A Survey of Swimmer's Itch–Causing Cercariae and their Intermediate Snail Host Species in Devil's Lake Wisconsin

by

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Abstract

Cercarial dermatitis or swimmer's itch has been a problem at Devil's Lake (Sauk County, Wisconsin) for decades. We investigated swimmer's itch in Devil's Lake during the summer of 1999. The project focused on identifying the species of schistosome cercariae and their snail intermediate hosts causing the swimmer's itch problem in the lake. We determined the aquatic habitats associated with intermediate host snail species and their densities to elucidate ecologically safe management options to reduce the incidence of swimmer's itch to the users of Devil's Lake. Swimmer's itch was not a significant problem at Devil's Lake this summer. Visitors reported 5 swimmer's itch cases to park officials, while 50-100 cases a summer have been reported in past years. No cercariae causing swimmer's itch were found in our samples. However, 3 of the 17 snail species found in the lake were documented in the scientific literature to be intermediate hosts of swimmer's itch parasites. All three host species – *Physa skinneri*, *Gyraulus parvus* and *Fossaria obrussa* (Say) group (exigua strain) – were most dense along the entire north and south shorelines of the lake. At least one of the three species was found at all 10 sampling sites around the perimeter of the lake. We suggest that broad ecological control measures that reduce snail densities are needed to control the swimmer's itch problem in the lake. These include reducing lake phosphorus concentrations through various management options, which in turn would lead to a reduction in periphyton growth, the major food source of snails. Periphyton growth is currently high in the lake.

Alternatively, sustained fish manipulations that lead to greater predation rates on snails also may be effective. Both control measures are directed at decreasing the probability of snail infection by the short-lived miracidia released from parasite-infected waterfowl, which seasonally frequent the lake in large numbers. Finally, we recommend that public surveys of the swimmer's itch problem on not only Devil's Lake but lakes throughout Wisconsin be conducted each year to help direct future state-wide research efforts.

Introduction

"Swimmer's itch" is a dermatitis caused by a larval Trematode fluke called a cercaria that penetrates into human skin while swimming. It is rarely dangerous and not contagious but it can be uncomfortable. Symptoms include small red welts, itching and swelling on localized areas of the body near the point of entry of the cercariae; in severe cases pain and fever can occur (Bean 1968, Kirschenbaum 1979). Most people suffer only from an irritating rash that can last for a few hours to several weeks.

Swimmer's itch has been a significant problem for decades at Devil's Lake, (Sauk County, Wisconsin). The lake is located in Wisconsin's most heavily used state park - Devil's Lake State Park. In past years, hundreds of people reported swimmer's itch symptoms after swimming in the lake. As a result, swimmer's itch can deter visitors from using the water and enjoying their visit to the park. In addition, swimmer's itch has raised concerns about causing negative economic impacts on tourism. Historically, Devil's Lake was treated with copper sulfate in the 1950's and early 1960's to control the problem (K. Lange, retired park naturalist, pers. com. 1999). Tim Miller, park superintendent from 1986-1999, recounted that swimmer's itch had been a chronic nuisance since 1979, when he first started working at the park. He said that swimmer's itch usually becomes a problem at the park in mid June to early July.

In 1992, swimmer's itch at the park became a media issue when the "Devil's Lake Itch Group" was formed. This fifteen-member committee of concerned citizens asked the Department of Natural Resources to address the swimmer's itch problem. The attention prompted the park to post warning signs at the north and south shore beaches after the first few swimmer's itch cases of the season were reported to park officials. Control methods such as copper sulfate treatments and the use of Praziquantel™ were investigated but found to be impractical for the lake (Lange, pers. com. 1993). In 1998, a visiting international parasitologist, Dr. Ivan Kanev, conducted a short-term pilot study to determine the species of parasites that cause the problem in the lake (Holtan 1998). Of the 5,000 snails that Kanev collected in his two-week study, he found that snails in the Physidae and Lymnaeidae families were infected with 2 different species of the cercariae causing swimmer's itch, *Cercaria ocellata*, and 2 other furcocercariae species. (Kanev Stoyanov 1998). Upon further analysis of photos, Dr. Scott Snyder, parasitologist at the University of Wisconsin-Oshkosh, determined that the *Cercaria ocellata* that Dr. Kanev identified were indeed *Trichobilharzia ocellata* and the 2 species of furcocercariae were most likely from the Strigeidae family and not swimmer's itch causing.

Due to the lack of long-term swimmer's itch control methods and because of the mounting complaints about swimmer's itch at Devil's Lake State Park, the Wisconsin

Department of Natural Resources and the Friends of Devil's Lake State Park funded a project to thoroughly investigate swimmer's itch in Devil's Lake during the summer of 1999. The project focused on identifying the species of schistosome cercariae and their snail intermediate hosts causing the swimmer's itch problem in the lake. A particular emphasis was placed on determining the aquatic habitats associated with intermediate host snail species and their densities to elucidate ecologically safe management options to reduce the incidence of swimmer's itch to the users of Devil's Lake.

Background Information on Swimmer's Itch

The first record of swimmer's itch was in 1928 on Douglas Lake, Michigan (Cort 1936a). While it was first reported in Wisconsin lakes that same year (Cort 1936b), swimmer's itch may have been a problem in Wisconsin since the lake 1800's (Brackett 1940). It has been reported from all parts of the world in tropical, temperate and arctic climates, in both freshwater and marine environments (Hoeffler 1977, Kirschenbaum 1979, Mulvihill and Burnett 1990). In the United States, cases have been reported from 27 out of the 50 states with most reports concentrated in the upper Midwest (Loken et al. 1995). These midwestern states are in close approximation to the Mississippi waterfowl flyway, a migration route for many of the avian hosts that can carry the swimmer's itch causing trematodes (Hoeffler 1977, Kirschenbaum 1979, Mulvihill and Burnett 1990).

Over the years, the dermatitis has been called "swimmer's itch," "duck itch," "lake itch," or "sedge itch" in freshwater environments, and "seabathers eruption," "clam digger's itch," or "weed itch" in marine environments (Featherston et al. 1988). In north temperate climates, swimmers itch is most often reported in the first warm period of the year from late May to early July when water temperatures rise, causing high levels of cercarial shedding (Lindblade 1998, Blankespoor and Reimink 1999).

Trematodes in the family Schistosomatidae are characterized by a two-host life cycle and are primarily parasites of birds and mammals (Schell 1985, Fig. 1). The adult parasites grow inside the blood vessels and intestines of the definitive host –a particular bird or mammal species. The female schistosome lays thousands of eggs in the intestinal

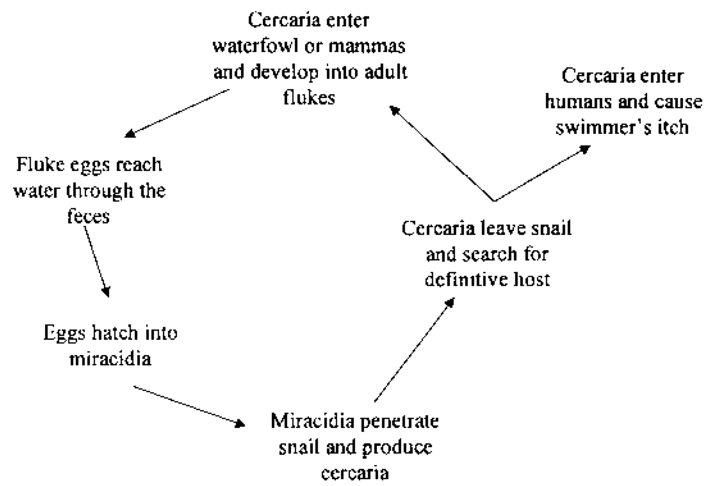

Figure 1. Life-cycle of digenetic Trematodes

wall and these eggs are excreted into the lake via feces. Each egg hatches into a miracidium once the egg reaches the water. Miracidia are free-swimming and have 12-48 hours to find a snail intermediate host. Once a miracidium finds the proper snail host, it penetrates into the snail's soft tissue and undergoes further development through a sporocyst stage capable of producing many cercariae via asexual reproduction. After about 5 weeks, infected snails begin to shed free-swimming colorless cercariae with forked tails and a body length of approximately 0.7mm (Mulvihill and Burnett 1990, Spencer and Loken 1993). Cercariae can live for 24-36 hours free-swimming while trying to find and invade the proper definitive mammalian or avian host species. The cercariae are attracted to the host by sensing short-chained fatty acids, skin surface lipids and long-chain unsaturated fatty acids, which promote attachment to the host's skin (Shiff et al. 1993). Attachment is also stimulated by at least a 1° C temperature difference between the host (or other organisms, such as a human) and by shadow stimuli that induce forward swimming movements (Feiler and Haas 1988). The cercariae secrete proteolytic enzymes that allow them to penetrate the host's epidermis. When they enter the skin the cercariae lose their tails and form a new stage, the schistosomule. The schistosomules migrate via the blood vessels to the lungs and finally to the hepatic (liver) veins where they complete their life cycle by maturing into adult male and female flukes.

Humans become "dead-end" hosts when schistosome cercariae accidentally penetrate the skin after which the human immune system causes the cercariae to die. Itching results from an allergic reaction to the proteolytic enzymes the cercariae secreted upon skin penetration and from the dead cercarial remains under the skin. Each red spot, or papule, is the result of one penetrated cercaria. About 30-40% of people who come in contact with schistosome cercariae are sensitive to the parasite and experience a reaction (Koshere 1999). In addition, cercarial dermatitis is a sensitization phenomenon, with more intense reactions often occurring with each subsequent exposure (Kirschenbaum 1979, Mulvihill and Burnett 1990).

Penetration of the cercariae can occur when the water evaporates on skin, resulting in a tingling sensation. One possible way to prevent swimmer's itch is to briskly towel off immediately upon leaving the water. Showering after swimming should also help. Some evidence has shown that applying oily substances such as sunscreen can reduce cercarial penetration, but these measures and others are not completely effective (Koshere 1999). Once swimmer's itch is contracted, treatment options are limited except for topical lotions and creams to reduce the itching symptoms.

Many species of schistosomes cause swimmer's itch. Blankespoor and Reimink (1988a,b) reported up to 20 different species in Michigan alone. In addition, each trematode species often uses both a specific snail and bird species as its intermediate and definitive hosts (1988a,b,; Blankespoor and Reimink 1999). Thus, efforts to control or treat the problem in a lake are difficult.

In the past, scientists have attempted to control swimmer's itch with less than successful long-term results. Control efforts focused on interrupting the life cycle of the schistosome either at the level of the intermediate snail host or the adult schistosomes in the definitive host. Cort (1950) reports the usage of copper sulfate and other inorganic copper compounds as molluscicides to kill snail species in swimmer's itch infested lakes. Treatments were only conducted in small lakes under calm conditions. These methods were successful for approximately 1-3 years, requiring lakes to be treated on an annual basis. In addition, some treated sites experienced "cercarial drift" where cercariae were later blown into the treated area from other parts of the lake.

Blankespoor and Reimink (1991) concluded that copper sulfate programs have limited success for numerous reasons. First, mollusks reproduce and disperse at surprising rates. Second, many lakes are treated without thorough snail monitoring and little effort is made to determine if snails that are infected with swimmer's itch schistosomes are found in the treated areas. Third, persons involved in applying copper sulfate to the lake often lack knowledge and experience with the application processes. Finally, some evidence suggests that snail populations exposed to copper sulfate over long periods can develop some resistance to the chemical (Blankespoor et al. 1985). Recent pesticide laws have since banned the use of molluscicides due to the negative effects that they have on non-target snails and other invertebrates, and the build up of copper carbonate in lake sediments (Koshere 1999).

Blankespoor and Reimink (1991) discuss an alternative method to control swimmer's itch by targeting and treating the definitive host before it can pass the parasite into a lake. They inject or feed the avian host, in some cases several times a season, with the anti-helminthic drug Praziquantel ™ that eliminates the adult schistosomes from the hosts' blood vessels. This expensive and labor-intensive process requires that all avian hosts be live trapped or pre-baited and then treated with the drug. They found positive results with both the common merganser and mallards and reported fewer cases of swimmer's itch in a lake (Reimink et al. 1995). However, the only reason why this method succeeded at their site in Michigan is that the birds remained on the lake for the entire summer and the spring and fall migrants were generally not infected with parasites causing swimmer's itch. It should be noted that this method has only been tested on two species of avian hosts (common merganser and mallard) and infection rates were measured on only one snail species (*Stagnicola emarginata*) from the lake. Additionally, this solution involves adding a new chemical into an aquatic environment, which can thus be considered a contaminant, for which no treatment protocol for use in wild species has been developed. In the end, success of this method will be limited to extremely specific situations. Koshere (1999) concluded that the procedure is considered impractical on a lake wide scale in Wisconsin, especially in large lakes with large migratory flocks of waterfowl (such as in Devil's Lake).

Although swimmer's itch has been a research topic since the late 1920's when scientists first attempted to determine methods to control its frequency and transmission, outbreaks of swimmer's itch are currently on the rise. Blankespoor and Reimink (1991) and Spencer and Loken (1993) offer several explanations for this phenomenon. Growing human populations and booming tourism industries exert increasing pressures on inland lakes for recreational purposes, exposing more people to schistosome cercariae. Increased usage of lakes also means increased human related nutrient inputs, allowing for more periphyton (attached algae) growth and larger snail populations that graze the periphyton. Breeding ranges of some bird definitive host species have increased, thus more parasites are transferred between sites. Finally, medical doctors and health officials are more familiar with swimmer's itch and its symptoms, resulting in more accurate documentation of clinical cases.

Methods

This study was conducted from May to August 1999 in Devils Lake, near Baraboo, Wisconsin. Devil's Lake is 149 ha (368 ac) in surface area and has a maximum depth of approximately 14.3 m, although its maximum depth can range anywhere between 13 and 15 m (Lathrop et al. 1994). The lake is a seepage lake with one small inlet stream and no outlet. As a result, annual variations in precipitation are reflected in rather dramatic water-level fluctuations both seasonally and between years. Because the east and west shorelines drop off rapidly from the surrounding steep quartzite bluffs, the lake's littoral zone (shallow water capable of supporting rooted aquatic plants) is mostly confined to the north and south ends of the lake (Fig. 2). Table 1 summarizes general water chemistry parameters for Devil's Lake.

Table 1. Mean annual values for water chemistry parameters of Devil's Lake collected during 1985-86 (from Lathrop et al. 1989).

Color (Pt-Co)	Conduct. (μmhos/cm)	pH	Alk. (μeq/L)	Ca (mg/L)	Tot. P (μg/L)	Chl-*a* (μg/L)
7	76	6.8	449	7	12	8.0

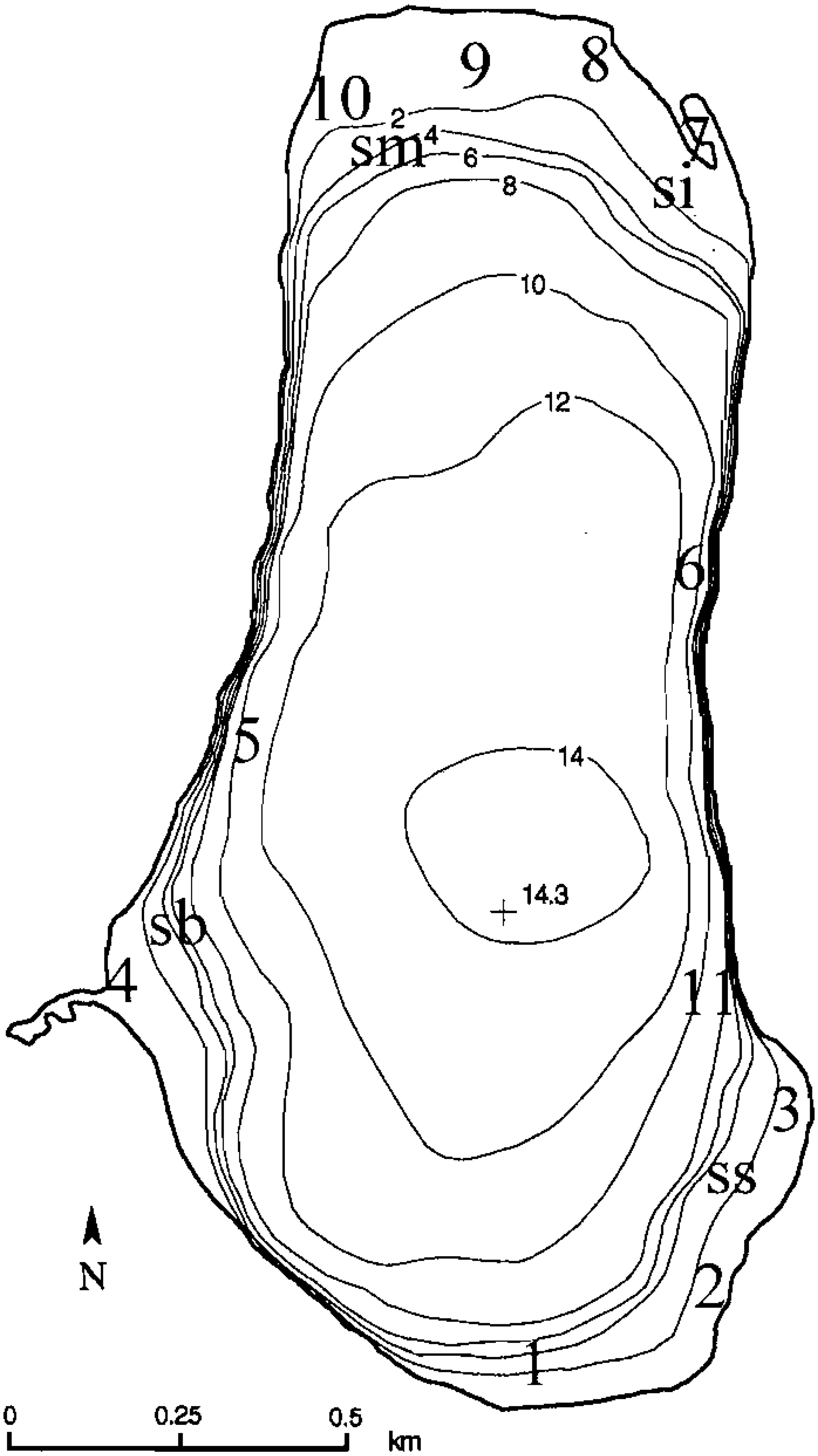

Figure 2. Location of sample sites on Devil's Lake.

Sites

Sites 1-10 were chosen in order to sample the wide array of underwater habitats in Devils Lake (Fig. 2, Table 2). Eight sites were concentrated around the North and South

Table 2. Habitat Descriptions.

SITE	HABITAT
1	Sand and small aquatic macrophytes
2	Sand, small rocks, detritus and small aquatic macrophytes
3	Sand, detritus and small aquatic macrophytes
4	Tall aquatic macrophytes, large rocks and sand
5	Boulders and periphyton
6	Boulders, periphyton, pebbles, sand and small aquatic macrophytes
7	Sand and tall aquatic macrophytes
8	Sand, pebbles, small rocks and tall aquatic macrophytes
9	Sand, periphyton and small aquatic macrophytes
10	Boulders, periphyton, sand, detritus and small aquatic macrophytes

beaches due to heavy human use in those areas. Two sites were located along the east and west rocky shorelines, midway between the two beach areas. Site 11 was chosen as a site to monitor only periphyton. Sites **sm**, **si**, **ss** and **sb** were located in macrophyte beds and used only for a short-term experiment to determine cercarial densities in macrophytes.

Snail Sampling

Snails were sampled monthly at sites 1-10 from June through August 1999. SCUBA diving was used in conjunction with a hand-held D-shaped net (30 cm diameter) that was pushed along the lake bottom (Featherston et al. 1988) for 5 separate 1-m intervals constituting one sample, which was consistent with other snail research methods being conducted by University of Wisconsin-Madison scientists (David Lewis, UW Center for Limnology, pers. com. 1999). Air temperature, surface water temperature and dissolved oxygen (D.O.) were generally taken at each site in the lake.

Once back in the laboratory, the contents of each site's composite net sample were then placed in a dissecting tray and snails were removed and placed in a separate container containing fresh lake water. The snails were then identified, counted and individually placed in plastic cups (either 3.5 x 3.4 cm or 9.0 x 7.0 cm) filled with non-chlorinated tap water. In the event of high snail densities from a single site, all snails of species documented in the literature to host parasites causing cercarial dermatitis were isolated in cups, while only 10-15 snails of species that do not host the parasites were isolated in cups. The snails were maintained at room temperature overnight. At about 8:30 A.M. the next day, the snails were exposed to 2 hours of bright fluorescent light (Guth et al. 1979, Kulesa et al. 1982) to induce cercarial shedding. Each cup was then examined under a dissecting microscope to determine the presence of released cercariae from the snails. The cups were checked daily for cercariae for three days (Laman et al. 1984). In June, the snails were only subjected to bright fluorescent light on the first day of observation and water was changed only in cups with dirty water. In July and August, the snails were exposed to 2 hours of bright fluorescent light in the morning on all three days of observation. In addition, water was changed daily. Only snails actively shedding cercariae were considered infected.

Live cercariae were stained with neutral red solution to examine morphological features (Shostak 1992, Loken et al. 1995). Cercariae were identified to family according to Combes et al. (1980) and Schell (1985). Length and width measurements (mm) were made of all isolated snails. Length was measured from the spire tip to the base of the aperture and width was measured from between the lateral-most edges of the body whirl (D. Lewis, pers. com. 1999).

Free-Floating Cercariae Sampling

A simple floating trap modified from a stationary cercarial trap designed by Shiff et al. (1993) was used to detect free-floating cercariae in the water column. A 36 x 30 x 5 cm block of foam was connected to one end of a 0.9 cm diameter, 1.2 m long aluminum rod using two small hose clamps and two washers. A maximum of 21 medium sized paper binder clips were positioned on the rod in a helix fashion by sliding the rod through the two semicircular openings on the clip so that each clip remained in the closed position with enough tension to hold one microscope slide. Approximately 10-20 pretreated microscope slides were inserted in the clips. Because of the helix rotation design and successive clips being about 4 cm apart, microscope slides had good exposure to the water.

The 75 x 25mm microscope slides were treated with a matrix comprising of clear nail varnish (AM Cosmetics, Inc., Brooklyn, NY) and linoleic acid (99% pure, Aldrich Chemical Co., Milwaukee, WI), a fatty acid that cercariae are attracted to. One drop of nail varnish was placed on the end of each slide and 10 μl linoleic acid was added using a micropipette. The compounds were mixed on the slide using a watercolor brush and spread over 4 cm^2 of the surface. The slides were allowed to dry at room temperature for at least an hour before they were used. Unused slides were stored in the dark for no more than 24 hours (Shiff et al. 1993). The slides were arranged in a helix design to capture as many settling cercariae as possible. The first clip was positioned so the opening was 10 cm below the water surface. If 15 or 20 slides were used in the trap, consecutive clips were used and slides were approximately 4 cm apart. If 10 slides were used, every other clip was used and slides were approximately 8 cm apart.

A nylon rope was tied on the bottom end of the rod and connected to a brick on the lake bottom which held the trap upright and kept the apparatus stationary at each site. Traps were deployed at each site weekly from June-August 1999. Traps were immersed for 2 hours during the period of most intense sunlight (11 A.M.-3 P.M.) when maximum cercarial densities were expected at the surface (Brackett 1940, Appleton and Lethbridge 1979, Ouma et al. 1989).

Two cercarial traps were deployed for 2 hour time periods in areas of dense vegetation on August 13 and 19, 1999 to determine if a relationship existed between dense vegetation and cercariae densities. On August 13, traps were set at sites **sm** and **si**, two Eurasian watermilfoil macrophyte beds in the north shore beach area. On August 19, traps were set at sites **ss** and **sb**, two Eurasian watermilfoil macrophyte beds on the south shore of the lake.

In addition, three cercarial traps were set for 2 hours each at site 6 on August 26, 1999 to sample free-floating cercariae. Previously that week, 3 *Physella vinosa* snails shed cercariae morphologically similar to cercariae that cause cercarial dermatitis. We performed this experiment to check the accuracy of the traps in collecting cercariae.

Periphyton Sampling

Periphyton traps were deployed for 2-week periods in up to four sites in the lake continuously from June through August 1999. The traps consisted of a small 16 x 9.5 cm plastic tray that held eight 75 x 25 mm microscope slides. The tray was attached to two small floats and then tied to a brick on the lake bottom. The tray floated approximately 20 cm above the brick. Traps were placed in 0.5-1.5 m water, where they would receive maximum sunlight. Four sites were used from June 11-July 23: sites 5, 6, 10 and 11. Three sites were used from July 23-September 3: sites 6, 10 and 11. Some of the deployed traps were either vandalized or stolen in all but the last incubation period.

The slides were analyzed for Chlorophyll *a* according to American Public Health Association (1989) methods for the June 11-25 sampling. From June 25-September 3, slides were taken to the Wisconsin State Laboratory of Hygiene where they were analyzed for Chlorophyll *a* and dry weight using EPA approved methods.

Results

Five cases of swimmer's itch were reported in 1999. The first case was reported on 7/10/99. The final case was reported 8/5/99. In past years, 50-100 cases were reported each summer.

Snail Sampling

Seventeen species of snails were found in Devil's Lake (Table 3). None of the

Table 3. Snail species collected with average length and width measurements (± 1 std. dev.) in Devil's Lake from June-August 1999. Species in bold lettering are documented in the scientific literature to be an intermediate host of parasites causing swimmer's itch.

SNAIL SPECIES	TOTAL COLLECTED	TOTAL INCUBATED IN LAB	AVERAGE LENGTH (mm)	AVERAGE WIDTH (mm)
Amnicola limosa	1508	199	3.1 ± 0.9	2.6 ± 0.6
Amnicola walkeri	16	16	2.6 ± 0.7	2.1 ± 0.6
Campeloma decisum	18	18	11.9 ± 4.1	9.1 ± 2.9
Fontigens nickliniana	3440	144	3.1 ± 0.4	1.9 ± 0.2
Fossaria obrussa* (Say) group	3	3	5.4 ± 1.6	2.8 ± 0.5
Gyraulus deflectus	30	18	1.3 ± 0.5	3.6 ± 1.7
Gyraulus hornensis	15	14	0.9 ± 0.2	2.5 ± 0.9
Gyraulus parvus	51	49	1.5 ± 0.7	2.9 ± 0.6
Gyraulus spp. (broken)	2	2	1.6	2.8
Helisoma anceps	280	124	3.9 ± 1.5	5.8 ± 2.6
Hoyia sheldoni	4	4	3.3 ± 0.6	2.0 ± 0.3
Marstonia lustrica	1	1	4.4	3.4
Physa skinneri	178	168	6.1 ± 3.0	4.0 ± 1.9
Physa spp. (dead)	44	44	5.2 ± 2.5	3.6 ± 1.8
Physella vinosa	15	15	11.4 ± 2.2	8.0 ± 1.7
Planorbella campanulata	11	11	6.1 ± 0.8	12.0 ± 2.2
Planorbella truncata	5	5	6.3 ± 0.5	10.9 ± 0.4
Promenetus umbilicatellus	1	1	0.7	1.7
Seed	26	26	0.6 ± 0.3	1.7 ± 0.6
Viviparus georgianus	398	322	14.9 ± 6.1	12.5 ± 4.7
TOTAL	**6046**	**1184**		

*Believed to be in the exigua strain, based on morphological characteristics

1184 snails incubated in the laboratory shed cercariae causing schistosome dermatitis. However, ten of the seventeen snail species were infected with larval trematodes that shed non-swimmer's itch cercariae (Table 4). Three of the snail species found in Devil's Lake are documented in the scientific literature to be an intermediate host for swimmer's itch cercariae (Table 5). *Physa skinneri* were found at all 10 sites. *Gyraulus parvus* were found at sites 1, 2, 8, 9 and 10 and *Fossaria obrussa* group (exigua strain) were found at sites 1 and 9. Densities of these three snail species were highest at sites 1-4 and sites

Table 4. Prevalence of larval trematodes in snail species in Devil's Lake. Snails were collected June-August 1999.

Snail Species	Number Infected	% Infected	Trematode Infections	Definitive Host
Amnicola limosa	1	1.0	1 Monostome	Birds, Mammals, Rodents, Meadow Mouse, Muskrat, Turtles, Fishes (rarely)
Amnicola walkeri	1	6.3	1 Monostome	Birds, Mammals, Rodents, Meadow Mouse, Muskrat, Turtles, Fishes (rarely)
Fontigens nickliniana	15	10.0	15 Monostome	Birds, Mammals, Rodents, Meadow Mouse, Muskrat, Turtles, Fishes (rarely)
Gyraulus parvus	2	4.1	1 Gymnocephalous	Herbivorous Mammals, Birds
			1 Spirorchiidae	Turtles
Helisoma anceps	3	2.4	1 Armatae	Vertebrates, Amphibians, Reptiles, Turtles, Tadpoles, Fishes
			1 Gymnocephalous	Herbivorous Mammals, Birds
			1 Strigeidae	Birds, Mammals
Hoyia sheldoni	1	25.0	1 Mononstome	Birds, Mammals, Rodents, Meadow Mouse, Muskrat, Turtles, Fishes (rarely)
Physa skinneri	5	3.0	2 Spirorchiidae	Turtles
			1 Cystocercous	Fishes, Amphibians, Reptiles, Turtles
			1 Gymnocephalous	Herbivorous Mammals, Birds
			1 Strigeidae	Birds, Mammals
Physella vinosa	3	20.0	3 Spirorchiidae	Turtles
Planorbella campanulata	4	36.0	3 Virgulate	Amphibians, Birds, Mammals (Bats), Turtles
			1 Echinostome	Reptiles, Birds, Mammals
Viviparus georgianus	45	14.0	45 Virgulate	Amphibians, Birds, Mammals (Bats), Turtles

8-10 along the south and north ends of the lake, respectively (Fig. 3). Monthly snail densities per site and average monthly snail sizes are presented in Appendices 1-4.

Table 5. Snail species from Devil's Lake documented in the scientific literature to be an intermediate host for parasites that cause swimmer's itch.

Snail Intermediate Host	Schistosome Species	Definitive Host	Source
Fossaria obrussa (Say) group*	*Cercaria elvae*		Cort 1936
Gyraulus parvus	*Cercaria elongata*		Brackett 1940b, Cort 1950, Laman et al. 1984
	Cercaria gyrauli	Blackbird	Brackett 1940b, Cort 1950, Laman et al. 1984
Physa skinneri	*Cercaria gyrauli*	Blackbird	Brackett 1942
	Cercaria physellae	Blue winged teal, mallards, pigeons canaries	Brackett 1940b, Cort 1950,
	Trichobilharzia physellae	Blue winged teal, mallards, pigeons canaries	Spakulova et al. 1997

* Believed to be in the exigua strain, based on morphological characteristics

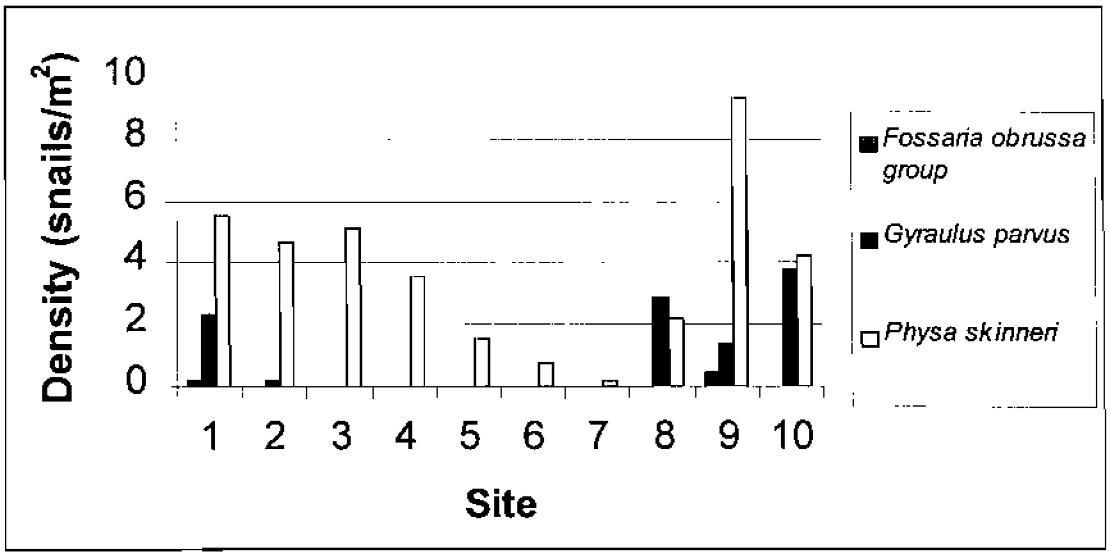

Figure 3. Density (snails/m^2) of snails with the potential to be intermediate hosts for parasites that cause schistosome dermatitis. Snails were collected monthly at the 10 sapling sites in Devil's Lake during the period from June through August 1999. Sites 1-4 are representative samples from the entire south shoreline and sites 7-10 are representative samples from the entire north shoreline. Sites 5 and 6 are representative samples from the east and west shorelines.

Free-Floating Cercariae Sampling

Out of 916 slides observed, only 19 forked tails and 2 forked full bodies were found attached to the matrix of linoleic acid and nail varnish (Table 6). Only 2 forked tails were found in the matrix on the slides from the vegetation experiment at sites **sb**, **si**, **sm**, and **ss**. No forked tails or forked full bodies were found in the matrix on any of the slides from the site six experiment on August 26 (Table 6).

Table 6. Free-floating cercariae body parts collected on cercarial trap slides. Sites 1-10 were sampled weekly from 6/10/99-8/20/99. Sites **sm** and **si** were sampled on 8/13/99. Sites **ss** and **sb** were sampled on 8/19/99. Sites 6(6), 6(7) and 6(9) were sampled on 8/26/99

Site	**Forked Tails**	**Forked Full Bodies**	**Heads**	**Non-Forked Tails**	**Non-Forked Full Bodies**
1	1	1	34	55	9
2	2	0	14	37	8
3	1	0	10	21	11
4	0	0	13	25	6
5	1	0	18	34	4
6	5	0	24	45	8
7	0	1	8	15	11
8	4	0	11	13	4
9	0	0	8	8	5
10	3	0	10	43	8
sb	1	0	1	3	0
si	0	0	0	2	0
sm	1	0	0	0	0
ss	0	0	0	1	0
s6(6)	0	0	0	0	0
s6(7)	0	0	0	0	0
s6(9)	0	0	1	2	0
TOTAL	**19**	**2**	**152**	**304**	**74**

Periphyton Sampling

Periphyton varied both spatially and temporally from June to August 1999 (Table 7a,b). Average chlorophyll *a* and average dry weight measurements were highest at sites 10 and 11, which are located in close proximity to both the north and south shore swimming areas (Table 7a, Fig. 2). Average chlorophyll *a* varied in the later half of the summer while average dry weight varied over the entire summer. Appendix 5 summarizes all periphyton data for the summer.

Table 7a. Average daily periphyton growth per site of from June-August 1999. Data only includes traps that were in the lake for the entire 14-day sample period.

Site	**Average Chlorophyll *a* mg/m^2/day**	**Average Dry Weight mg/m2/day**
5	0.09	50
6	0.13	99
10	0.27	199
11	0.27	110
Summer Average	0.19	115

Table 7b. Average daily periphyton growth per sampling period from June-August 1999. Data only includes traps that were in the lake for the entire 14-day sample period.

Sample Period	**Date**	**Average Chlorophyll *a* mg/m^2/day**	**Average Dry Weight mg/m2/day**
1	6/11/99-6/25/99	0.17	.
2	6/25/99-7/9/99	0.17	154
3	7/9/99-7/23/99	0.17	122
4	7/23/99-8/6/99	0.15	205
5	8/6/99-8/20/99	0.03	19
6	8/20/99-9/3/99	0.22	92
Summer Average		0.15	118

Discussion

Swimmer's itch has a widespread occurrence in Wisconsin as well as all over the world. There are few, if any, special characteristics of lakes having the problem (Koshere 1999), although it would seem unlikely that lakes with very low fertility (ultra-oligotrophic) would have sufficient nutrients to grow enough periphyton needed to support adequate snail populations. Because many of Wisconsin's lakes are at least moderately fertile, swimmer's itch can plague some of Wisconsin's finest recreational waters, such as Devil's Lake. However, the intensity of swimmer's itch outbreaks in a specific lake can fluctuate greatly from year to year (Brackett 1942, Blankespoor and Reimink 1999)

Swimmer's itch has been a problem at Devil's Lake for more than 50 years (Lange pers. com. 1999). Yet in the summer of 1999, we found no swimmer's itch cercariae in either our cercarial traps or in our snail incubation studies. Coincidentally, park officials only reported 5 visitor complaints of swimmer's itch compared to 50-100 (Becky Meisenburg, park ranger, pers. com. 1999) per summer for many earlier years. Blankespoor and Reimink (1999) discuss several reasons that can account for this occurrence.

First, the distribution and number of snails that can serve as intermediate hosts can influence the occurrence of swimmer's itch. Only 3.8% of the snails we collected from June-August 1999 were species that the scientific literature indicates could be intermediate hosts for parasites that cause swimmer's itch. In addition, results from other studies (Kulsea et al. 1982, Laman et al. 1984, Daniel 1984, Spencer and Loken 1993, Koshere 1999) have found that only 1-5% of possible intermediate snail hosts actually are infected with the parasites causing swimmer's itch. In our study, that would mean that only one *Fossaria obrussa* (Say) group, three *Gyraulus parvus* and nine *Physa skinneri* out of the 6,046 total snails collected would have been infected. With so few infected snails, it is easy to see how infected snails would be hard to locate at our 10 different sites.

Second, the distribution and number of definitive bird hosts on a lake can determine the severity of swimmer's itch. In addition, Keas and Blankespoor (1997) found that variable aggregations of definitive hosts affect the prevalence of larval trematodes at specific locations on a lake. Fifteen species of migratory birds known to use Devil's Lake are documented in the scientific literature to be definitive hosts for parasites causing swimmer's itch (Table 8). Lange (1996) showed fluctuations in numbers, dates and length of stay of 14 of these 15 water birds species in both the spring and fall migratory seasons on Devil's Lake from 1966-1995. In 1999, park staff indicated migratory bird numbers may have been low that spring. The past history of migrant waterfowl fluctuations and the low numbers observed this spring suggest that swimmer's itch parasite numbers would be low. However, because infections in snails can survive through the winter (Kulsea et al. 1982, Laman et al. 1984) and no fall 1998 migration numbers were noted, it is difficult to claim with certainty that spring migratory waterfowl numbers were down as the sole reason for the lack of swimmer's itch in our samples.

We did not study other factors that have been suggested as reasons why swimmer's itch can fluctuate annually. Wind direction and water currents can move

Table 8. Migratory waterfowl present at Devil's Lake documented in scientific literature to be definitive hosts for swimmer's itch causing parasites.

Migratory Waterfowl Species Present At Devil's Lake *	**Schistosome Species**	**Intermediate Host(s)**	**Source**
Plied-billed Grebe	*Gigantobilharzia elongata (Cercaria elongata)*	*Promenetus exacuous Gyraulus parvus*	Daniell 1984, Brackett 1940b
Mute Swan	*Bilharziella polonica*		Blankespoor and Reimink 1991, Guth et al. 1979, Brackett 1940b
Canada Goose	*Ornithobilharzia pricei*		Loken et al. 1995, Spencer and Loken 1993, Blankespoor and Reimink 1991, Guth et al. 1979, Brackett 1940b
Teal	*Trichobilharzia ocellata*	*Lymnaea stagnalis*	Hoeffler 1977
American Black Duck			Guth et al. 1979, Brackett 1940b
Canvasback	*Microbilharzia canadensis Microbilharzia manitobensis*		Brackett 1940b
Lesser Scaup	*Microbilharzia chapini*		Brackett 1940b
White-winged Scoter	*Dendribilharzia* spp.		Brackett 1940b
Common Merganser	*Trichobilharzia stagnicolae*		Keas and Blankespoor 1997, Loken et al. 1995, Spencer and Loken 1993, Blankespoor and Reimink 1991
Ring-billed Gull	*Ornithobilharzia* spp.		Loken et al. 1995, Spencer and Loken 1993, Blankespoor and Reimink 1991, Brackett 1940b
Herring Gull	*Ornithobilharzia lari Ornithobilharzia aviani Ornithobilharzia* spp.		Spencer and Loken 1993, Blankespoor and Reimink 1991, Brackett 1940b
Caspian Tern			Brackett 1940b
Mallards	*Bilharziella yokogawai Dendribilharzia pulverulenta Trichobilharzia ocellata Trichobilharzia* spp.	*Lymnaea stagnalis*	Loken et al. 1995, Reimink 1995, Blankespoor and Reimink 1991, Guth et al. 1979, Hoeffler 1977, Brackett 1940b
Ducks (other)	*Bilharziella polonica Trichobilharzia ocellata Trichobilharzia stagnicolae Trichobilharzia physellae*	*Lymnaea palustris Lymnaea emarginata Physa parkeri Physa gyrina Physa integra*	Feiler and Haas 1988, Hoeffler 1977, Cort 1950 Taylor and Baylis 1930
Gulls (other)	*Cercaria emarginatae*		Keas and Blankespoor 1997, Spencer and Loken 1993

*Devil's Lake Migratory bird information from Lange (1996) and Bouche pers com (1997) cercariae around in the lake, accumulating them near the shoreline or blowing them away from shore. Some cercariae causing swimmer's itch are vulnerable to the wind and currents because they are phototactic and cling to the surface of the water (Feiler and Haas 1988). The number of hours that people stay in the water and the time of day they are exposed to the water can effect if people will contract swimmer's itch. Cercariae are most abundant between 11 A.M. and 3 P.M. (Brackett 1940, Appleton and Lethbridge 1979, Ouma et al. 1989) and the longer you are exposed to water, the more likely you are to come into contact with a swimmer's itch cercariae. In addition, each person has a different sensitivity to swimmer's itch cercariae and increased exposure will cause more severe reactions (Kirschenbaum 1979, Mulvihill and Burnett 1990, Koshere 1999). Lake temperature can also play a factor, with increasing temperatures linked to increased cases of swimmer's itch (Appleton and Lethbridge 1979).

Cercarial Trap Sampling

Shiff et al. (1993) evaluated a simple stationary trap to measure schistosome cercariae in small containers, tanks, small ponds, and irrigation canals. In each case, known quantities of *Schistosoma mansoni* cercariae were added to the water. They found that the recovery rate of cercariae on the traps were reasonably consistent to calculated theoretical values of cercariae that should have been captured on the trap given random distribution in the water column. Under field conditions in the irrigation canal, recovery rates were only 30% of the calculated theoretical values of cercariae that should have been captured on the trap given random distribution in the water column.

The modified floating traps we constructed to capture cercariae in the water column of a much larger experimental area - Devil's Lake - were not successful at capturing cercariae in the lake. While we used the same pretreated microscope slides, matrix materials and time period as Shiff et al. (1996), we did not find cercariae on our traps in the field even though we had capture successes in preliminary laboratory experiments. This conforms to results from field tests of cercarial traps conducted in lakes in Michigan (Nathaniel Coady, graduate student at Michigan State University, pers. com. 1999).

To the best of our knowledge, this is the first time that anyone has tried using a floating cercarial trap in a lake. Because we found no cercariae that cause schistosome dermatitis in our snail samples and with only 5 reported swimmer's itch cases this summer, it is hard to determine if the cercarial trap design influenced our results. Our low results most likely reflect the fact that there were few, if any, cercariae causing swimmer's itch in the lake this summer. In addition, Shiff et al. (1993) used known concentrations of only one cercariae species, *Schistosoma mansoni*, which made identification and counting of cercariae on the microscope slide easy. In our study, we captured many organisms on the slides, such as plankton, detritus and possibly many different species of cercariae from unknown concentrations in the water column. Identification of the captured cercarial species were nearly impossible. We were only able to determine if the tail of the cercaria was forked or non-forked. Many other organisms in the lake besides snails, such as fishes and turtles, are intermediate hosts of cercariae in the lake that could be confused with the cercariae causing swimmer's itch because of morphological similarities. Overall, using a floating trap for the detection of schistosome cercariae in a large body of water, such as Devil's Lake, was not successful.

Periphyton Sampling

Periphyton, or attached algae, usually dominate the algal biomass of a lake's littoral zone (Wetzel 1983). Within the littoral zone (or shallow areas), periphyton growth and production is influenced heavily by light and nutrient availability. Experimental evidence from an oligotrophic lake showed that periphyton biovolume and cell densities increased significantly with increased levels of nitrogen and phosphorus (Marks and Lowe 1993). Therefore, biomass of periphyton is directly related to nutrient content of the water and sediments. We showed that average chlorophyll *a* and dry weight, two measurements of periphyton standing crop, varied between sites in Devil's Lake during a three-month period. The two sites closest to the beaches had the highest levels, although specific reasons for these spatial disparities are unclear. In addition, we show that both growth and biomass of periphyton also vary over time, but reasons for this are unclear and nutrients were likely important factors.

Broader Ecological Controls for Swimmer's Itch

Methods for control of swimmer's itch have thus far been short-term solutions that require special situations to be successful. Examples of methods include applying molluscicides to small areas within a lake (Cort 1950) or injecting definitive bird hosts with Praziquantel (Blankespoor and Reimink 1991, Reimink et al. 1995). At Devil's Lake, seventeen snail species were found throughout the lake and only three of these species could be intermediate hosts for cercariae causing swimmer's itch. At least one of these three snail species was found at all 10 sites, although they were most dense along the north and south shorelines. In addition, fifteen species of migratory birds known to use Devil's Lake at various times during the year are documented in the scientific literature to be definitive hosts for swimmer's itch parasites. These bird populations fluctuate in number and duration at the lake from year to year (Lange 1996). Because intermediate snail hosts are found throughout the lake and their densities are highest along the entire north and south shorelines, treating the lake with a toxic chemical such as copper sulfate would be not be practical or ecologically safe. In addition, because migratory bird host numbers fluctuate greatly in the spring and fall and these species are not permanent summer residents of Devil's Lake, the process of capturing and treating them with an anti-helminthic drug such as Praziquantel™ would be costly and extremely difficult. Therefore, broader ecological controls for swimmer's itch are required that involve the whole lake, such as controlling aspects of the food web to reduce intermediate snail host populations.

A "bottom up" control method would involve reducing nutrient inputs into the lake and reduce internal nutrient recycling rates. The particular nutrient of most concern to control algal growth, both for phytoplankton and periphyton, is phosphorus. As phosphorus concentrations increase, periphyton, a major food base for snails (Spencer and Loken 1993) increases (American Public Health Association 1989). In addition, Chlorophyll *a*, a measurement of periphyton, has been significantly associated with the development of swimmer's itch (Lindblade 1998). We took periphyton measurements from June-August 1999 (Table 7) and showed that biomass densities in the lake vary both spatially and temporally over three months.

While excessive phosphorus inputs to Devil's Lake from its watershed are no longer a problem, internal recycling of phosphorus from the lake's bottom sediments has supported excessive algal growth in recent years (Lathrop et al. 1994). Within the past few years fall blooms of free-floating algae (phytoplankton) have been less of a problem while attached algae (periphyton) growing on rocks has become more noticeable. Because the lake is located in a quartzite outcropping with minimal surface water inputs from its small watershed, we believe the periphyton growth is higher than should be for a lake in this geologic setting. Methods to reduce internal phosphorus recycling rates have been assessed in recent years (Lathrop et al. 1994), but no action has been taken. If phosphorus concentrations would decline in the lake, then reductions in periphyton growth should occur. This should lead to a subsequent reduction in snail densities and ultimately a reduction in the production of cercariae causing swimmer's itch. If miracidia released from their definitive hosts cannot find their appropriate snail intermediate host (because of lower snail densities) within the relatively short period the miracidia are free-swimming, then their life cycle is disrupted and fewer cercariae will be produced.

Another approach to reducing snail densities is through "top down" controls via predation on the snails by other lake organisms. Predators such as fish and crayfish determine snail abundance and species composition within most lakes (Lodge et al. 1987). In Trout Lake Wisconsin, pumpkinseed (sunfish) and crayfish were shown to control snail abundance and possibly influence snail habitat selection (Lodge et al. 1987).

Historically, Devil's Lake has had relatively low and stable numbers of pumpkinseed sunfish. However, in the 30-year period from the early 1950's to the early 1980's pumpkinseed numbers increased dramatically as a result of fish stocking efforts (Lillie and Mason 1986). In more recent years pumpkinseeds appear to have declined along with bluegill. Stocking more pumpkinseed sunfish in Devil's Lake could be used as a technique to reduce snail densities and ultimately densities of cercariae that cause swimmer's itch. Currently, brown trout fingerlings are stocked in significant numbers (5-18 thousand) in Devil's Lake each year. It is unclear what role the brown trout have in the food web of Devil's Lake, but their affect on snail densities (either positive or negative) should be evaluated. They may be controlling snail densities by directly feeding on them, or they may be reducing planktivorous fish densities allowing more filter-feeding zooplankton (*Daphnia*) to reduce phytoplankton in the water. The excessive phosphorus being recycled from the lake's sediments would then be available to support higher periphyton densities on the rocks and other substrates, thus providing more food for producing snails.

Visitor Involvement

In the past, visitors have reported swimmer's itch symptoms to park officials and many times information such as where they swam or what time of day they were in the water were never recorded. Visitor information about swimmer's itch cases would help scientists to determine swimmer's itch control efforts. A questionnaire should be designed for visitors having swimmer's itch symptoms that includes:

-type of water activity
-location, time and duration of exposure to water
-any past swimmer's itch history
-part of body effected
-precautions taken

Education and community outreach on ways to prevent swimmer's itch will help reduce the number of reported swimmer's itch cases each summer. More information about swimmer's itch should be made available at the park. Swimmer's itch signs posted around the park should be larger and more concise. Short classes or seminars on swimmer's itch should be given the park to teach the public about swimmer's itch, the parasites that cause it, and about how to avoid developing the "itch".

Expanding visitor involvement to lakes statewide would be extremely beneficial to understand the swimmer's itch problem in Wisconsin. With help from the public, scientists could increase their knowledge about swimmer's itch and characteristics of lakes prone to swimmer's itch problems. This new information will help provide the building blocks to better swimmer's itch management techniques.

Management Options

The 1999 swimmer's itch project at Devil's Lake focused primarily on the identification and biology of schistosomes and their intermediate snail hosts. From the results of this information and an extensive cercariae dermatitis literature review, the following are recommended management options to explore:

1. Reduce phosphorus concentrations in Devil's Lake by reducing internal phosphorus recycling rates from the bottom sediments.

2. Increase predation on snail populations.

3. Encourage visitors to report swimmer's itch symptoms to park officials at Devil's Lake and have them fill out a questionnaire.

4. Increase swimmer's itch information and education at Devil's Lake.

5. Encourage other Wisconsin lake associations to implement usage of a swimmer's itch questionnaire and increase swimmer's itch information and education for lake users.

6. Fund future swimmer's itch research on Wisconsin lakes and incorporate lakes with immediate swimmer's itch problems.

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Appendix 1. Snail density (snails/m^2) of snails collected in June 1999. Area was calculated from five 1-m swoops with a 0.3m long D-net per sample effort.

SPECIES	**SITE** 1	2	3	4	5	6	7	8	9	10	**TOTAL COMBINED SNAIL DENSITY**
Amnicola limosa	4.7	2.7	-	3.3	-	0.7	2.0	36.0	26.7	18.0	**94.0**
Amnicola walkeri	0.7	-	-	-	-	-	-	-	-	-	**0.7**
Campeloma decisum	0.7	-	-	-	-	-	1.3	0.7	1.3	0.7	**4.7**
Fontigens nickliniana	4.7	-	12.0	-	-	-	-	854.7	845.3	8.7	**1725.3**
Fossaria obrussa (Say) group (exigua strain)	-	-	-	-	-	-	-	-	-	-	**0.0**
Gyraulus deflectus	-	-	-	-	-	-	-	4.0	2.7	4.0	**10.7**
Gyraulus hornensis	-	-	-	-	-	-	-	2.0	-	-	**2.0**
Gyraulus parvus	0.7	-	-	-	-	-	-	-	2.7	6.0	**9.3**
Gyraulus spp. (broken)	-	-	-	-	-	-	-	-	-	-	**0.0**
Helisoma anceps	-	1.3	1.3	-	-	2.0	0.7	7.3	1.3	2.0	**16.0**
Hoyia sheldoni	-	-	-	-	-	-	-	-	-	-	**0.0**
Marstonia lustrica	-	-	-	-	-	-	-	-	-	0.7	**0.7**
Physa skinneri	1.3	1.3	0.7	0.7	1.3	1.3	0.7	-	8.0	4.7	**20.0**
Physa spp. (dead)	-	-	-	-	-	-	-	-	-	0.7	**0.7**
Physella vinosa	-	-	-	-	-	-	-	-	-	-	**0.0**
Planorbella campanulata	0.7	-	-	0.7	-	-	-	0.7	-	1.3	**3.3**
Planorbella truncata	-	-	-	-	-	-	-	-	-	-	**0.0**
Promenetus umbilicatellus	-	-	-	-	-	-	-	-	0.7	-	**0.7**
Viviparus georgianus	4.7	7.3	14.7	7.3	-	-	22.0	17.3	19.3	2.0	**94.7**
TOTAL SNAIL DENSITY PER SITE	**18.0**	**12.7**	**28.7**	**12.0**	**1.3**	**4.0**	**26.7**	**922.7**	**908.0**	**48.7**	**1982.7**

Appendix 2. Snail density (snails/m^2) of snails collected in July 1999. Area was calculated from five 1-m swoops with a 0.3m long D-net per sample effort.

SPECIES	SITE 1	2	3	4	5	6	7	8	9	10	1 extra	6 extra	TOTAL COMBINED SNAIL DENSITY
Amnicola limosa	2.7	-	6.0	2.0	3.3	2.0	1.3	66.7	58.7	141.3	1.3	-	**285.3**
Amnicola walkeri	0.7	-	-	-	-	-	-	0.7	1.3	-	-	-	**2.7**
Campeloma decisum	-	0.7	-	-	-	-	-	-	1.3	0.7	0.7	-	**3.3**
Fontigens nickliniana	-	-	8.7	-	-	-	-	318.0	96.0	61.3	-	-	**484.0**
Fossaria obrussa (Say) group (exigua strain)	-	-	-	-	-	-	-	-	-	-	0.7	-	**0.7**
Gyraulus deflectus	0.7	-	-	-	-	-	-	3.3	-	0.7	-	-	**4.7**
Gyraulus hornensis	-	-	-	-	-	-	-	-	2.0	0.7	-	-	**2.7**
Gyraulus parvus	2.7	-	-	-	-	-	-	-	1.3	4.7	4.7	-	**13.3**
Gyraulus spp. (broken)	-	-	-	-	-	-	-	-	-	-	-	-	**0.0**
Helisoma anceps	0.7	2.0	12.0	-	-	0.7	2.0	7.3	2.0	1.3	2.0	-	**30.0**
Hoyia sheldoni	1.3	-	-	-	-	-	-	-	-	-	-	-	**1.3**
Marstonia lustrica	-	-	-	-	-	-	-	-	-	-	-	-	**0.0**
Physa skinneri	13.3	10.0	10.7	3.3	1.3	2.0	-	6.0	6.0	2.0	6.0	2.7	**63.3**
Physa spp. (dead)	0.7	2.7	6.0	-	-	-	-	-	-	1.3	-	-	**10.7**
Physella vinosa	-	-	-	-	-	-	-	-	-	-	-	-	**0.0**
Planorbella campanulata	-	-	0.7	0.7	-	0.7	-	-	-	-	-	-	**2.1**
Planorbella truncata	-	-	-	2.7	-	-	-	-	-	0.7	-	-	**3.3**
Promenetus umbilicatellus	-	-	-	-	-	-	-	-	-	-	-	-	**0.0**
Viviparus georgianus	18.0	5.3	26.0	14.0	-	-	12.0	18.0	10.7	5.3	-	-	**109.3**
TOTAL SNAIL DENSITY PER SITE	**40.7**	**20.7**	**70.0**	**22.7**	**4.7**	**5.3**	**15.3**	**420.0**	**179.3**	**220.0**	**15.3**	**2.7**	**1748.0**

Appendix 3. Snail density (snails/m^2) of snails collected in August 1999. Area was calculated from five 1-m swoops with a 0.3m long D-net per sample effort.

SPECIES **SITE**

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**6 extra**	**TOTAL COMBINED SNAIL DENSITY**
Amnicola limosa	14.0	20.0	72.0	118.7	8.0	4.7	96.7	30.7	170.7	90.7	-	**626.0**
Amnicola walkeri	-	-	-	4.7	2.7	-	-	-	-	-	-	**7.3**
Campeloma decisum	0.7	-	-	-	-	-	-	0.7	-	2.7	-	**4.0**
Fontigens nickliniana	0.7	0.7	15.3	-	-	-	0.7	57.3	4.0	5.3	-	**84.0**
Fossaria obrussa (Say) group (exigua strain)	-	-	-	-	-	-	-	-	1.3	-	-	**1.3**
Gyraulus deflectus	1.3	-	-	-	-	-	-	-	2.7	0.7	-	**4.7**
Gyraulus hornensis	1.3	0.7	-	-	-	-	-	-	2.0	1.3	-	**5.3**
Gyraulus parvus	1.3	0.7	-	-	-	-	-	8.7	-	0.7	-	**11.3**
Gyraulus spp. (broken)	-	-	-	-	-	-	-	1.3	-	-	-	**1.3**
Helisoma anceps	1.3	6.0	42.7	0.7	-	2.0	-	18.7	62.0	7.3	-	**140.7**
Hoyia sheldoni	0.7	-	-	-	-	-	-	-	-	0.7	-	**1.3**
Marstonia lustrica	-	-	-	-	-	-	-	-	-	-	-	**0.0**
Physa skinneri	1.3	2.7	4.0	4.0	2.0	0.7	-	0.7	14.0	6.0	-	**35.3**
Physa spp. (dead)	0.7	10.0	0.7	-	-	0.7	-	0.7	2.7	2.0	0.7	**18.0**
Physella vinosa	-	-	-	-	-	4.7	-	-	-	-	5.3	**10.0**
Planorbella campanulata	0.7	-	0.7	0.7	-	-	-	-	-	-	-	**2.0**
Planorbella truncata	-	-	-	-	-	-	-	-	-	-	-	**0.0**
Promenetus umbilicatellus	-	-	-	-	-	-	-	-	-	-	-	**0.0**
Viviparus georgianus	0.7	5.3	18.0	2.7	-	-	2.7	12.7	18.7	0.7	-	**61.3**
TOTAL SNAIL DENSITIES PER SITE	**24.7**	**46.0**	**153.3**	**131.3**	**12.7**	**12.7**	**100.0**	**131.3**	**278.0**	**118.0**	**6.0**	**1014.0**

Appendix 4. Average monthly snail size (± 1 std. dev.) of incubated snails collected June-August 1999.

SPECIES	JUNE Average Length (mm)	JUNE Average Width (mm)	JULY Average Length (mm)	JULY Average Width (mm)	AUGUST Average Length (mm)	AUGUST Average Width (mm)
Amnicola limosa	4.1 ± 0.6	3.2 ± 0.6	2.9 ± 1.1	2.5 ± 0.8	3.0 ± 0.5	2.5 ± 0.5
Amnicola walkeri			3.1 ± 0.9	2.3 ± 0.9	2.5 ± 0.5	2.1 ± 0.5
Campeloma decisum	12.0 ± 4.1	8.9 ± 2.8	10.3 ± 2.7	7.6 ± 1.9	13.2 ± 5.2	10.5 ± 3.4
Fontigens nickliniana	3.0	1.9 ± 0.2	3.1 ± 0.4	2.0 ± 0.3	3.0 ± 0.4	1.9 ± 0.3
Fossaria obrussa (Say) group			5.0	3.1	5.7 ± 2.1	2.7 ± 0.6
Gyraulus deflectus	1.1 ± 0.6	3.5 ± 2.5	1.5 ± 0.2	3.4 ± 1.2	1.4 ± 0.4	3.8 ± 0.9
Gyraulus hornensis	1.3 ± 0.4	3.5±2.5	0.7 ± 0.5	2.0 ± 0.5	0.8 ± 0.2	2.5 ± 0.4
Gyraulus parvus	2.5 ± 0.8	3.4 ± 0.9	1.1 ± 0.3	2.7 ± 0.3	1.4 ± 0.3	2.9 ± 0.5
Gyraulus spp. (broken)					1.6	2.8
Helisoma anceps	5.4 ± 1.2	9.1 ± 2.0	3.2 ± 1.4	4.6 ± 2.4	3.7 ± 1.3	5.2 ± 1.9
Hoyia sheldoni			3.4 ± 0.7	2.2 ± 0.2	3.2 ± 0.7	1.8 ± 0.3
Marstonia lustrica	4.4	3.4				
Physa skinneri	8.4 ± 5.4	5.2 ± 3.3	6.2 ± 2.8	4.0 ± 1.9	5.3 ± 2.0	3.6 ± 1.3
Physa spp. (dead)			4.5 ± 1.2	2.9 ± 0.8	5.7 ± 3.0	4.0 ± 2.1
Physella vinosa					11.4 ± 2.2	8.0 ± 1.7
Planorbella campanulata	6.4 ± 0.6	13.6 ± 2.1	6.0 ± 1.0	11.5 ± 2.3	5.8 ± 0.6	10.8 ± 1.7
Planorbella truncata			6.3 ± 0.5	10.9 ± 0.4		
Promenetus umbilicatellus	0.7	1.7				
Viviparus georgianus	14.4 ± 7.1	11.9 ± 5.3	14.7 ± 5.4	12.5 ± 4.0	16.5 ± 5.1	14.5 ± 4.0

Appendix 5. Periphyton data collected from June-August 1999.

Sample Period	Date	Days in Lake	Site	Chlorophyll *a* mg/m^2	Dry Weight mg/m^2	Chlorophyll *a* mg/m^2/day	Dry Weight mg/m^2/day
1	6/11/99-6/25/99	14	5	1.78	.	0.13	.
1	6/11/99-6/25/99	14	6	2.99	.	0.21	.
1	6/21/99-6/25/99	4	10	0.98	.	0.25	.
2	6/25/99-7/9/99	14	5	0.49*	487	0.04	35
2	6/25/99-7/9/99	14	6	1.61	1920	0.12	137
2	6/25/99-7/9/99	14	10	5.15	4050	0.37	289
2	7/6/99-7/9/99	3	11	1.06	250	0.35	83
3	7/9/99-7/23/99	14	5	1.67	908	0.12	65
3	7/9/99-7/23/99	14	6	2.43	2510	0.17	180
3	7/16/99-7/23/99	7	10	0.83*	697	0.12	100
3	7/9/99-7/23/99	14	11	13.5	1700	0.96	120
4	7/30/99-8/6/99	7	6	0.13	276	0.02	39
4	7/23/99-8/6/99	14	10	2.14	2870	0.15	210
4	8/2/99-8/6/99	4	11	0.22*	184	0.06	46
5	8/6/99-8/20/99	14	6	0.48	270	0.03	19
5	8/17/99-8/20/99	3	10	0.31*	289	0.10	96
5	8/12/99-8/20/99	8	11	0.04*	145	0.01	18
6	8/20/99-9/3/99	14	6	1.68	868	0.12	62
6	8/20/99-9/3/99	14	10	3.96	1450	0.28	100
6	8/20/99-9/3/99	14	11	3.75	1540	0.27	110

*Low absorbance for Chlorophyll *a*, result approximate