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Forum

Introgression in Lake Malaŵi: Increasing the Threat of Human Urogenital Schistosomiasis?

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Abstract: For the last 15 years, we have studied the relationships among cichlid snail-eating fishes, intermediate snail-host density, and the prevalence of human infection of *Schistosoma haematobium* in Lake Malaŵi and concluded that the increase of human infection is correlated with the decrease in snail-eating fishes in the shallow waters of the lake. We postulated that a strain of *S. haematobium* from other parts of Africa, which was introduced into the Cape Maclear region of Lake Malaŵi by tourists, was compatible with *Bulinus nyassanus*—which is a close relative of *B. truncatus*, and interbred with the indigenous strain of *S. haematobium*, which ultimately produced via introgression a strain that can use both *B. globosus* and *B. nyassanus* as intermediate hosts. This actively evolving situation involving intermediate snail–host switching and decline of *Trematocranus placodon*, a natural cichlid snail predator, will impact on transmission of urogenital schistosomiasis within the local communities and on tourists who visit Lake Malaŵi.

Keywords: schistosomiasis, integradation, intermediate hosts

Schistosomiasis is a parasitic disease of major public health importance throughout Africa, Asia, and South America. Although five species of schistosomes are recognized as human metazoan parasites, only *Schistosoma haematobium* (Bilharz) is implicated in human urogenital schistosomiasis (Rollinson 2009). The infection of snails by *S. haematobium* can be summarized as follows: (a) strains most closely adapted to *Bulinus truncatus*, a tetraploid member of the *B. truncates/tropicus* species complex; (b) strains most closely adapted to members of the *B. africanus*, of which *B. globosus* (Morelet) from Lake Malaŵi is a member; and c) strains most closely adapted to the *B. forskalii* species group (summarized in Stauffer et al. 2008).

In Malaŵi, the overall prevalence of urinogenital schistosomiasis infection (all age classes combined) ranged from 10.2 to 26.4% in inland villages and from 21.0 to 72.7% in lake shore villages, with higher prevalence being observed in school aged children (Madsen et al. 2011). For the last 15 years, we have studied the relationships among cichlid snail-eating fishes, intermediate snail–host density, and the prevalence of human infection of *S. haematobium* in Lake Malaŵi (Fig. 1) (Stauffer et al. 1997a, b, 2006; Madsen et al. 2011; Madsen and Stauffer 2011). The widespread occurrence of urogenital schistosomiasis in the Lake Malaŵi catchment basin has been documented for more than 80 years (Dye 1924). Historically, transmission of urogenital schistosomiasis was limited to swamps and protected backwaters in the Lake, where the snail host,

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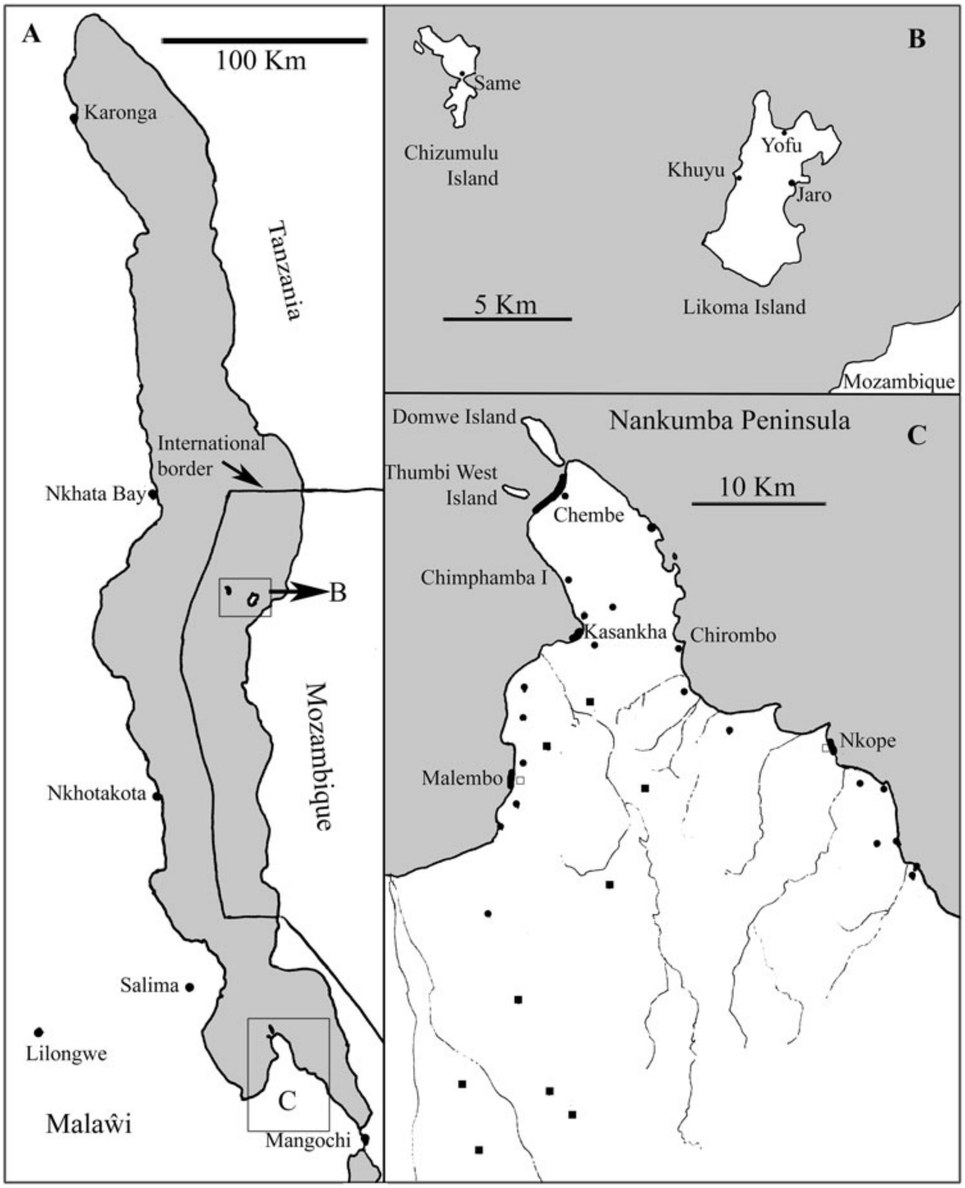

Figure 1. Study areas in Lake Malaŵi.

B. globosus was abundant (Teesdale and Chitsulo 1983). Evans (1975) regarded the open waters of Lake Malaŵi to be schistosomiasis free. In 1991, five of six divers contracted urogenital schistosomiasis after diving in the open waters at Cape Maclear (14°05′S 34°54′E), Lake Malaŵi (Stauffer et al. 1997a, b). Until the turn of the century, the paradigm of urogenital schistosome transmission in Lake Malaŵi was that *B. globosus* was the only intermediate snail host. At this time, it was postulated that the divers were infected by schistosomes that were transported into the open waters from more secluded areas, or that over-fishing of the shallow waters reduced the endemic snail-eating fishes to the point where *B. globosus* successfully established populations. Stauffer et al. (1997a, b) demonstrated that a decline in the number of snail-eating fishes, particularly *Trematocranus placodon,* was correlated with a rise in the prevalence of schistosomiasis in school-age children residing in Cape Maclear. In 2001, Madsen et al. (2001) discovered that an endemic snail, *B. nyassanus* Smith, adapted for living exclusively in the lake and characterized by a much thicker shell, was also an intermediate host of *S. haematobium*. Unlike *B. globosus*, *B. nyassanus* lives in the open waters of the lake and can burrow ∼2 cm below the sand surface (Madsen and Stauffer 2012). Importantly, Madsen et al. (2004) showed that transmission of *S. haematobium* occurred along the open shorelines characterized by sandy substrate, and postulated that the *B. nyassanus* was the intermediate host in these environs.

With the increase in human travel and the movement of infected people, theoretically the spread of parasite strains could increase; thus, if suitable intermediate hosts were present, then new transmission foci might be established (Stauffer et al. 2007). Stauffer et al. (2008) demonstrated that the *S. haematobium* isolates from *B. globosus* and *B. nyassanus* could not be distinguished using nuclear or mitochondrial sequences. Other studies from this author group (Stauffer et al. 2006, 2008; Madsen et al. 2011; Madsen and Stauffer 2011) have shown that both *B. globosus* and *B. nyassanus* are intermediate hosts for *S. haematobium* in the Cape Maclear region of Lake Malaŵi, but interestingly no infected *B. nyassanus* have been found in the northern portions of Lake Malaŵi. Furthermore, the miracidia of *S. haematobium*, from eggs isolated from infected children living in areas where *B. globosus* was the only intermediate host, were shown to be compatible with *B. nyassanus* (Stauffer et al. 2008); thus, *S. haematobium* from the Cape Maclear region of Lake Malaŵi can infect snails from both the *B. truncatus/tropicus* and the *B. africanus* groups. The lack of genetic variation between the *S. haematobium* isolates from the two different intermediate snail hosts was surprising, especially because *B. nyassanus* (*B. truncatus/tropicus* complex) is an unusual intermediate host for this parasite (Madsen et al. 2001). Within the *B. truncates/tropicus* complex, most diploid species seem resistant to infection in nature, although *B. liratus* on the island of Madagascar appears to be an exception (Stothard et al. 2001). The fact that *B. nyassanus* is also susceptible is therefore another interesting exception to the rule, because it is diploid (Madsen et al. 2001), and is a species within the *B. truncatus/tropicus* complex. Thus, because of the increased use of the Cape Maclear National Park by Egyptians among others, we postulate that a strain of *S. haematobium* probably from Northern Africa compatible with *B. truncatus* (also member of the *B. truncatus/tropicus* complex) was introduced into the Cape Maclear region of Lake Malaŵi by tourists or immigrant workers. This strain was pre-adapted to infect *B. nyassanus*, which is a close relative of *B. truncatus*, and interbred with the indigenous strain of *S. haematobium*, to produce a population of parasites that can now use both *B. globosus* and *B. nyassanus* as intermediate hosts.

In addition to the above novelties, anomalies in the location of the schistosomes have been reported in travelers who visited Lake Malaŵi. Schwartz et al. (2000) reported pulmonary manifestations associated with early schistosome infection; six of the eight cases were exposed in Malaŵi. Pathological changes in the lungs are primarily the result of granuloma formation around ectopic eggs (Schwartz et al. 2000) and pulmonary arterial hypertension is normally associated with hepatoplenic schistosomiasis caused by *S. mansoni* (Fernandes et al. 2012). In addition, Corachan et al. (1994) reported schistosome eggs via hematospermia and ultra-sonographic evidence in the prostate and/or seminal vesicles in ten male tourists after recreational exposure to freshwater in Malaŵi. Cetron et al. (1996) reported that two Peace Corps volunteers who visited the Cape Maclear portion of Lake Malaŵi developed central nervous system schistosomiasis after infection by *S. haematobium*. While such infection is essentially an evolutionary dead-end for the parasite, the observed pathology is of concern. Whether the mixing of parasite strains is responsible in part for these unusual pathologies remains unclear.

Speciation via hybridization or mixing of strains has been acknowledged in the evolution and adaptation of many plant species (Grant 1981), and Stauffer et al. (1997a, b) gave several examples of hybridization in the speciation of vertebrates. Hybridization/intergradation between schistosome species/strains is well recognized and may play a role in host switching events. Webster et al. (2005) reported on the interaction of *S. guineenisis* genes with *S. haematobium* in Cameroon and suggested that hybridization and introgression had led to the replacement of one species by another. Rollinson et al. (1990) reported viable hybrids between two bovine parasites, and Huyse et al. (2009) demonstrated bidirectional introgression between bovine and human *Schistosoma* spp., which resulted in heterosis (e.g., higher fecundity, faster maturation times, and wider intermediate host spectra). The epidemiological data clearly implicate Cape Maclear as the site contributing to the most frequent transmission of schistosomiasis; thus, visitors to Cape Maclear were 2.85 times more likely to be seropositive than visitors elsewhere (Cetron et al. 1996). These observations are consistent with transmission via two intermediate hosts (i.e., *B. globosus* and *B. nyassanus*) and vigor of the schistosome. This actively evolving situation, involving intermediate snail–host switching and decline of the natural cichlid snail predator, will impact on transmission of urogenital schistosomiasis within the local communities and on tourists who visit Lake Malaŵi and should be closely monitored. Data must be collected to determine (a) why there is higher infection rate in the waters of Cape Maclear than other areas along the lake shore; (b) if mixing of strains will permit other *Bulinus* species to become intermediate hosts in Lake Malaŵi; and (c) if the strain now present in Lake Malaŵi is capable of using other *Bulinus* spp. in other parts of Africa.

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