cichlids to transport and process food; thus enabling the mandibular jaws to develop specializations for acquiring a variety of food items. This distinct feature has allowed cichlids to achieve great trophic diversity, which in turn has lead to great species diversity.

By far, the greatest radiation of cichlids is found in the Great Lakes of Africa, with Lake Malaŵi alone having as many as 850 species. The phylogenetic diversity ranges from the single invasion of Lake Malaŵi, which resulted in the endemism of all but a few species, to multiple invasions in Lake Tanganyika, which resulted in the presence of 12 different tribes. The rich fauna of these lakes is primarily attributable to the explosive adaptive radiation and speciation of the pseudocrenilabrine cichlids. The driving mechanism for these speciation events is unknown. The two most widely proposed methods are allopatric speciation and intrinsic isolating mechanisms. Furthermore, biologists generally agree that female mate choice can act as a strong driving force in runaway speciation where the average female preference for a specific male trait differs between two allopatric populations. Thus, behavioral traits are important tools for the diagnosis of these African cichlids, primarily because behavioral traits played a very important role in and facilitated the rapid radiation of these fishes, which may not always be accompanied by discernable morphological changes. The importance of behavioral traits in delimiting the many species of Lake Malaŵi cichlids necessitates the use of SCUBA gear to document and record unique behaviors of the species being studied. In many cases, unique species can only be discerned by recording their different behaviors.

The driving mechanisms for the speciation events that led to the explosive radiation of the haplochromine cichlids in Lake Malaŵi is undiscovered; the two most widely proposed methods are allopatric speciation (Fryer & Iles, 1972) and intrinsic isolating mechanisms. Several authors (Lande, 1981, West-Eberhard, 1983) proposed that rapid divergence of mate recognition via sexual selection could promote behavioral isolation and facilitate speciation. Runaway sexual selection has been proposed to partially explain rapid radiation of these fishes and Deutsch (1997) provided evidence that sexual selection may be associated with the color diversification of the Lake Malaŵi rock-dwelling cichlids.

5.2 Fisheries in Lake Malaŵi

The traditional fishing methods on Lake Malaŵi consisted of traps and beach seines operated from dugout canoes and small plank boats (Cohen et al., 1996). Fishing was originally artisanal using small craft, open water seines (chirimila), and gillnets. The fisheries consisted of *Oreochromis* spp. (chambo), the catfishes especially *Bagrus meridionalis*, the small pelagic cyprinid *Engraulicypris sardella* and small zooplanktivorous cichlid species (utaka). *Labeo mesops* was the most important riverine fishery and was originally second only to the chambo fishery. Ringnets were introduced in 1943, initially for catching *Oreochromis* species, and later to catch small pelagic species such as *E. sardella* (usipa) and small, zooplanktivorous haplochromine cichlids (utaka) (Ogutu-Ohwayo et al., 1997). The cyprinid *L. mesops* which was the most important riverine species was, as in the case of the Lake Victoria *L. victorianus* (Ogutu-Ohwayo, 1990), depleted due to intensive gillnetting of gravid individuals on breeding migrations (Cohen et al., 1996).

The first fishery survey of Lake Malaŵi showed that the main commercial fisheries were supported by cichlid tilapia caught in shore seines and open water ringnets. Since then however, tilapia abundances have declined and the species of endemic tilapia are now so scarce that the main commercial fishery (Maldeco, which works in association for the Malaŵi fisheries department) has resorted to breeding tilapia in fish farm ponds to stock large enclosures fixed in open waters in the south east arm of the lake (Lowe-McConnell, 2009). Here they rear endemic tilapia *Oreochromis shiranus* (Lowe-McConnell, 2009).

Research into environmental conditions affecting fish production in Lake Malaŵi has included, for example, the work by Duponchelle et al. (2005) on food partitioning within the species-rich benthic fish community. Using a combination of stable isotopes and stomach analysis, they found that, although benthic algal production contributed to the energy requirement of offshore fishes living in water 10-30 m deep, the larvae of the abundant lake fly *Chaoborus edulis* were the most important food source for demersal fishes; thus supporting the hypothesis that demersal fish production in Lake Malaŵi is sustained mainly through the pelagic food chain, rather than from benthic detritus.

Systematic overfishing of fresh waters is largely unrecognized because of weak reporting and because fishery declines take place within a complex of other pressures (Allan et al., 2005). Indeed, one of the symptoms of intense fishing in inland waters is the collapse of particular stocks even as overall fish production rises--a biodiversity crisis more than a fisheries crisis (Allan et al., 2005).

The annual trawl catch for the entire lake has fluctuated between 1000 and 3000 tonnes over the last 40 years. The small-scale fisheries exploit an estimated 110 species, with 25 species comprising 80% of the total catch by weight (FAO, 1993; Turner, 1995; Turner et al., 1995; Weyl et al., 2005). There is, however cause for caution as surveys in southern Lake Malaŵi have shown considerable overlap between artisanal and trawl fisheries (Weyl et al., 2005) and there is evidence that the artisanal gill net fishery is now operating at depths greater than 50 m (Weyl et al., 2005).

In addition, degradation of the spawning grounds due to excessive siltation following deforestation and de-vegetation of the catchment area may have affected *L. mesops* (Cohen et al., 1996). An industrial trawl fishery which was introduced on Lake Malaŵi during the 1970's to harvest small cichlids (Turner, 1977), accelerated the decline in stocks of certain species in the lake. The size and the number of cichlid species caught was reduced by 20% in some parts of the lake.

5.3 Molluscivores

Several molluscivorous fish species exist in Lake Malaŵi and of these, *Trematocranus placodon* (Regan, 1922) is the most abundant and widely distributed (Fig. 10) and it has been considered the potentially most active biological control agent for schistosomiasis (Chiota et

Fig. 10. *Trematocranus placodon* (Photo by Dr. Adrianus Konings).

al., 1991a,b; Msukwa & Ribbink, 1997). Since then, experiments have been conducted to understand its foraging behavior and impact on snail distribution in natural and semi-natural environments (Chiota et al., 1991a; Msukwa & Ribbink, 1997). *Trematocranus placodon* has earlier been described as *Haplochromis placodon*, *Cyrtocara placodon* and *Lethrinops placodon* (Regan, 1922;Fryer & Iles, 1972; Axelrod & Burgess 1979; Slootweg, 1994). *Trematocranus placodon* is placed in the endemic “Hap” species flock, compared to the endemic Malaŵian rock fishes or the “mbuna” flock (Fryer & Iles, 1972). The cichlid is widespread throughout the lake (Axelrod & Burgess, 1979) and it has three black spots on a silvery body and reaches a maximum total length of 23 cm (Konings, 2001). It is common in shallow waters on sandy bottoms where it forages mainly on gastropods. It exhibits sexual dimorphism during the breeding season from July to September, where the ripe male assumes a blue color, probably caused by hormones causing the chromatophores to expand (Fryer & Iles, 1972; Konings, 2001). *Trematocranus placodon* has a very well developed pharyngeal jaw apparatus including upper and lower pharyngeal bones and ingested snails are moved to the pharynx where they are crushed (Fryer & Iles, 1972). During the breeding season, the males are territorial, constructing bowers, which function as spawning sites. The females are mouth brooding (Konings, 2001). *Trematocranus placodon* possibly forage in groups, relying on group members to locate food (Chiota et al., 1991a); it feeds on benthic insects, detritus and fish scales before reaching maturity (at about 10 cm) where it almost exclusively feed on bivalves and gastropods (Msukwa & Ribbink, 1997). *Trematocranus placodon* locates snails in the sediment by their movements. When *T. placodon* detects a movement in the sediment via its enlarged pores on its chin, it attacks.
The molluscivorus fishes are particularly vulnerable to the artesian fishing gear when they are spawning or in shallow areas. We attribute the observed decrease in density of *Trematocranus placodon*, which is one of the most widespread snail-eating fish species, from

1980 to 2003 to overfishing and the increased use of fine-meshed beach seines that collect juvenile fishes. During the 1970s and early 1980s most fishing activity took place in offshore waters. As these fishing stocks became depleted, fishermen moved inshore with illegal fine-meshed nets. As these fishing pressures built, people started using beach seines and the fish in water less than 7 m were removed. The peak abundance of *T. placodon* then shifted to deeper waters where they were not susceptible to beach seines. We therefore concluded that we must encourage people from Chembe Village to consider a fish ban during certain times of the year in an effort to restore *T. placodon* to it former population levels in the shallow waters of Lake Malaŵi.

Trematocranus placodon feeds in preference on *B. nyassanus* although *Melanoides* species dominate in its stomach content. The proportion of large (>4 mm) *B. nyassanus* of all *B. nyassanus* consumed increased with fish size (Evers *et al.* 2006). *Bulinus nyassanus* seems to constitute a more profitable prey than *Melanoides* when evaluated on the basis of organic material gained relative to effort invested in shell crushing (Evers *et al.*, 2011).

Our data suggest a negative relationship between density of *T. placodon* and density of *B. nyassanus*, and of *Melanoides* spp., while there is a positive relationship between densities of the two snail species (Madsen & Stauffer, in press). Both snail species are the major elements in the diet of *T. placodon* and *B. nyassanus* appears to be the preferred species (Evers et al., 2006) especially during times of this snail's highest abundance in the field (Madsen et al., 2010).

6. Controlling *B. nyassanus* through protection of fishes at village areas

From the data, it is likely that prior to the mid 1980's, density of *B nyassanus* was kept low due to predation by *T. placodon*, i.e. biological control at work. Whether the changed distribution pattern of *T. placodon* is entirely the result of overfishing should be evaluated by following changes in fish and snail distribution after implementation of a fish-ban. Changes in fish populations may occur rapidly; when fish population density is high, beach-seining is attractive to the local people but after a period of intense beach seining fish population density will drop to levels where beach seining is no longer attractive. Subsequently, when beach seining is reduced fish populations will recover.

Because of the observed trend, we are optimistic about reversing the situation through an effective fish ban in village areas. Whether this would be sufficient to also reduce schistosome transmission remains to be seen. The intermediate host, *B. nyassanus*, undergoes marked seasonal variation in density in the very shallow water (i.e. water depth less than about 1.5 m) close to the shore. Each year in December-January, *B. nyassanus* is virtually eliminated from these depths at Chembe Village and possibly other shore lines with a northerly exposure owing to wave action. During this period, *B. nyassanus* populations, however, persist in deeper water, where the density fluctuations are much less pronounced than in the shallows. Populations of *B. nyassanus* in the shallow water will then increase again close to the shore as the prevailing wind direction shifts from a northerly to a southerly direction. At present, snails in the very shallow water close to the shore appear not to be vulnerable to predation from *T. placodon*, but if *T. placodon* could return to forage in shallow water through implementation of a fish ban, as in 1978 (Stauffer et al., 1997), the annual increase of *B. nyassanus* in shallow water might be prevented, because it must be recruited from snails living in slightly deeper waters. Certainly, this was the situation in the late 1970s, when the open waters of Lake Malaŵi were regarded as schistosome free.

It is interesting that also for *Melanoides* density there is a significant inverse relationship with density of *T. placodon*. Evers et al. (2006) showed that although *T. placodon* preferentially feeds on *B. nyassanus*, the major component in its stomach content is actually *Melanoides* due to its dominance in the snail fauna (94%-96% as opposed to the 3-5% for *B. nyassanus*). Evers et al. (2006) also showed that the maximum size (shell height) of *Melanoides* consumed by *T. placodon* of up to 230 mm (standard length) was about 15 mm. Larger *T. placodon* probably would be able to handle slightly larger snails, but it is likely that the largest *Melanoides* specimens are not susceptible to predation by *T. placodon*. Another interesting observation is that density of *B. nyassanus* is positively related to density of *Melanoides*, contrary to the prediction of Genner et al. (2004).

The only realistic possibility for reducing density of *B. nyassanus* and thereby hopefully *S. haematobium* transmission is to protect populations of *T. placodon* in the near-shore areas of the lake. Although the use of fish for biological control of freshwater snails has failed in some areas (Slootweg et al. 1994, Slootweg 1995), this should not happen in the case of *T. placodon* in Lake Malaŵi, because nothing really changes i.e. the food availability for the fishes does not change and due to interactions with other fish species that are also protected we would expect its feeding repertoire to remain unaltered. Attempts should be made through government extension workers to introduce a community enforced shallow water fishing ban. We assisted in forming a committee at Chembe that should be promoting such a fish-ban by educating community members on the need for practicing sustainable use of fish resources. The committee engaged local leaders, villagers as well as fishermen on the need for implementing a community enforced fish ban in the period during which fish should be allowed to breed. Initially the committee worked well but at the end of the project, there was evidence that it was no longer effective. Thus, there has been no estimation of fish population density after implementation of the fish ban.

7. Controlling *B. globosus* in back waters and inland sites

Even if *T. placodon* can control *B. nyassanus* and transmission along open shorelines, *S. haematobium* transmission will persist in inland habitats and other measures will have to be implemented in those areas. Many villages have several inland sites where *B. globosus* can exist – e.g., often streams that during the dry season turn into a series of ponds. Several of the inland sites may contain water through the dry season almost until the following rainy season, while many others just contain water for a few months into the dry season. Beach seining probably constitutes an important source of protein for local people and, if banned, many people may not afford to purchase fish from fishermen who catch outside the fish ban zone. We therefore think that, possibilities of utilizing these inland sites for aquaculture should be explored. Although aquaculture have well documented positive effects (e.g., improved nutrition, better food security, better job opportunities and financial benefits), there are also concerns that such activities may lead to increased transmission of various water related diseases because installations (canals and ponds) often function as excellent habitats for intermediate hosts of trematodes (notably schistosomes and liver flukes). Furthermore, cultured species should be from the local watershed due to the high risk of escape to the lake. Fish ponds would probably be organically loaded and this might favor proliferation of the intermediate host snails, i.e. *Bulinus globosus* and possibly *Biomphalaria pfeifferi*. Aquaculture using polyculture including molluscivore species might not control the intermediate host snails although Chiotha et al. (1991a, b) have demonstrated that a mix culture that included *T. placodon* significantly reduced intermediate hosts. Experience from Cameroon and elsewhere was not promising because soft food items might be abundant in inland waters and molluscivores might shift to such food items and this can lead to reduction in the crushing mill reduing their ability to crush snails. Slootweg et al. (1993) even warns against aquaculture in schistosomiasis endemic areas. It may be necessary to control access to the fish ponds such that they do not become transmission sites even if they sustain dense populations of intermediate host snails.

8. Conclusion

Fishes from Lake Malaŵi comprise most of the animal protein consumed by Malaŵians, thus fishing pressure on inshore fishes is intense. We attribute the observed decrease in density of *T. placodon* from 1980 to 2003 in the shallow waters to overfishing and the increased use of seine-meshed beach seines. It is obvious that the peak abundance of *T. placodon* has shifted to deeper waters when compared to observations in earlier years (Stauffer et al., 1997; Stauffer et al., 2006). Furthermore, as density of snail-eating fishes decreased the density of the intermediate host, *B. nyassanus*, increased.

There is no doubt, that *B. nyassanus* is a major player in the transmission of urinary schistosomes in Lake Malaŵi. In those areas where both *B. globosus* and *B. nyassanus* are intermediate hosts, the prevalence of infection in school-aged children is 2-3 times higher than where only *B. globosus* is a host (Stauffer et al., 2006; Stauffer et al. 2008). Relative to *B. nyassanus*, we found: (1) *Schistosoma haematobium* transmission through *B. nyassanus* is limited to sites where it occurs in shallow water close to shore; (2) Infected *B. nyassanus* have been found only on Nankumba Peninsula; (3) Density of *B. nyassanus* is generally higher in the southern part of the Lake (Nankumba and Matola) than in the northern part; and (4) Density of *B. nyassanus* is partly governed by sediment composition, i.e. particularly a high content of the clay fraction is a negative predictor.

Based on the above, we initially postulated that a different strain of *S. haematobium* was introduced into Lake Malaŵi that was preadapted to infect *B. nyassanus*. *Bulinus nyassanus* is a diploid member of the *Bulinus truncatus/tropicus* group. Most members of this group that are intermediate hosts are tetraploid, thus it was surprising that *B. nyassanus* was a player in transmission of urinary schistosomes in Lake Malaŵi. Stauffer et al. (2008) reported that the schistosomes found in *B. globosus* and *B. nyassanus* could not be genetically differentiated. Furthermore, they demonstrated that miracidia shed from children that originated from *B. globosus* could infect *B. nyassanus*. Thus, Stauffer et al. (2008) suggested that *S. haematobium* in Lake Malaŵi always had the potential to infect both *B. globosus* and *B. nyassanus*.

Finally, we concluded that if reductions in prevalence of schistosome infections in people are achieved through chemotherapy campaigns, we will need to protect native fish populations in near shore areas of the lake. The question is whether an effective prevention of fishing within a 100 m zone from the shore will restore fish populations and will this lead to reduced density of *B. nyassanus*, especially in the shallow waters. We have shown that a fish ban can be established and implemented, but it will require continued support from extension workers in the village. In order to reduce fishing pressure in the lake, we should consider creating alternative sources of fish protein and thereby reduce dependence on the natural fish populations.

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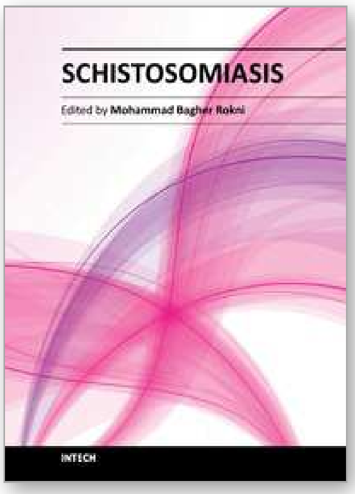

Schistosomiasis
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In the wake of the invitation by InTech, this book was written by a number of prominent researchers in the field. It is set to present a compendium of all necessary and up-to-date data to all who are interested. Schistosomiasis or blood fluke disease, also known as Bilharziasis, is a parasitic disease caused by helminths from a genus of trematodes entitled Schistosoma. It is a snail-borne trematode infection. The disease is among the Neglected Tropical Diseases, catalogued by the Global Plan to combat Neglected Tropical Diseases, 2008-2015 and is considered by the World Health Organization (WHO) to be the second most socioeconomically devastating parasitic disease, next to malaria. WHO demonstrates that schistosomiasis affects at least 200 million people worldwide, more than 700 million people live in endemic areas, and more than 200.000 deaths are reported annually. It leads to the loss of about 4.5 million disability-adjusted life years (DALYs).

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