OCCURRENCE, DISTRIBUTION AND CONTROL OF THE PARASITES THAT CAUSE SWIMMER'S ITCH IN MICHIGAN

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Section I. Introduction

Swimmer's itch, also called cercarial dermatitis (Figure 1), is a disease of humans that occurs worldwide, with cases reported from every continent except Antarctica. It is called "koganbyo" in Japan, "sawah itch" in Malaya and "clamdigger's itch" on Long Island, New York. Any pond, wetland, lake or estuary that is inhabited or visited by both intermediate snail and final bird or mammal hosts is a potential source of infection. Swimmer's itch is caused by cercariae (free-swimming larval stages) of several species of parasitic blood flukes (family Schistosomatidae). These cercariae are produced in and emerge from several species of snails that serve as intermediate hosts (Table 1). The disease occurs throughout North America and is common in the central and eastern regions of the United States and Canada that correspond to the Atlantic and Mississippi flyways for migrating waterfowl. Several species of waterfowl and other birds and some aquatic mammals such as muskrats serve as final hosts for adult parasites (Table 1).

For more than 100 years, swimmer's itch has been reported from lakes in the North Central region of the United States, including Michigan. In the late 1800s, reports to health officials in Wisconsin described rashes that appeared on people who had been swimming in Green Bay, Wisconsin. Cort (1928) was the first scientist to determine that a snail-borne parasite was responsible for swimmer's itch. Students conducting studies in the "Sedge Pool" area of Douglas Lake at the University of Michigan's Biological Station at Pellston, Michigan, were plagued by a rash, called "Sedge Pool itch", that Dr. Cort linked to
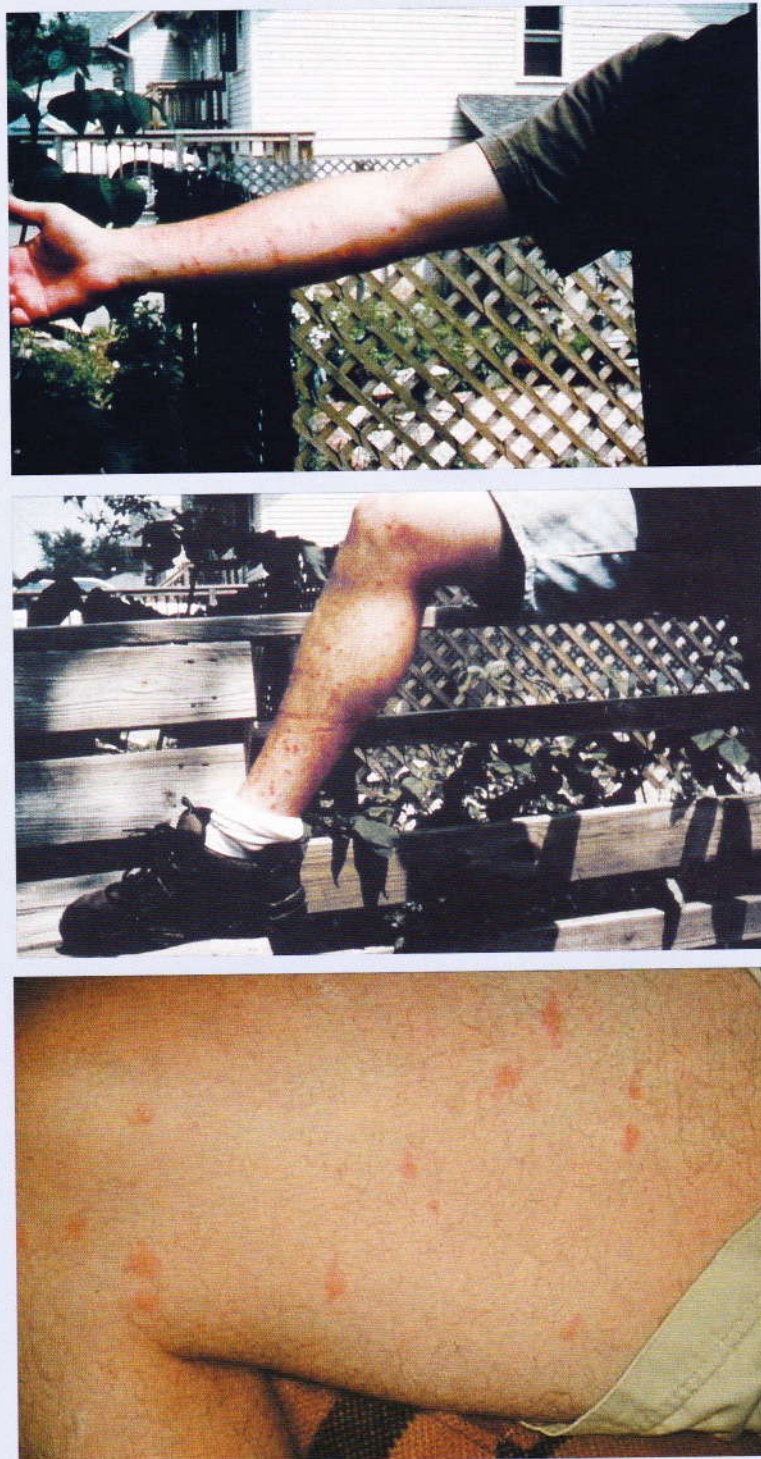

Figure 1. Examples of swimmer's itch.

specific snails and cercariae being shed from them. He named this rash "schistosome dermatitis".

An increasing number of outbreaks of the disease during the 1930s prompted the Michigan Stream Control Commission to form a Division of Water Itch Control in 1939 to develop and administer a control program (McMullen et al., 1940). This program relied on the application of copper sulfate to beaches to kill the snail intermediate hosts in areas where swimmer's itch outbreaks had occurred. However, the repeated applications of copper sulfate may have resulted in the accumulation of copper in sediments to levels that could become toxic. This continues to be of concern and has led to calls for development of more benign procedures for prevent-

ing or reducing the impact of the disease. Unfortunately, no completely effective benign procedure for control of the parasites is known.

According to Wall (1968), swimmer's itch was reported in more than 170 Michigan lakes from 1939 through 1967. He noted that the disease was so common in Houghton Lake that beaches were sometimes closed. Data from the Michigan Department of Natural Resources indicated that swimmer's itch was reported from 71 bodies of water in Michigan (three in the Upper Peninsula and 68 in the Lower Peninsula) in 1968, and that it had never been reported from 45 percent of these lakes before 1968 (Levy and Folstad, 1969). Historically, reports of swimmer's itch have been less common from

lakes in the Upper Peninsula. Levy and Folstad (1969) reported cases from the Muskegon and Tobacco rivers, but swimmer's itch is more commonly acquired while swimming or engaged in water-based activities in lakes rather than rivers in Michigan.

The discomfort associated with swimmer's itch, especially among children, may lead to major economic losses. Local citizens have pointed out that fewer tourists rent cottages or visit lakes, and summer residents spend less time in vacation homes during outbreaks of swimmer's itch. It seems likely that decreased use of rental cabins and vacation homes results in lower income for cabin and resort owners and lower retail activity for local businesses. We know of no studies

Table 1. Some species of schistosomes known to cause swimmer's itch and their intermediate and vertebrate final hosts in Michigan.

Schistosome	Intermediate snail hosts	Final vertebrate hosts
Gigantobilharzia huronensis	Stagnicola elodes[1], Physa (Physella)[2] gyrina[3], P. (Physella)[2] acuta[4], P. (Physella) parkeri, Aplexa elongata	American goldfinch, black duck, blue jay, Canada goose, cardinal, grackle, gray catbird, house wren, mallard, mute swan, red-winged blackbird, song sparrow, tufted titmouse, whistling swan, wood duck, yellow-headed blackbird
Trichobilharzia ocellata	Stagnicola elodes[1], Lymnaea stagnalis appressa[5]	Domestic duck, goldfinch, mallard
Trichobilharzia physellae	P. (P.) gyrina, P. (P.) parkeri	Blue-winged teal, goldfinch, mallard, pigeon
Trichobilharzia stagnicolae	Stagnicola emarginatus	Canada goose, goldfinch, grackle, gulls, mallard, merganser, wood duck
Schistosomatium douthitti	Lymnaea stagnalis appressa, Stagnicola elodes, Stagnicola exilis, Stagnicola emarginatus, Stagnicola elodes f. reflexa[6], P. (P.) gyrina, P. (P.) parkeri, Pseudosuccinea columella	Mice, muskrat, meadow vole, red-backed vole, porcupine

[1]Burch and Tottenham, 1980 = S. palustris.
[2]Burch, 1991 = Physa (Physella) spp.
[3]This species will probably include P. (P.) anatina and sayii, according to R. Dillon, in litt., 2002.
[4]This species includes P. (P.) integra and heterostropha, according to R. Dillon, in litt., 2002.
[5]According to Burch, 1991.
[6]Burch, 1991.

that have quantified such losses but suggest they may be potentially quite large.

Several scientists have conducted research on swimmer's itch in Michigan, including Cort (1928) and Wall (1968). In recent years, Harvey Blankespoor from Hope College (Michigan), his co-worker R. L. Reimink and their colleagues have worked with several lake associations and conducted research on many aspects of swimmer's itch in Michigan. Their work has led to several reports and articles on this subject. Lindblade (1998) studied the relationships between limnological variables and the occurrence of swimmer's itch in Walloon Lake, Michigan. We have incorporated these studies, published literature from other states, information from brochures and pamphlets available from the Michigan Departments of Natural Resources and Environmental Quality, and results

of our own research in Higgins Lake, Walloon Lake and Lake Leelanau from 1998 to 2002 to develop the information presented in this bulletin.

The eradication of the parasites that cause swimmer's itch is not possible with current knowledge. It may be possible, however, to reduce substantially the occurrence of these parasites or their impacts on humans. Current methods of control involve mainly applications of chemicals that target snail (intermediate host) populations. Eventually, control methods may include a combination of chemical, physical and biological techniques that disrupt the life cycle of the parasite, combined with repellent lotions and creams that prevent human infection. A thorough understanding of the effects of various environmental conditions on host-parasite relation-

ships and biotic interactions between hosts is essential for evaluation of existing control strategies of swimmer's itch and for designing effective management options for this disease while minimizing introduction of chemicals into the aquatic environment.

The objectives of this bulletin are to summarize current knowledge about the host-parasite relationships of the parasites that cause swimmer's itch infecting their snail intermediate hosts and to summarize the known information about the occurrence, distribution, ecology and control of swimmer's itch in Michigan. We also discuss proposed methods of control and prevention of swimmer's itch and offer comments on potential problems and benefits of each method based on our own research and information from the work of other investigators.

Section II. Life Cycle of Parasites that Cause Swimmer's Itch

Swimmer's itch (cercarial dermatitis) is caused by free-swimming larval stages (cercariae) of several species of parasitic blood flukes (flatworms in the family Schistosomatidae) (Table 1; Figure 2). It is uncertain how many species of blood flukes can cause swimmer's itch in Michigan, but as many as 12 to 15 species may be involved (see Blankespoor and Reimink, 2002). The more common blood fluke species that cause swimmer's itch in Michigan are listed in Table 1. Blood flukes (flatworms) that cause swimmer's itch require a snail intermediate host and a bird or mammal final host to survive. The intermediate host is an animal in a parasite's life cycle required by the parasite to complete its life cycle; the parasite undergoes some morphological change or development but does not reach sexual maturity. The final host is an animal in which the parasite obtains sexual maturity and undergoes sexual reproduction. The bird or mammal final host must visit or occur in the same lake where the suitable snail intermediate host lives for the life cycle to be completed.

Adult flukes live in blood vessels of intestines and other internal organs of the bird or mammal final host. Female and male flukes mate in the blood vessels of the final host and produce fertilized eggs that move from the blood vessels through the intestinal wall, using enzyme secretions from the developing embryo in the egg. The eggs containing the embryos are released with the feces of the bird or mammal host into the lake, where they hatch in less than an hour under optimal conditions, releasing tiny larvae called miracidia (Figure 2). Miracidia are free-swimming, non-feeding individuals that usually die within 30 hours if they don't reach a suitable snail host.

If a miracidium (pronounced mir-a-si-de-um) contacts the particular species of aquatic snail that serves as its suitable host (Table 1; Table 2), it penetrates its skin, moves to the liver or pancreas, and elongates into a reproductive sac called a sporocyst (Figure 2). Through asexual reproduction (a type of reproduction involving a stage that produces genetically identical offspring), the sporocyst produces a second generation of sporocysts that form and release larvae called cercariae (pronounced sir-care-e-e). A single miracidium that infects a single snail can produce many sporocysts that, in turn, release large numbers of cercariae through a process of asexual reproduction. The development of cercariae usually takes 4 to 5 weeks at temperatures typical of lakes during the spring and summer in Michigan.

Cercariae burrow out of and emerge from the snail to become non-feeding, free-swimming, colorless organisms that measure approximately 0.7 mm (1/32 inch) in length. Cercariae have eyespots and a forked tail, and a life span of up to 24 hours (Figure 3). Completion of the life cycle of the swimmer's itch parasites occurs when a cercaria penetrates the skin of a suitable bird or mammal host, develops into yet another stage that burrows through various tissues into blood vessels (usually those near the intestines) of the final host and then develops into an adult blood fluke (Figure 2). After a suitable bird or mammal host becomes infected, adult flukes start producing eggs in approximately 2 weeks. Humans and other unsuitable animals (dogs, horses) become infected when larvae penetrate their skin accidentally.

Research by Authors

Cercariae can live for up to 24 hours, so one of our crew members conducted an experiment on Higgins Lake to see how far a floating object could be carried by wind and waves over a 24-hour period. Specially painted fish bobbers were released on one side of the lake on a windy day and recovered in less than 24 hours from about a mile away on the other side of this large lake. Some bobbers were returned by volunteer observers. Though the hydrodynamics of the much smaller cercariae would be different from those of the partially submerged fish bobbers, this experiment may indicate that cercariae emerging from infected snails on the lee side of most inland lakes can easily be carried to beaches on the windward side. These results also support published reports that cercariae can be transported to an area from as much as a mile away.

Because the cercariae cause swimmer's itch, data and information on their abundance, behavior and distribution are of particular interest. Other studies report that when conditions are right, as many as 4,000 cercariae per day can be produced by a single infected snail. Our studies of 14 infected snails confirmed this number; these snails shed an average of 1,033 cercariae per snail per day, with numbers varying from 32 to 4,814. Cercariae can barely be seen with the unaided eye when isolated in small transparent containers in the laboratory. Identification to species requires microscopic exami-

nation of morphological and behavioral differences between species (Table 3; Figure 3). Important characteristics used to identify schistosome cercariae are the presence of a forked tail (tail furcae) and pigmented eyespots, with a tail stem that is longer than the furcae. Also, cercariae of some species are attracted to light and will concentrate at the water's surface. Reports in the literature suggest that cercariae may be carried for up to a mile by wind, waves and currents in a lake.

The environmental cues that trigger cercarial shedding from a snail are not completely known. Bracket (1940b) concluded that cercariae emerge from the snails at about 4:30 a.m. in northern Michigan lakes and swim toward light. Our research corroborates the tendency for cercariae to emerge from the snails early in the day, although our observations over 24-hour periods suggest that emergence from snails peaks between 6 and 8 a.m. Collection of snails for determining the number (percentage) of snails shedding cercariae, or protocols for sampling cercariae in the water, should include consideration of peak emergence behavior.

Brackett (1940b) also concluded that cercarial emergence from snail hosts could be triggered by sudden changes in water temperature and that emergence could be inhibited in malnourished snails. If emergence is inhibited by poor nutrition, cercarial emergence rates might be affected by nutrient enrichment of lakes. Moderate increases in nutrients typically lead to increased algal production on sand or other substrates. Snails graze the algae and

detritus from these substrates, so they will obtain food and grow faster in nutrient-rich than in nutrient-poor (oligotrophic) lakes. On the other hand, if excessive nutrient inputs increase phytoplankton cells and other particles in the water to the point where light no longer penetrates to the bottom, algal growth is inhibited and less food is available for snails in highly nutrient-rich (eutrophic) lakes. Our observation that cercariae emerge only from snails that are at least 10 mm long indicates that snail size and growth influence cercarial emergence from infected snails.

Brackett (1940a) found that cercariae of *T. stagnicolae* (Figure 3) swim vigorously toward shadows in lighted containers. Perhaps this is an adaptation that increases their chance of encountering the final bird host. Some people have expressed the belief that cercariae are attracted to them when they are working on docks or rock walls at lake edges. The behavioral response described by Brackett of cercariae moving toward dark objects in lighted containers seems to substantiate this belief.

Swimmer's itch control usually concentrates on disrupting the parasite's life cycle by reducing numbers of intermediate snail or final bird hosts in the lake. The next sections summarize what is known about the host-parasite biology and interactions for each of the hosts.

Schistosomiasis, A Disease of Humans Caused by Flukes
Other flukes in the family Schistosomatidae (genus *Schistosoma*) produce a disease in humans called schistosomiasis. These blood flukes have a life cycle similar to that of the species that cause swimmer's itch, but their final hosts are humans. They occur in the blood vessels of the human intestine and urinary bladder and produce a variety of pathological problems, which may result in death if they go untreated. Some 200 million people in approximately 75 countries worldwide are estimated to be infected with at least one species of blood fluke. Though millions of dollars have been spent for research on schistosomiasis and even more money has been spent on preventing and controlling it, eradication and control of this disease remains an elusive goal. Experience with controlling schistosomiasis suggests that control of swimmer's itch may not be possible and that preventing or reducing exposure to it may be a more realistic goal.

Figure 2. Generalized life cycle of *Trichobilharzia* spp.

Waterfowl host
(cercariae penetrate host
and adult blood flukes occur
in veins near intestine)

Schistosome egg
(passed with duck
feces)

Egg hatches in
water, releasing
miracidium

Cercariae emerge
from snail
into water

(miracidium penetrates snail
and forms sporocysts in snail's
liver and pancreas; sporocysts
produce cercariae)
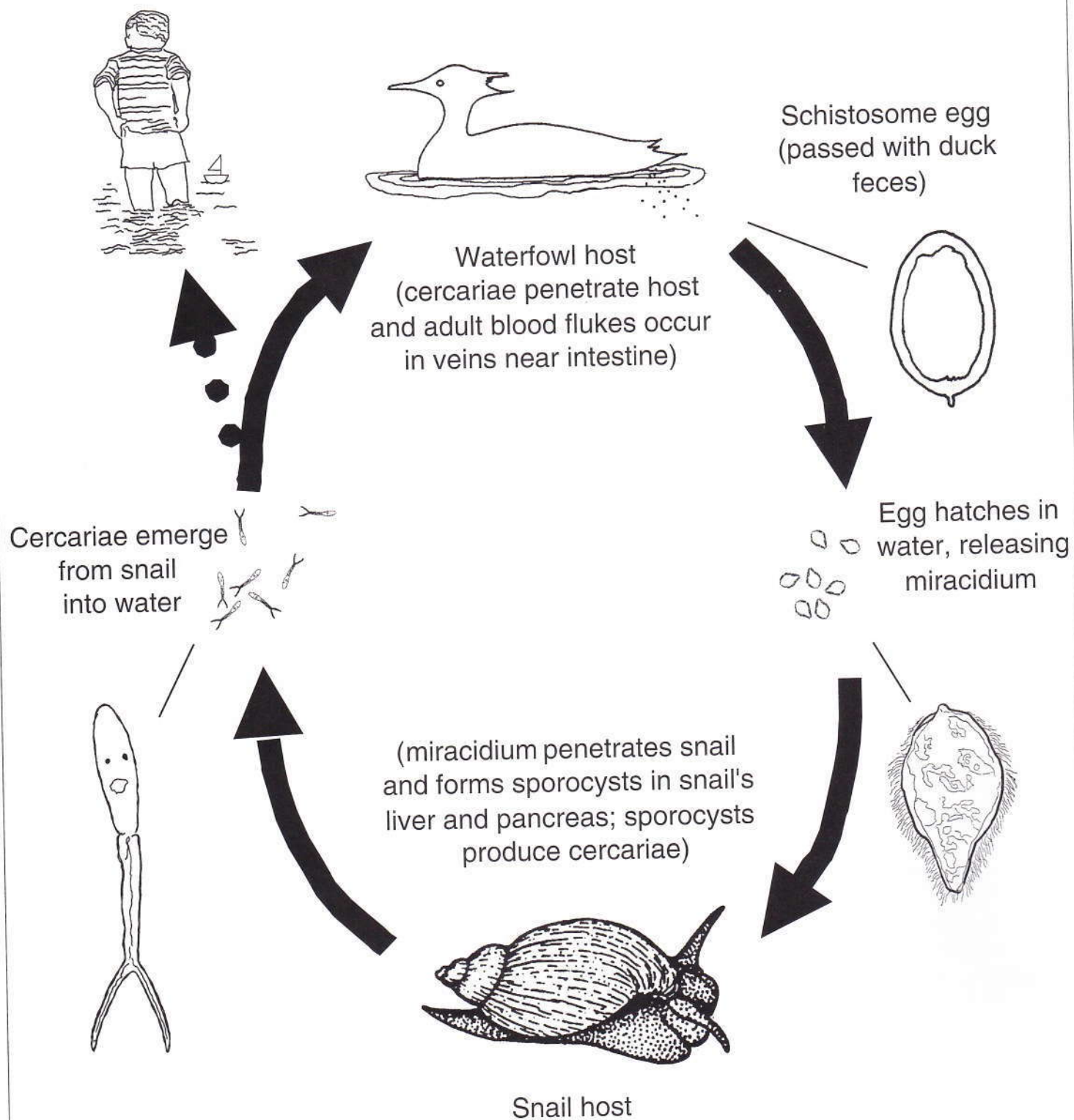
Snail host

Table 2. Scientific names, known distribution, morphology and illustrations of common snail hosts for flukes that cause swimmer's itch in Michigan.

Class Gastropoda
Subclass Pulmonata (Cuvier, 1817)

Family Lymnaeidae (Rafinesque, 1815)

Lymnea stagnalis appressa Say
Cheboygan Co., Emmet Co., Presque Isle Co.[1] Great Lakes - St. Lawrence River drainage area.[1] Walloon Lake, Higgins Lake, Lake Leelanau.

Shell coiled right, conical, high spire; columella (see Figure 4) folded back; aperture about half length of shell; thin shell, light cream to olive; size — 5.2 cm for adults.

Pseudosuccinea columella (Say)
Eastern North America.[1]

Shell coiled right, conical, short spire; columella folded back, aperture 3/4 length of shell; thin, fragile shell, light greenish to horn color; size — 1.2-2.1 cm for adults.
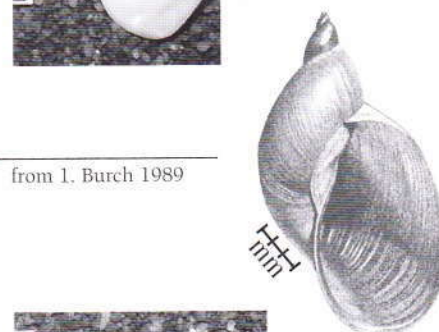
from 1. Burch 1989

Stagnicola elodes (Say)
Cheboygan Co., Emmet Co., Presque Isle Co.[2] North America.[1]

Shell coiled right, high, conical; columella folded back; whorls rounded; aperture little more than 1/3 length of shell, oval to D-shaped; tan to light brown-olive, sometimes with zebra stripes; size — 3.4 cm for adults.

Stagnicola elodes f. reflexa (Say)
Cheboygan Co., Emmet Co., Presque Isle Co.[2] Great Lakes Region.[1]

Similar to *S. elodes*, separate the subspecies from *S. elodes* by its larger size and reduced aperture length compared to overall length; size may exceed 4 cm for adults.
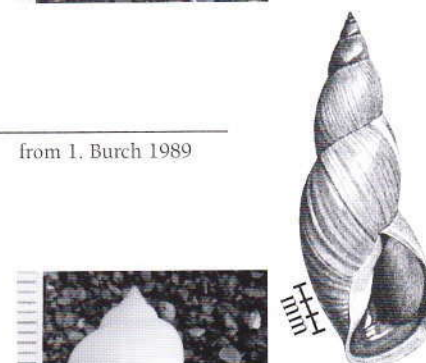
from 1. Burch 1989

Stagnicola emarginatus (Say)
Cheboygan Co., Emmet Co., Presque Isle Co.[2] Great Lakes Region.[1] Higgins Lake, Walloon Lake, Lake Leelanau.

Shell coiled right, globose, without spiral ridges; columella folded back with kink; color white to tan; size up to 3.5 cm for adults.

Stagnicola exilis (Lea)
Cheboygan Co., Emmet Co.[2] Upper Great Lakes Region.[1]

Shell coiled right, elongate, whorls flat-sided in profile; aperture less than 1/2 length of shell; columella folded back; tan to brown, frequently zebrated; size — 4 cm for adults.

from 2. Burch & Jung. 1992.
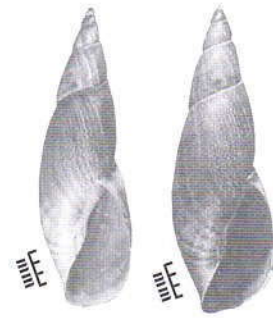
Family Physidae (Fitzinger, 1833)

Physa (Physella) acuta (Draparnaud)
Cheboygan Co., Emmet Co., Presque Isle Co.[2] Widespread.[1] Higgins Lake, Walloon Lake, Lake Leelanau.

Shell coiled left, aperture D-shaped, over 1/2 length of shell; columella folded back, with weak kink; pale yellow-brown; size — up to 1.2 cm for adults.

Physa (Physella) gyrina (Say)
Cheboygan Co., Presque Isle Co.[2] Widespread.[1] Walloon Lake, Higgins Lake, Lake Leelanau.

Shell coiled left, aperture over 1/2 length of shell; columella folded back with a weak kink; translucent, glossy, tan to olive-brown or buff; size — up to 2 cm for adults.
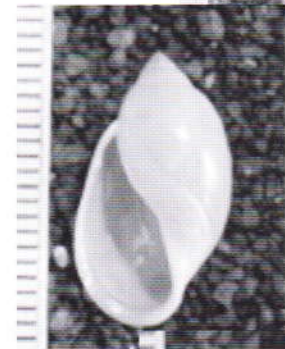
Physa (Physella) parkeri (Currier)
Cheboygan Co., northern Lower Peninsula[2], Michigan, Wisconsin.[1]

Shell coiled left, globose, short spire; columella folded back with a kink; opaque, translucent, dull to glossy, white to dark horn color; size — up to 2.5 cm for adults.
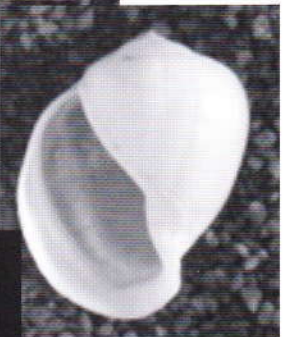
Aplexa elongata (Say)
Cheboygan Co., Emmet Co., Presque Isle Co.[2] Great Lakes states.[1]

Shell coiled left, high spire; columella folded back about 1/2 its length and smooth, not kinked; tan to dark brown, very glossy; size — 1.5 cm for adults.

Family Planorbidae (Rafinesque, 1815)

Gyraulus (Torquis) parvus (Say)
North America.[1]

Shell flat, when placed with spire down; coils to left; whorls with distinct fine striae; pale horn color; size — 5 mm diameter for adults.

[1]Burch, J. B., 1989.
[2]Burch, J. B., & Y. Jung, 1992.
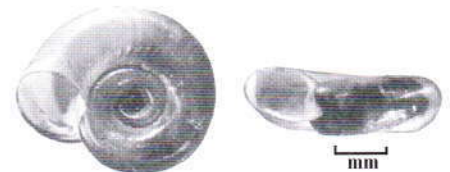
from 2. Burch & Jung, 1992. All figure scales in mm.

Figure 3. Morphology of cercariae of five species of schistosomes that cause swimmer's itch in Michigan.
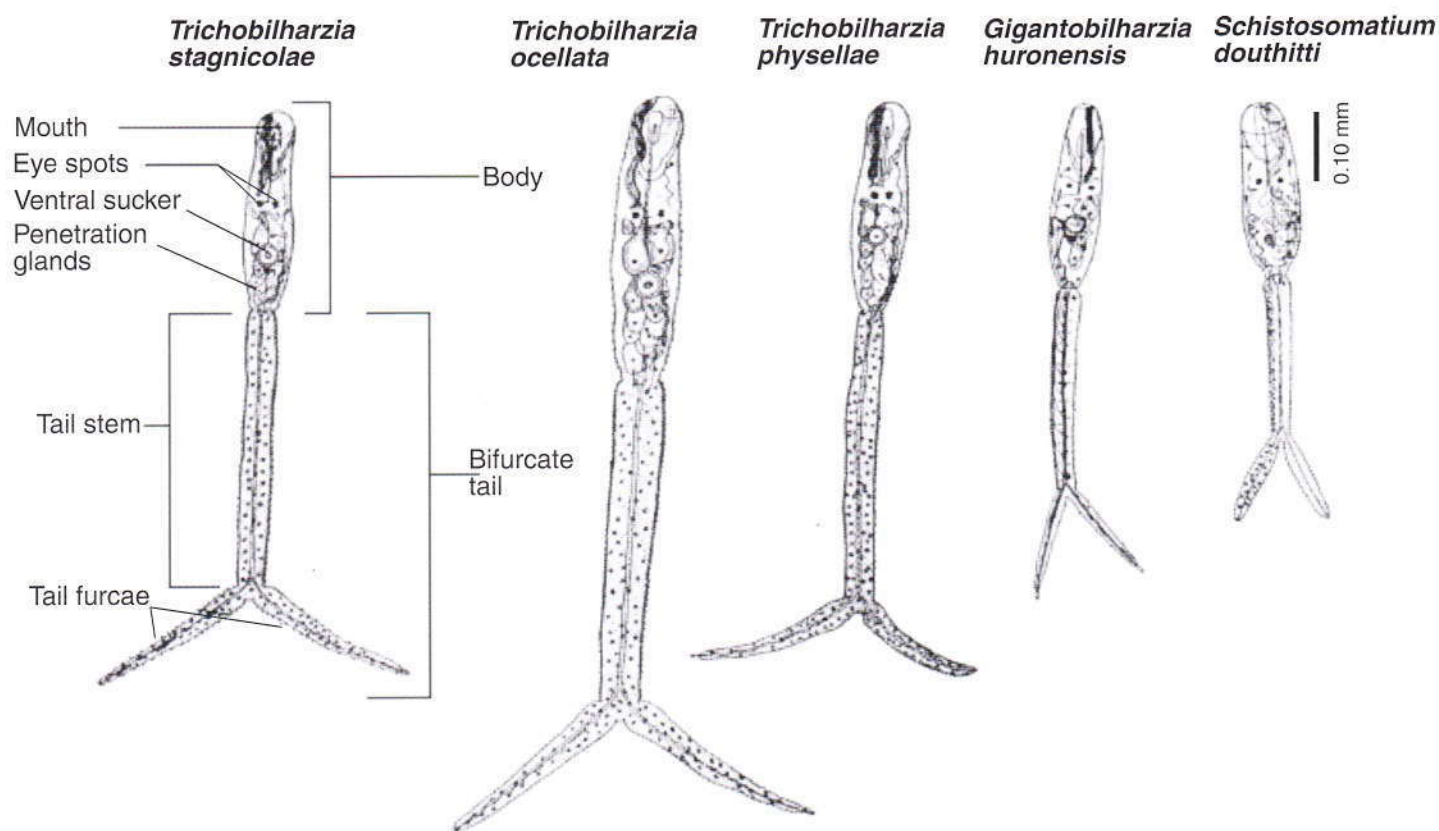
Table 3. Morphology and behavior of cercariae of five species of schistosomes that cause swimmer's itch in Michigan.

Trichobilharzia stagnicolae	Trichobilharzia ocellata	Trichobilharzia physellae	Gigantobilharzia huronensis	Schistosomatium douthitti
Morphology: slender bodies, long tails with narrow tail stems (very similar to other species of Trichobilharzia)	**Morphology:** slender bodies, long tails with narrow tail stems (very similar to other species of Trichobilharzia)	**Morphology:** slender bodies, long tails with narrow tail stems (very similar to other species of Trichobilharzia)	**Morphology:** body is unusually short and thick and tail is shorter than that of most schistosome cercariae; finfolds present on furcae (similar to Schistosomatium douthitti)	**Morphology:** its body is unusually short and thick and its tail is shorter than that of most schistosome cercariae, finfolds absent on furcae (similar to Gigantobilharzia huronensis)
Behavior: strongly attracted to light, does not attach to side or bottom of container but remains suspended in water	**Behavior:** strongly attracted to light, attaches with both suckers to side of container toward the top on light side; if left undisturbed, when attached it holds the tail at right angles to the surface of attachment with the furcae spread apart	**Behavior:** not strongly attracted to light, attaches to side or bottom of container on light side; if left undisturbed, when attached it holds the tail at right angles to the surface of attachment with the furcae spread apart	**Behavior:** not affected by light, becomes attached to underside of surface film soon after emergence and is not easily disturbed into activity	**Behavior:** perhaps not affected by light, becomes attached to underside of surface film soon after emergence and is not easily disturbed into activity

Section III. Infection and Sensitivity of Humans

The cercariae penetrate the skin of humans engaged in water-based activities. Olivier (1949) demonstrated that cercariae of some species could successfully penetrate fully submerged human skin but that cercariae of other species may be able to penetrate the skin only after the person has emerged from the water. Toweling off after swimming, a procedure often recommended to reduce chances of developing swimmer's itch, might be effective in reducing swimmer's itch for the latter species but not the former. Some infected individuals have reported that cercarial entry could be felt as a dull, prickly and itchy sensation; others have stated they could not feel the entry. Children in shallow water may become heavily infected, with exposed legs, waists and arms being most prone to infection.

Humans are not suitable hosts. Either immunological responses kill the larvae after skin penetration or the larvae die naturally in the body. Following exposure, 30 to 40 percent of infected humans develop a skin rash of localized, pus-filled pimples and papules (small, solid elevations on the skin) in response to allergens released by the cercariae (Figure 1). The rash may consist of many papules, each caused by a cercaria, and/or in highly sensitized individuals may be a more generalized allergic response to allergens produced by cercarial penetration. These individuals typically experience painful and irritating itching associated with the rash for a week or more. This rash is not contagious and cannot be spread by itching. Sensitization from repeated infections of cercariae causes increasingly severe reactions that may result in nausea and sleepless nights.

In contrast, many people (60 to 70 percent) are never aware of having been infected. Failure of some people to develop an allergic reaction has been attributed to a lack of sensitivity to the proteins of dead cercariae. Sensitivity may not develop until several exposures to cercariae have occurred, and some people may never develop sensitivity. Wall (1968) reported that experiments by L. Olivier during 1947 and 1948 resulted in 78 percent of people not previously exposed to dermatitis-causing cercariae becoming sensitized after two to eight exposures. Individual family members may demonstrate varying degrees of sensitivity to the parasite. Erroneous reports of swimmer's itch may result from incorrect diagnosis of other skin allergies, reactions to stinging nettles or poison ivy; mosquito, chigger or other insect bites; or fungal infections. Cercariae may also produce a condition similar to swimmer's itch in other non-suitable mammal hosts such as dogs and horses.

Section IV. Snail Intermediate Hosts and Their Interactions with the Parasites

The occurrence of swimmer's itch in humans is related to the occurrence and distribution of the snail intermediate hosts. In Michigan, freshwater snails of three families (Lymnaeidae, Physidae and Planorbidae) are known to serve as intermediate hosts for blood fluke parasites that cause swimmer's itch (Table 1; Table 2). Although there are many snail species in Michigan lakes (Burch, 1989; Burch and Jung, 1992; and Dillon, 2002, who provided updates on snail classification), only the species listed in Table 1 (see pictures of some of the more common species in Table 2) are currently known to serve as intermediate hosts for swimmer's itch parasites. The shell morphology of two snail species that are intermediate hosts for flukes that cause swimmer's itch in Michigan lakes is presented in Figure 4. The distribution of the most important intermediate snail hosts in Michigan varies geographically. *Stagnicola emarginatus*, sometimes called the blue or common beach snail, is more common in the northern half of lower Michigan than elsewhere. It prefers the sandy (beach) areas of lakes and is the most important intermediate host for swimmer's itch parasites in many of these lakes. *Stagnicola emarginatus* has a scattered distribution in the Upper Peninsula.

Physa (Physella) spp. (Table 2) may be the most important intermediate hosts for parasites causing swimmer's itch in southern Michigan lakes (Table 1). Some snail guidebooks place these snails in the genus *Physella*. Some species of *Physa (Physella)* are associated with submerged plants rather than the sandy beach areas where *Stagnicola emarginatus* are commonly found. Therefore, in lakes where *Physa (Physella)* and *S. emarginatus* occur

Figure 4. Shell morphology of two snail species found in Michigan lakes that are intermediate hosts for flukes that cause swimmer's itch. 4a. *Lymnea stagnalis appressa*, a shell that coils to the right (dextral). 4b. *Physa (Physella) parkeri*, a shell that coils to the left (sinistral).
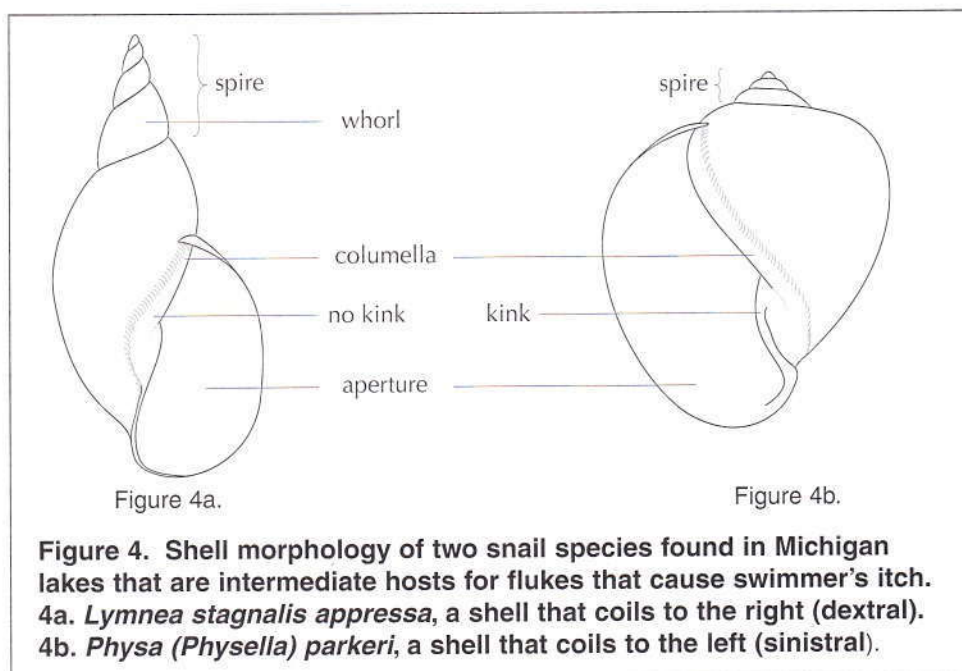
together, both the beach area and nearby submerged plant beds are areas of concern for cercarial production and infection.

Laman et al. (1984) reported that *Gyraulus (Torquis) parvus* (Table 2) in Michigan is an intermediate host for three species of avian schistosomes (not identified) and that cercariae of all three species were capable of causing swimmer's itch. These authors reported that at least six species of avian schistosomes (not identified) utilized *Gyraulus (Torquis) parvus* as an intermediate host in Michigan and Wisconsin. *Gyraulus (Torquis) parvus* is often overlooked in field studies because of its small size.

Most species of blood flukes that cause swimmer's itch in Michigan utilize more than one species of snail as intermediate hosts (Table 1). *Gigantobilharzia huronensis* infects six species of snails in three genera, while *Schistosomatium douthitti* uses eight snail species in four genera. *Trichobilharzia physellae* uses two snail species in the genus *Physa* as

intermediate hosts. *Trichobilharzia stagnicolae* uses only one snail species, *Stagnicola emarginatus*, as its intermediate host. Species that use more than one snail species as intermediate hosts may be particularly difficult to control because the various snail species inhabit a variety of habitats. Thus, for possible control of swimmer's itch using a molluscicide (chemical used to kill snails and clams) such as copper sulfate to be effective, application to multiple habitats within a lake would be necessary. On the other hand, *T. stagnicolae* uses only *S. emarginatus* as its intermediate host, so it may be more amenable to control by selective treatment of beaches. Even so, effective control of this widespread and common snail species has proven difficult. *Stagnicola emarginatus* was the dominant intermediate snail host in the lakes we studied from 1998 to 2001 (Higgins and Walloon lakes and Lake Leelanau) and in many of the lakes studied by Blankespoor and co-workers (Keas and Blankespoor, 1997).

Section V. Reports of Swimmer's Itch and Patterns of Cercarial Shedding from Snails

The first outbreaks of swimmer's itch usually occur in May, and outbreaks continue through the summer in some lakes but occur for only a limited time in others. Our data support reports from other investigators that maximum percentages of snails shedding cercariae tend to occur from late June through July. Cases of humans developing the disease, as reflected by reports to swimmer's itch hotlines, may or may not peak at the same time. During most of the years of our studies, reports of cases of swimmer's itch peaked at about the same time as percentages of cercarial shedding from snails. However, reports to the Higgins Lake hotline in 2000 peaked later than percentages of snails shedding cercariae and continued at a high number in late July and August. Lindblade (1998) reported that cases of swimmer's itch tended to peak in Walloon Lake in July, when human use of the lake was also at its highest.

Biological reasons for variability in outbreaks of swimmer's itch may include availability and the depth to which light can penetrate, day length, changes in water temperature and accumulation of degree-days above a threshold temperature needed for growth of the snails and/or parasites. Wind direction, fetch and speed may also affect distribution of cercariae in the water, since cercariae can be blown by wind for considerable distances from the point of shedding. The percentage of snails infected and the distribution and activity of the bird or mammal final hosts may also affect this variability, as may differences in distribution and behavior of the snail intermediate hosts. For example, snails in an area near a roosting or nesting area of infected birds would likely be exposed to many

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In our studies of Higgins Lake, Walloon Lake and Lake Leelanau during 1998-2001, we assayed the shedding of cercariae of *T. stagnicolae* from a total of 77,326 common beach snails (*S. emarginatus*) (31,205 from Higgins Lake, 17,170 from Lake Leelanau and 28,951 from Walloon Lake) using the light box technique (Blankespoor and Reimink, 1998). Averaged across all sites and dates, the percentage of beach snails shedding *T. stagnicolae* was 1.52, but the percentage of snails shedding varied greatly by lake and sampling date. Spatial variation among lakes was obvious in any particular year. For example, the average percentage of snails shedding cercariae in 2001 was 1.34 for Walloon Lake, 0.78 for Higgins Lake and 0.30 for Lake Leelanau. The lake with the highest percentage of snails shedding cercariae differed among these lakes from one year to the next, with Higgins Lake having higher percentages of snails shedding in earlier years. The percentage of snails shedding cercariae was also highly variable among sites in a given lake in a given year. For example, shedding percentages varied from an average of 0.28 to 2.30 in 1999 and from 0.11 to 2.24 for four sites in Higgins Lake (Saxton, 2001). High variability over time was also common, with the percentage of snails shedding cercariae differing markedly among days, weeks, months and years. For example, snails collected from one site in Higgins Lake were not shedding cercariae on either of two dates sampled in May; however, 0.43 percent and 1.69 percent were shedding on the two dates sampled in June; 1.3 percent and 6.5 percent were shedding cercariae on the two dates sampled in July, and 1.53 percent were shedding cercariae on the single date sampled in early August 2000. This site had the highest overall percentage of snails shedding cercariae of any Higgins Lake site in 1999 and 2000 (2.30 percent in 1999 and 2.24 percent in 2000) (Saxton, 2001). Failure to sample this site would have dropped the average percentage of shedding for Higgins Lake to levels below 0.5 percent in each year. Elimination of the two dates sampled in May 2000 would have resulted in an average shedding percentage for the year of 2.54 rather than 2.24 and would have made the 2000 data more comparable to the 1999 data, when no snails were sampled in May 1999. The percentage of common beach snails shedding *T. stagnicolae* in a given lake was also often significantly different from one year to the next (e.g., for Walloon Lake, it was 1.07 percent in 1998, 0.54 percent in 1999, 0.92 percent in 2000 and 1.34 percent in 2001). This high natural variability has to be taken into account when interpreting results from any potential control strategy tried on any particular lake.

more miracidia than would snails in non-roosting or non-nesting areas.

Variation in weather from year to year affects water temperature, wind speed and wind direction, and is often reflected in the number of reports of swimmer's itch by swimmers. Warmer water is believed to increase the rate of development of the cercariae in snails and the rate of shedding of cercariae into the water. Cooler water inhibits these processes. When the weather is warm, more cercariae are shed, more people use the lakes and more people acquire swimmer's itch than when weather conditions are cooler. Though it does not appear that the occurrence of swimmer's itch in humans has a specific seasonality in all Michigan lakes, most cases occur sometime in July in many lakes in the Lower Peninsula (Lindblade, 1998). July is also the month when most people are enjoying water-based activities. Usually by late July or early August, the number of cases of swimmer's itch has decreased and most of the adult snail intermediate hosts have died or migrated to deep water. Sporadic outbreaks after early to mid-August may be caused by newly infected juvenile snails or by surviving large snails in deeper water upwind of a beach. In northern Wisconsin, most cercariae are released in late June or early July, coinciding with peak water-related recreational activities (Wisconsin press release, 2001, Swimmer's Itch: A Common Summertime Pest).

Schistosome cercariae released from snail intermediate hosts are the single source of human infection for swimmer's itch in Michigan. Assessing the densities of snail hosts, the percentage of snails infected and the conditions under which cercariae are shed is thus essential for estimating the prevalence of

swimmer's itch and predicting future occurrences of the disease. Unavoidably, evaluation of samples of snails forms the basis for these estimates; their accuracy is highly dependent on the place and time of sampling and on the procedures used to determine snail infection and cercarial release from the snails. Information available to date indicates that the distribution of the parasites within a single lake can be very uneven over time and space, leading to high variability in density and prevalence estimates. In the following, we discuss the extent of this variability and its potential causes, and suggest possible ways to fine-tune current monitoring protocols.

Other potential causes of variability in determining the numbers of snails shedding cercariae include methods of snail sampling, numbers of snails examined (at a typical percentage of 1 to 2 percent of snails shedding, several hundred snails would have to be examined to obtain high precision in estimates), time of day and month of snail sampling, and lengths of snails examined. We have found that small *S. emarginatus* rarely shed cercariae, so elimination of snails below 10 mm from those sampled would markedly change the percentage of snails shedding cercariae.

This variability within a lake and in sampling protocol is important in considering the weight given to the overall number (percentage) of snails infected in the lake. Such values (percentages of snails shedding cercariae) may be highly dependent on what sites are sampled; when, where and how they are sampled; and the type of procedure used to determine snail infection percentages. Sometimes, snails at some sites may not be infected in one year while snails at other sites in the

The light box assay determines only the number of snails actively shedding cercariae. It does not yield data on the total number of infected snails in the population, which is best determined by direct dissection and microscopic examination of the snails' liver and pancreas. A subsample of several hundred snails that did not shed cercariae in the light box were dissected to determine if any infected snails had not been detected by the light box assay. We found that several snails with infections of the liver or pancreas had not shed cercariae in the light box assay. Adding the total number of infected snails detected by dissection to the number that had shed cercariae in the light box increased percentages of infection for this sample of snails from 0.46 to 3.05 percent in 1999, from 0.95 to 1.63 percent in 2000, and from 1.37 to 1.61 percent in 2001. These results suggest that not all infected snails shed cercariae on any particular date.

same lake and the same year will have high infection percentages. The next year the situation may be reversed or the same, or infections may not be present at any site. This variability should be considered when interpreting data collected in different years and from different sites on the lake. Changes in prevalence of snails shedding cercariae may not be correlated with the number of humans with swimmer's itch, especially since the number of swimmers and their willingness to report infections to telephone hotlines or participate in other types of surveys also affect estimates of disease occurrence.

The high variability, over space and time, in the percentages of snails shedding cercariae also makes it difficult to use prevalence of shedding or reports of cases of swimmer's itch to document whether any potential control procedure is or is not effective. For example, treatment of waterfowl such as common mergansers with a drug that kills blood flukes has been reported to result in a 50 percent decrease in the percentage of snails shedding cercariae from one year to the next in some Michigan lakes (Reimink et al., 1995). Natural variability is so high, however, that this reduction is well within the range of variability expected when comparing one year to the next without any treatment at all. The pattern of decreases following treatment of waterfowl with a drug would have to be repeated for several experimental and reference lakes in the same year and/or for pairs of treated and reference (untreated) lakes over several years before the treatment could truly be judged effective. It might have been effective, but this cannot be confirmed scientifically unless the pattern occurs across a large enough sample of lakes to be statistically significant.

Many studies have reported that less than 2 percent of snails examined from a given beach are infected with schistosomes that can cause swimmer's itch. Although this number of infected snails might seem too low to produce enough cercariae to cause swimmer's itch in a large number of people, snail densities can be as high as 400 snails/m² and a single infected snail may release up to 4,000 cercariae per day. At 2 percent prevalence, 400 snails/m² would produce 32,000 cercariae/m² per day if each infected snail were shedding 4,000 cercariae per day.

According to our studies, a shedding rate of 1,000 cercariae per day and snail densities below 20/m² may be more realistic. If the maximum rate of shedding and the highest snail density were to occur, this would translate into a possible 29 million cercariae per day released from a 30 m² (about 100 ft²) beach area (Wisconsin press release, 2001, Swimmer's Itch: A Common Summertime Pest). It would be rare to have 400 snails/m² or that all of them would be shedding at the maximum rate, so this is certainly an overestimate. Because large numbers of cercariae can be produced per snail per day (from 32 to 4,814, according to our observations), small changes in the number of infected snails can have a big impact on the number of cercariae released in an area. These estimates also suggest that only a small increase in the number of infected snails in lakes with large host snail populations would result in substantial increases in the likelihood of human exposure to cercariae.

The depth from which snails are sampled may also contribute to variable estimates. In most monitoring programs, collectors obtain snail samples while wading in shallow water along swimming beaches. Snails are known to occur in deeper water, however. Given our experiments on the potential for wind and waves to transport floating objects across the lake on a windy day, we suspect that snails in deeper water were also serving as a source of cercariae for swimming beaches. Preliminary results suggested that snails from deeper water (2.1 to 6 m) may also contribute a large number of cercariae to the swimmer's itch problem on Higgins Lake. This certainly raises a red flag for effectiveness of control where molluscicides are applied only to shallow beach areas.

In our monitoring efforts, we observed that numbers of large snails collected from shallow areas declined dramatically in mid-July. Some of our crew members thought that many of these snails died (perhaps after reproducing) and cited increases in the number of dead snails in shallow areas as evidence of a die-off in Lake Leelanau and Walloon Lake. Another possibility was that large snails had moved to deeper water, and this seemed more likely to be the case on Higgins Lake in 1999, when large snails were still common in collections in July and reports of swimmer's itch to the hotline continued at high levels. Therefore, it is possible that snails in deeper water did not die and continued to release cercariae.

One of our studies in 2000 on Higgins Lake investigated whether the common beach snail tended to migrate to deeper water (Saxton, 2001). In the first trial conducted in late June 2000, no significant directional bias in movement of the snails was detected after they were placed in the middle of a large (10 m radius) circular arena. However, there was a significant movement of snails towards deep water in the late July and early August trials. These results confirm Cheatum's (1934) suggestions from studies in the laboratory that snails tended to move to deep water in August to avoid warmer waters and that they moved back to shallow water in the spring. Such movements and/or die-offs of large snails also need to be considered when designing programs for monitoring cercarial shedding. The smaller snails that dominated collections in late July after large snails migrated to deep water and/or died off tended to shed fewer cercariae than the larger snails.

The specificity of the snail host-parasite relationships (i.e., which snail species is a suitable host for a given species of blood fluke) is not always known. In the three lakes we studied, physid snails (Figure 3) may not be major sources of cercariae that cause swimmer's itch. Fifty-nine *Physa (Physella) gyrina* (= *sayii*) from Walloon Lake and 18 *Physa (Physella) acuta* (= *integra*) from Higgins Lake were examined for infections in 2001, and none were infected. Physids were more common in Lake Leelanau; 715 *Physa (Physella) acuta* and 31 *Physa (Physella) gyrina* were examined for *T. physellae* from Lake Leelanau. Only one *Physa (Physella) acuta* was infected with *T. physellae*. The snail species most commonly infected with cercariae in the lakes we studied was *S. emarginatus*.

An additional impediment to studying and quantifying host-parasite relationships is that several reports and published articles on swimmer's itch in Michigan do not mention which genus or species of blood fluke was under investigation. This makes it difficult to discuss specific species of schistosome that cause swimmer's itch. The cercariae of some species shed from snails can be identified to species using their appearance and behavior while they are alive, and the size and morphology of specimens mounted on microscope slides (Table 3; Figure 3). For example, the cercariae of *Gigantobilharzia huronensis* rest at the water surface with their tails hanging down. The tails and bodies of these cercariae are approximately equal in length. The cercariae of *Trichobilharzia physellae* rest attached to the bottom or sides of the container. Their tails are much longer than their bodies.

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A goal of our study was to develop techniques to sample lake water for the presence and density of schistosome cercariae. If this effort was successful, the presence and density of cercariae in water could be used to warn swimmers of the potential risk of contacting cercariae and/or could be used to design control strategies for lake treatment. One technique, called cercariometry, involved filtering a known amount of water through 35 um mesh nylon filters to collect cercariae. Cercariometry could be used to study the relationship between cercarial emergence and limnological variables. In 2001, one of the crew developed a procedure for pumping lake water through the filters and produced some interesting preliminary results. A total of 6,303 liters (1,665 gallons) of Higgins Lake water were filtered for cercariae from May 20 through July 26; 100 cercariae were obtained, 96 of which were *T. stagnicolae*. There was no significant difference in density of cercariae in the water collected between the shoreline and 0.4 m depth. No cercariae were collected after 10:30 a.m. Cercariae were not found in water cooler than 17° C, and the majority of cercariae were found in water between 20 and 24° C. Cercarial density was significantly correlated with sampling date, with the highest densities being found in mid- to late July.

The expansion of this research on cercariometry could provide much more information on the effects of environmental conditions on cercarial emergence and their distribution in the water. If enough such information could be obtained, it might be possible to develop a monitoring procedure and model to allow prediction of swimmer's itch outbreaks in any particular lake. Then lake associations might be able to provide swimmer's itch warnings.

Section VI. Vertebrate Final Hosts and Their Interactions with the Parasites

The final hosts for the blood fluke species that cause swimmer's itch in Michigan include waterfowl (ducks, geese and swans), many species of passerine birds (gulls, red-winged blackbirds and many species of terrestrial songbirds) and several species of mammals, including some terrestrial species that may visit and defecate in the water or on rocks along the shore (Table 1). Harvey Blankespoor, from Hope College, and co-worker R. L. Reimink have reported that common mergansers are important final hosts for some species of flukes that cause swimmer's itch in Michigan, including *T. stagnicolae*. According to their unpublished reports to lake associations and information on their Web site (www.hope.edu/swimmers-itch/faq.html#8), they sampled feces from a variety of birds and mammals and found that a higher percentage of merganser feces was infected compared with feces of other final hosts. They also determined that each infected merganser produced higher numbers of parasite eggs per gram of feces than other waterfowl. However, mallards, geese and other species with higher populations on some lakes or that migrate and rest on lakes in large numbers may be quite important as sources of infection for the intermediate snail host. Infection values of ducks and geese may be lower than those of mer-

gansers, and the adult flukes may produce and release fewer eggs in the bird's feces, but where ducks and geese are numerous, they may release similar or even higher total numbers of eggs into the water than a smaller, more highly infected merganser population. Blankespoor and co-workers suggested that geese and mute swans are unlikely to be a major source of swimmer's itch in Michigan lakes because the parasite that infects them has an intermediate snail host that inhabits marshy areas where swimmers are unlikely to be exposed to the cercariae.

Guth et al. (1979) reported that 35 percent of 318 swans, ducks and geese, and 6 percent of 926 passerine birds such as songbirds were infected with swimmer's itch-causing schistosomes in lower Michigan. Strohm et al. (1981) found *Gigantobilharzia huronensis* in nine (69 percent) of 13 red-winged blackbirds. They found that all 10 common grackles examined were infected with schistosomes, which were identified as *G. huronensis* in three cases. The number of schistosome adult flukes in five of the grackles exceeded 15 flukes per bird. Blankespoor and Reimink (1991) found that Canada geese, mallards, mergansers, wood ducks and grackles were infected with *Trichobilharzia* spp.

Schistosomatium douthitti is believed to be the only swimmer's itch-causing parasite species in Michigan that uses mammals associated with water as final hosts (Table 1). Blood flukes of this species have been reported from muskrats, meadow voles, red-backed voles, porcupines and jumping mice. Zajac and Williams (1980) found that 33 (70 percent) of 47 meadow voles were infected with *S. douthitti* in Michigan; the average number of flukes per animal was 40.

So little has been published on the host-parasite relationships of bird and rodent schistosomes in Michigan that it is impossible to know the actual number of species capable of causing swimmer's itch. It is possible that some species of flukes that cause swimmer's itch have not yet been described. The adult fluke in the final host may reach lengths up to 7 mm. With 12 to 15 or more parasite species with cercarial stages capable of causing swimmer's itch and so little known about the life cycle of some of these species, it is impossible to fully predict when and where swimmer's itch will be a problem from year to year.

Section VII. Methods for Monitoring Cercarial Shedding from the Snail Intermediate Hosts

The procedures for determining the percentage of snails shedding cercariae in a lake where swimmer's itch has occurred or is suspected are relatively straightforward and could be accomplished by volunteers with the proper equipment and a limited amount of training. The following guidelines should be followed. Snails should be collected between daybreak and 8 a.m. from the bottom of the lake and from or near beach areas where swimmer's itch cases have been reported. Though snails in deeper water may produce cercariae, most sampling programs assess snail populations in shallow water up to a meter deep. A glass-bottomed bucket is quite useful for locating snails. It can easily be constructed by cutting the bottom out of a metal bucket and gluing a piece of glass on the bottom using aquarium or some other waterproof adhesive. A face mask and snorkel are also useful and even necessary if the snails are to be collected in deep water. The snails can be picked up by hand or by use of a wire mesh strainer (available in the kitchen supply area of department stores) attached to a wooden handle such as a broom handle or a long, wooden dowel rod (Figure 5, see p. 26). The glass-bottomed portion of the bucket is placed under the surface to eliminate interference from waves and reflection of light from the surface. In most clear lakes, the bottom can easily be seen using the bucket at depths of 1 meter or less. If not,

or if sampling in deeper water, a face mask and snorkel or SCUBA gear can be worn to collect the snails. Collected snails should be placed in lake water in a pail and transported to the laboratory or other facilities.

With practice, snails can be identified to genus or species using the key in Burch (1989) (see Table 2 and Figure 4 also). Snails are then isolated in 1-oz. transparent plastic cups (plastic cups from religious supply stores are ideal) and exposed to white fluorescent light for 2 to 3 hours to stimulate cercarial emergence (according to methods developed by Blankespoor and Reimink [1998]) (Figure 6, see p. 26). Each cup can be observed under a dissecting microscope to confirm the presence or absence of cercariae. Cercariae are wet mounted and identified under 10X to 40X power using a compound microscope following the procedures of Schell (1970). Cercariae of other fluke species that resemble schistosome cercariae but do not cause swimmer's itch may also be shed from the snail intermediate hosts. Therefore, it is important to identify schistosome cercariae and differentiate them from other, non-harmful cercariae. This can be done by observing their behavior and identifying the eyespots, furcated (forked) tail and tail stem longer than the furcae to signify that the cercariae are those that can cause swimmer's itch (Figure 3).

Misidentification of cercariae can lead to needless use of chemicals or wasted effort and expense to control a problem where none exists.

An infection value often calculated for snails shedding cercariae is termed prevalence. Prevalence is a percentage that is calculated by the following equation:

$$\frac{\text{Number of snails shedding cercariae}}{\text{Number of snails examined}} \times 100 = \text{prevalence}$$

Prevalences can be calculated for each location and can be compared between or among locations, years, length classes of snails and other variables. To achieve any kind of precision, a minimum of 500 snails per site per date should be examined. The effort needed to do this requires a very dedicated group of volunteers or use of a seasonal employee or student intern. Our experience indicates that *Stagnicola emarginatus* snails less than 10 mm (0.4 inch) long are unlikely to shed cercariae, so collecting efforts should concentrate on snails larger than this if *Stagnicola emarginatus* (Table 2) is the most common potential snail host present.

Section VIII. Prevention and Treatment of Swimmer's Itch

Preventive measures for swimmer's itch, even if applied with care and diligence, still may not be 100 percent effective.

Some individuals claim that certain lotions (e.g., some sunscreens) and oils (e.g., mineral or baby oil) reduce the incidence of swimmer's itch by acting as a physical barrier to cercarial penetration. As far as we know, this claim has not been scientifically tested, and some individuals claim that these methods do not work.

DEET, the active ingredient in many insect repellents, has been shown in laboratory studies by others and in our preliminary studies to kill cercariae at concentrations exceeding 7.5 percent. Some combinations of sunscreens and insect repellents contain DEET at concentrations higher than 7.5 percent and are designed to stay on the skin of bathers. They might offer some protection from cercarial penetration, but we were unable to test if sunscreens containing DEET work because of the difficulty of obtaining permits for studies involving human subjects. Regular insect repellent alone is not likely to work because DEET is quickly washed or is volatilized off the skin. The waterproof screen should keep it on the skin where it may be effective. Development, research and testing of candidate lotions or creams by pharmaceutical companies to prevent cercarial penetration should be possible, but their cooperation needs to be elicited. To date, laboratory results are suggestive, but there is no proof that repellent compounds containing DEET are effective. We can only recommend that individuals with known sensitivity to swimmer's itch experiment with currently available products. Furthermore, we suggest that a coalition of public officials and representatives of the concerned public use information on all facets of swimmer's itch to persuade a pharmaceutical company to research the development of a cream or lotion that would prevent cercariae from penetrating the human skin. Pharmaceutical companies have the funds for research and development and can obtain permits for research on human subjects.

It has also been recommended that individuals shower or towel off immediately after leaving the water. Larval parasites of some species are sticky, attach to the skin as the bather leaves the water and penetrate as the skin dries. Showering to dislodge them and/or toweling off may prevent penetration of cercariae of these species. Because some larval parasites can penetrate while the skin is submerged, toweling off or showering after swimming will not be 100 percent effective in preventing swimmer's itch. Even for species that penetrate while the skin is drying, toweling would not be efficient, especially for children and other swimmers who play in the water with parts of the body alternately submerged and drying before they ever leave the water.

Discouraging bird hosts from using beach areas has also been recommended as a preventive measure for swimmer's itch. For example, discouraging people from feeding the bird final hosts near beaches has often been recommended in brochures. The idea is to decrease defecation of parasite eggs in the area, thereby reducing snail infections. Given that a few infected birds can produce large numbers of eggs and that many people like to feed ducks, it seems unlikely that this measure will be particularly effective. Keeping all birds and mammals away from the beaches at all times is also difficult and impractical. Harassment of waterfowl is not allowed by Michigan or federal law.

Treatment for the rash and papules is similar to that for poison ivy. It may include warm baths and/or use of lotions to relieve the symptoms and help dry up the rash. Because an allergic reaction is involved, an antihistamine such as diphenhydramine hydrochloride in various lotions may be used to relieve the symptoms. Antihistamines are readily available in pill form without prescription, but obtaining advice and prescriptions from a physician is recommended. It is important not to scratch the rash (infected area) because broken skin may provide portals of entry for secondary bacterial infections.

Section IX. Use of Copper Sulfate and Other Chemicals and Means to Control Snail Intermediate Hosts

Copper Sulfate as a Chemical Control

The Division of Water Itch Control established by the state of Michigan in 1939 initiated efforts to control swimmer's itch in recreational lakes. The control method used during these early years remains essentially the same today and involves application of copper sulfate to kill snail intermediate hosts, thus interrupting the life cycle of the swimmer's itch parasite so that cercariae are not released. Application of copper sulfate requires a permit from the Michigan Department of Environmental Quality (MDEQ).

Long-term, repeated application of copper sulfate to lakes may result in accumulation of copper in sediments to levels that are potentially toxic to many organisms. Copper, like most heavy metals, tends to bind to the small clay, silt and organic particles that are present at low levels in sandy beach areas of lakes. These small particles often are resuspended by waves and deposited in deeper areas of lakes. Few studies have been conducted to follow resuspension and transport of copper in lakes or to determine its accumulation in sediments in deeper areas of the lake away from the beaches where it was applied. Such studies are needed. Ultimately, even local application may affect areas far from the area of application because of resuspension and transport of copper-containing sediments. Many citizens are concerned about the repeated use of copper sulfate, and alternatives would be desirable.

Copper sulfate has also been used extensively as a herbicide to control algae and submersed plants in lakes. All uses in a lake need to be included when long-term accumulation and effects are considered. Copper sulfate is toxic to algae, higher plants, invertebrates and fish if it is applied at excessive rates or if it accumulates to high levels because of repeated, long-term use. Thus, application of copper sulfate should be limited as much as possible and should be done by a trained operator, and the amounts used should be monitored carefully.

Michigan Public Act 58, approved in 1959 and amended to the Public Code, 1978, Public Act 368, gave the state authority to control and restrict use of copper sulfate and other chemicals to control snails. The goal of this was to protect Michigan citizens from indiscriminate use of untested chemicals to control swimmer's itch (and other problems) in infected lakes. In 1968 alone, 90,000 pounds of copper sulfate were applied to control swimmer's itch in Michigan, compared with 11,664 pounds in Minnesota in 1968 and 13,570 pounds in Wisconsin (Levy and Folstad, 1969). The use of copper sulfate has increased over time. To date, more than 2 million pounds of copper sulfate have been applied to Michigan lakes to control snails.

The MDEQ provided information, derived from the permit applications that are required before lakes can be treated, on the use of copper sulfate to control snails in Michigan from 1996 through 2001. A total of 32 lakes and one river in 18 counties received one or more applications of copper sulfate during those five years. The largest number of lakes and rivers receiving one or more applications of copper sulfate was 22 in 1997. Most treated lakes and rivers were in the northern half of the Lower Peninsula; five of the 32 were in Mecosta County, and four were in Muskegon County. One or more applications of copper sulfate occurred in all five years to Lake Leelanau, North Lake, West Lake and Winans Lake, and in four of the five years to Burt Lake, Independence Lake, Long Lake, Merrill Lake, Mullett Lake, School Section Lake and Twin Lake. The amounts of copper sulfate applied to a lake or river varied drastically from 10 to 10,890 pounds in 1999, from 19 to 2,056 pounds in 2000, and from 19 to 1,028 pounds in 2001. The applicants for use of copper sulfate included private individuals, resort owners, lake associations, camps, park commissions, townships and consulting companies.

Most copper sulfate products do not have use rate labels high enough for snail control. Only two products have labels for this use. They are Copper Sulfate crystals (EPA Registration #56576-1 for Chem One Limited) and Triangle Brand Copper Sulfate crystals (EPA Registration #1278-8, which requires an additional special local need label). Copper sulfate may be applied in granular form mixed in a slurry with lime, directly as pea-sized crystals or as an instant powder. The formulation of the chemical used depends on the size of area being treated, method of application, and presence of weed beds, boulders or rock walls. The recommended application rate is 2 pounds of copper sulfate per 1,000 feet^2 regardless of application method. This rate is equal to 87 pounds per acre and should result in 32 ppm (parts per million) in 1 foot of water above the bottom. Application with a motor-powered unit is an economical

Summary of the MDEQ (1999) guidelines for application of copper sulfate

■ Areas with infected snails should be determined before treatment to ensure that all areas with infected snails are treated. Procedures for conducting such a study have been summarized previously, and this requires examination of the snails by a knowledgeable volunteer or consultant.

■ A minimum of at least 1,000 feet of lake frontage should be treated because cercariae may be released from snails from areas near the beach being treated.

■ Written permission of landowners along the shore should be obtained before treatment.

■ Copper sulfate treatment should not be attempted during times of high wave action because it will be dispersed by waves and/or washed out of the treated area instead of remaining on the bottom in the desired area.

■ The applicant must give written notice to occupants of riparian dwellings in or within 100 feet of the area to be treated not less than seven days prior to treatment. Instructions include the statement: "Do not disturb the water (no swimming) for 24 hours after a swimmer's itch treatment, as this will tend to move the copper sulfate off the bottom of the lake and lessen the effectiveness of the treatment."

■ MDEQ-approved signs must be posted along the shoreline of the treatment area not more than 100 feet apart.

■ A permit (permit for chemical treatment to control swimmer's itch or other nuisance aquatic animals) for the use of copper sulfate is required by the MDEQ.

■ A treatment report must be returned even if treatment is not done.

method recommended for large areas. If the application of copper sulfate is performed by a licensed commercial applicator, the common method is to mix the copper sulfate with lake water and to subsurface inject the mixture using drop lines to place the chemical close to the bottom. The MDEQ no longer allows copper sulfate-lime slurry applications. If only a small area is to be treated, application of 2 pounds of small, pea-sized crystals of copper sulfate per 1,000 ft^2 with a fertilizer applicator or by hand sowing (broadcasting) is acceptable. Application of copper sulfate instant powder mixed with a small amount of water (to keep the powder from blowing in the operator's face) is recommended for areas that contain weed beds, large boulders, a breakwater or a wall where snails are living above the lake bottom. The powder/water mix can be sprayed from a tank or applied by dipping it from a pail. Some species of snails — e.g., *Physa (Physella) acuta* — deposit their eggs on concrete walls or on rocks that have been used as riprap to prevent erosion of the shoreline. Use of the instant powder is recommended to treat such areas.

Whether a machine is used or application is done by hand, the area to be treated should be adequately marked. Measuring and marking the area with floats or stakes is important to distribute the chemical evenly as well as to keep people out of the area during and immediately after application.

Copper sulfate is poisonous to humans and other animals if ingested. It will cause irritation to eyes, mouth and nose. Also, it will color, irritate and dry the skin. Glasses (goggles), face masks and gloves should be worn during application.

Toxic copper ions in copper sulfate kill snails at concentrations that can be tolerated by some of the less sensitive invertebrates and fish. The object is to kill snails in lakes where swimmer's itch occurs without killing other invertebrates or fish and other vertebrates. Its use should be discouraged if trout are present because trout are extremely sensitive to copper. Treating a local beach may be effective if all cercariae are coming from snails in the treated area. If cercariae are being blown (carried) to the area from untreated adjacent areas or areas upwind or upcurrent, localized treatment may not be effective. It is not known if all snails are killed by treatment nor how long it takes before snails from untreated areas recolonize the treated area.

Aquatic worms, insect larvae, leeches and other aquatic organisms eaten by fish can be killed by the copper sulfate. Copper sulfate treatment should be done after the middle of June in lower Michigan after bass, bluegills and other panfish have left their spawning beds in shallow

Research by Authors

Studies were conducted at three sites on Lake Leelanau in 2000 to assess the effectiveness of copper sulfate application to individual beaches. They were performed to assess the ability of snails to colonize areas treated with copper sulfate. At each site one day prior to application of copper sulfate, a 5-square-meter area was delineated with stakes, and all live snails present in the area were collected, identified, counted and then returned to the area. A snail inventory was performed in the same area one day after copper sulfate application, and again at two and four weeks after treatment. The application of copper sulfate was effective in killing snails and reducing the number of live *S. emarginatus* present. Decreases in snail density occurred at all sites one day after application, and numbers were still reduced at two sites two weeks after application. Most of the snails found in the areas after treatment were less than 10 mm in length. This indicates that snails colonizing the areas were young-of-the-year snails. Because most snails of this size did not shed cercariae in our studies, we assume the production of cercariae by snails on the treated beaches was reduced. However, we did not determine numbers of cercariae in the water or number of swimmers acquiring swimmer's itch before and after treatment. Cercariae being blown into the area by wind could have resulted in exposure of swimmers to swimmer's itch. The effects of copper sulfate on other invertebrates was also examined in this study. Preliminary analyses suggest that some other invertebrate populations may have been negatively affected.

water. Fish in live boxes should be moved out of the area to be treated prior to the treatment because they probably would be killed by the copper.

Copper sulfate treatment is not an effective and long-lasting method for controlling swimmer's itch. Many cottage owners, resort owners, park managers and youth camp personnel in Michigan have reported outbreaks of swimmer's itch in the same month or season that their lake had been treated with copper sulfate. Similarly, in Wisconsin, thousands of pounds of copper sulfate have been used to control snails in lakes, but the snails return the next year, if not sooner, and the problem reappears. Some people believe that copper sulfate is somewhat effective in controlling swimmer's itch, however, and that the problem would be worse if their lake had not been

treated. It is impossible to estimate how severe Michigan's swimmer's itch problem would be today if the copper sulfate control program had not been initiated by the state in 1939.

Alternative Chemicals for Control of Snail Populations

Copper sulfate is not always effective and has potential negative side effects, so alternative molluscicides (chemicals that kill mollusks) are needed. Two other molluscicides have been tested and used to kill snails that serve as intermediate hosts for blood flukes that cause schistosomiasis in humans in many parts of the world. One of these is sodium pentachlorophenate. It is an effective molluscicide that kills snails and their eggs as well as the

miracidia and cercariae of the flukes. The major problem is that it also kills fish.

Another molluscicide used for snail control in other parts of the world is bayluscide, also called niclosamide. Bayluscide is a pesticide that can cause eye problems in humans and can affect non-target organisms, and specialized training is required for the person who applies it. Andrews et al. (1987) provided detailed information on several aspects of bayluscide. Newton and Fetterolf (1967) conducted early experiments on the usefulness of bayluscide to control snails in Lake Mitchell and Houghton Lake and obtained promising results. Various studies have shown, however, that some aquatic plants, invertebrates, fish and amphibians are injured or killed by bayluscide. One study reported that frogs were sometimes leaving ponds shortly after treatment, indicating that some component of bayluscide is irritating to amphibians; a similar effect is also seen in fish, which become distressed and hyperactive soon after application. Wellborn (1971) demonstrated that bayluscide was toxic to 18 species of fish at the concentration level recommended for snail control. It is not listed for use as a molluscicide in Michigan or in any other of the lower 48 states. It is, however, registered for limited use by the U.S. Fish and Wildlife Service as a lampricide, and it has been used in recent years to control lampreys in the St. Mary's River. Because of concerns about its safety, long-term effects, its ultimate fate in lake sediments and food chains, and the fact that it is not registered for use as a molluscicide in Michigan, we do not recommend its use.

Non-chemical Methods of Control

Leighton et al. (2000) proposed that snail habitat destruction could be an effective way to control swimmer's itch. They found that snails from beach areas near host bird (merganser) roosting logs had a high prevalence of parasite infections. Experiments demonstrated that using a boat-mounted rototiller or a tractor and rake to mechanically disturb this snail habitat eliminated almost all snails. These methods destroyed snails, exposed their egg masses to predators and removed their food supply from cobble. The extent to which these mechanical controls affected cercarial shedding or the incidence of swimmer's itch was not assessed, however, because data were not presented on either numbers of infected snails from these habitats after mechanical controls were used or numbers of humans with swimmer's itch. Mechanical habitat disturbance is a method worth trying if known roosting areas can be located along the lakeshore or on islands in the lake. Additional research on this procedure should include determining the number of snails shedding cercariae in or near such areas before and after this disturbance. If a person chooses to use these activities (i.e., boat rototilling, tractor and rake), a permit may be required under Part 301, Inland Lakes and Streams, of the Natural Resources Protection Act, 451 P.A. 1994, as amended and/or Part 303, Wetlands Protection, of the Natural Resources Protection Act, 451 P.A. 1994, as amended. For more information, individuals should contact their DEQ district office.

The use of biological control agents, from parasites to pathogens to fish to fungi, against snail intermediate hosts of schistosomiasis has been encouraged because of their relatively low cost and presumed harmlessness, unlike the molluscicides that may disrupt the aquatic food webs because of their toxicity to non-target species (see review by McCullough, 1981). Most studies have been performed in a laboratory and have had limited success, but the efficiency of biological control agents has rarely been tested outside the laboratory. Controlling snails with other snails, snail-eating fish and other organisms has been tried in many parts of the world, again with limited success. Predators may determine the composition of snail assemblages in lakes (see review by Brown, 1991)—for example, redear and pumpkinseed sunfish that have crushing teeth and specialize in eating large, weak-shelled snails. Crayfish may also selectively eat snails, are capable of crushing them and can consume as many as 100 per night (Brown, 1991). Smaller, thicker shelled snail species tend to dominate in lakes with such predators. In addition, several invertebrates can invade shells and prey on snails. We know of no attempt in Michigan to introduce predators to control snail populations. One problem is that sunfish, crayfish and other such potential predators are themselves subject to predation by large fish and tend to inhabit weed beds and avoid the open beach areas where snails need to be controlled. Also, biological control programs based on the use of species that are not native to a lake may introduce exotic species that could affect the

existing lake ecosystem in unpredictable ways. Accidentally introduced exotic species such as the sea lamprey and zebra mussel provide well-known examples of the undesirable, long-term and large-scale effects that exotic species can have.

Any new recreational/swimming areas being developed on a lake should be located on the upwind side of the lake. For example, if prevailing winds during the summer blow from west to east or from southwest to northeast, beaches should be located on the southern or western shores of the lake so that cercariae that cause swimmer's itch will blow away from swimming areas. Regardless of beach location, individuals sensitive to the disease should refrain from swimming in lakes where swimmer's itch occurs.

Woytowich et al. (1997) presented information to control a swimmer's itch problem in a lake in Manitoba, which was considered for use during the 1999 Pan Am Games. The management control options discussed to improve the swimmer's itch problem and water quality included constructing swimming area enclosures, controlling water levels, removing organic sediments, installing geotextile weed barriers, providing aeration, dilution, ultraviolet disinfection, and using copper sulfate and bayluscide. These control options were evaluated on the basis of capital costs, operational and maintenance costs, operational aspects and aesthetics.

Section X. Possible Control and Prevention Activities Involving Bird Final Hosts

Reimink et al. (1995) and Blankespoor et al. (2001) discussed a procedure for controlling swimmer's itch that involved treating common mergansers and mallards with praziquantel, a drug developed to kill flatworm parasites of humans. Reimink et al. (1995) reported that capturing and treating waterfowl with the drug resulted in the percentage of snails shedding cercariae decreasing from 1 to 2 percent pre-treatment to 0.1 to 0.2 percent post-treatment within a two-year period following treatment without mentioning specific lakes. These studies should be replicated on several lakes over several years to scientifically determine the efficacy of this approach. Reduction of prevalence to this level, if proven by more replication, would be quite an achievement. Even if treatment of waterfowl proves to be effective, however, it would be difficult to adopt as a general treatment for all lakes in a region. A permit is required from the U.S. Fish and Wildlife Service (USFWS) to capture or treat common mergansers or other waterfowl because all are federally protected. The USFWS is reluctant to issue such permits except for research purposes. Some lake associations have tried to obtain permits for routine treatment, but their applications were rejected. In Wisconsin, the use of praziquantel is considered impractical on a lakewide basis (Wisconsin press release, 2001, Swimmer's Itch: A Common Summertime Pest).

Another control approach that Dr. Blankespoor and his colleagues are testing is to capture young birds (mergansers) that are flightless but old enough to obtain their own food. The birds are treated with praziquantel and are then moved to a lake where swimmer's itch does not occur. These parasite-free young birds are assumed to imprint on their new location, return to it the following year and establish parasite-free populations, thereby safeguarding the lake and its users. How effective and practical this approach will be for widespread use remains a question. Relocation of young birds of these federally protected species requires permits from the USFWS. Even if the bird populations are reduced, migrants may stop over on lakes and deposit enough eggs (miracidia) in their feces to reinfect snail populations. This procedure will have to be tested with more replication before its effectiveness can be assessed. It is also important to remember that other bird species and some mammals serve as final hosts for swimmer's itch parasites.

Figure 5. a. Snails being collected using the glass bottom metal bucket and strainer. **b.** Three snails in the hand of a collector, strainer is to the right of the hand. *Photographs by Richard Snider.*
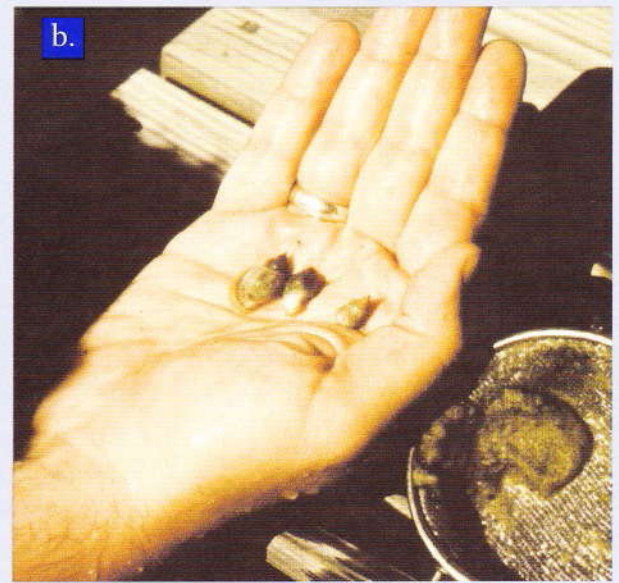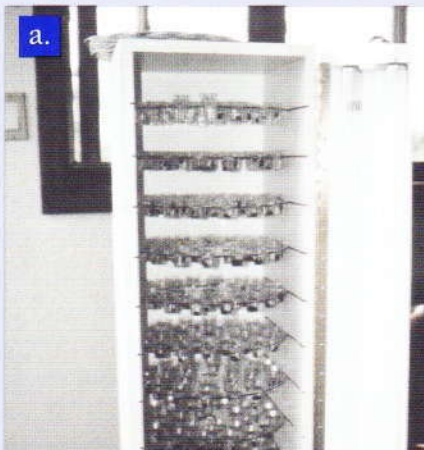

Figure 6. a. Light box showing circular inserts with holes containing individual plastic cups. Two fluorescent lights are attached on the right side ot the box by hinges. **b.** Circular insert with holes and some plastic cups containing snails. **c.** Individual plastic cup containing a snail being examined for cercariae with a microscope. *Photographs by Nate Coady.*

Section XI. Conclusions

Several reports suggest that the number of human swimmer's itch cases and the number of lakes where swimmer's itch occurs in Michigan are increasing annually. Possible reasons include:

■ Waterfowl populations are high and bird numbers are increasing on numerous lakes scattered throughout the state with habitats favorable for the survival of snail intermediate and final bird and mammal hosts.

■ Increasing numbers of people come to the lakes for water-based recreation at a time when the cercariae that cause swimmer's itch are being produced in the greatest numbers.

■ More homes and cottages are being built on lakes, another indication that the number of lake users is rising.

■ Better reporting procedures have been developed by some lake associations; therefore, annual increases may reflect improved reporting, not an increase in the occurrence of the disease.

Furthermore, Magnuson et al. (1997) predicted that warmer climates and increased evaporation in excess of precipitation in the Great Lakes area will lower net basin water supplies and water levels, and reduce stream flows. They also suggested that the warmer climates will decrease the spatial extent of ice cover on water in this area. Lower water levels and lower water flow promote retention of cercariae, retention of snail intermediate hosts and development of snail habitat. Less ice on lakes suggests that aquatic birds may remain on lakes for longer periods of time. These possible climatic changes and their effects on other organisms may mean that more cases of swimmer's itch will occur in the future in Michigan lakes and rivers.

In view of the importance of water-based activities to cottage owners and vacationers who use resort facilities, youth camps and public beaches in Michigan, developing methods for control or prevention of swimmer's itch should be a high priority. Active, continuous control, treatment and prevention programs, coupled with education of lake users, are required to manage impacts of swimmer's itch in Michigan lakes so that citizens can fully enjoy the benefits of this resource. A more thorough knowledge of the life histories, biology and ecology of the parasites and their hosts is vital to improving present control techniques and developing new ones. Future research studies using carefully designed experiments and statistical analyses could lead to improved understanding of natural variation in infection values of intermediate and final hosts. With more comprehensive and accurate information, models that predict outbreaks of swimmer's itch in lakes could be developed. These models, in turn, would provide guidelines for implementing the most effective and cost-effective control programs.

Although much money and effort have been spent studying many aspects of swimmer's itch, this disease still remains a problem. The causative agents of swimmer's itch will probably not be eradicated from lakes in Michigan in the foreseeable future. There is little new research to identify or develop newer, more efficient and safer molluscicides to control the snail intermediate hosts, and information on chemicals that could prevent cercariae from penetrating humans is in its infancy. For

Other Diseases of Humans Caused by Flukes

The swimmer's itch problem in Michigan is not unique. Diseases of humans caused by flukes are common in many parts of the world, where they can be much more deleterious (even fatal) than swimmer's itch because humans are the final host of the parasite. These diseases have been known for hundreds of years. We now know that interruption of the parasite's life cycle would be the most effective way to stop the incidence of such diseases. Given that we cannot eradicate final hosts, the obvious targets for control measures are the snail intermediate hosts. To date, none of the control measures have been effective in eradicating the snails that serve as intermediate hosts. Therefore, control of the mollusks that serve as intermediate hosts for flatworms that cause swimmer's itch will not be achieved in the near future.

those lake associations and riparian owners opposed to the use of chemicals, the following prevention and control measures, applied aggressively and in a timely manner, may diminish the swimmer's itch problem without the use of environmentally hazardous chemicals.

- Do not feed waterfowl. Feeding them will attract and congregate them in areas where they become sources of infection for snails.

- Remove bird roosting logs from the water. Forcing the birds to roost farther from the beach would decrease the chance of fecal contamination of lake water and minimize the opportunity for snails to become infected.

- Manually remove snails from beaches and destroy them. This would require major efforts by many volunteers to be effective.

- Destroy snail habitat and remove vegetation that the snails live in. Though this is easy to say, it is difficult to accomplish. If a permit is obtained, periodic raking or rototilling of a beach may help.

- Use some type of sunscreen/insecticide with DEET before entering the water. Insect repellent alone is likely to wash quickly off the skin, so combined sunscreen/bug repellent lotions are more likely to be effective.

- Avoid swimming in shallow water next to shore because cercariae may concentrate there, depending on wind direction.

- Take a shower immediately after getting out of the lake and remove your swimsuit as quickly as possible. If a shower is not available, towel your body dry as soon as you can. Though this is not likely to be completely effective, it may reduce cercarial penetration of the skin.

People utilizing lakes in Michigan that have a swimmer's itch problem should become more actively involved in control and take ownership of the problem. They should become informed about all aspects of the life cycles of these flatworms and how humans become infected. Only sustained effort and long-term commitment by the public working with legislative officials and/or with pharmaceutical companies to urge them to formulate preventive creams or lotions will solve the problem. A quick solution is currently not at hand.

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