A SUMMARY REPORT ON SWIMMER'S ITCH IN QUEBEC

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A Summary Report on Swimmer’s Itch in Quebec

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NOTICE TO READERS

Questions and comments may be addressed to the St. Lawrence Centre, Environmental Conservation Branch, Environment Canada – Quebec Region, 105 McGill Street, 7th Floor, Montreal, Quebec, H2Y 2E7.

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Management Perspective

Swimmer's itch is a short-term immune reaction occurring in the skin of people accidentally infected by waterborne parasites of snails and birds or rodents. Reports of swimmer's itch in the Great Lakes–St. Lawrence Basin have become more frequent since the condition was first described in 1928. Although not suspected to pose a serious health risk, outbreaks can limit recreational activities and affect local economies in lake districts. Cases have been reported throughout southern Quebec, where human populations are expected to increase in coming decades. Together with habitat changes predicted to occur with development and climate change, this demographic trend is likely to bring more people into contact with the parasites that cause swimmer's itch and thereby increase incidence in humans in the St. Lawrence watershed. This report provides a biological summary of the parasites that cause swimmer's itch and reviews control measures studied to date. Its publication was made possible by the St. Lawrence Action Plan, a Canada–Quebec initiative aimed at understanding, protecting and restoring the St. Lawrence ecosystem.

Perspective de gestion

La dermatite du baigneur, appelée également dermatite schistosomiale, est une réaction cutanée immunitaire de brève durée de personnes infectées accidentellement par des parasites aquatiques d'escargots, d'oiseaux ou de rongeurs. La dermatite du baigneur, décrite pour la première fois en 1928, est maintenant fréquemment rapportée dans le bassin Grands Lacs–Saint-Laurent. Bien qu'elle ne soit pas supposée présenter un risque sérieux pour la santé, une flambée de cas peut limiter les activités récréatives et avoir un impact sur les économies locales des régions de lacs. Des cas ont été rapportés dans tout le sud du Québec où il est prévu que la population humaine augmentera dans les décennies à venir. Accompagnée de perturbations des habitats dues au développement et aux changements climatiques, cette tendance démographique augmentera le nombre de personnes en contact avec les parasites qui causent la dermatite du baigneur et accroîtra par conséquent le nombre de cas dans la population humaine du bassin Grands Lacs–Saint-Laurent. Ce rapport décrit brièvement la biologie des parasites qui causent la dermatite du baigneur et passe en revue les mesures de contrôle étudiées jusqu'à maintenant. Ce document a été produit dans le cadre du Plan d'action Saint-Laurent, une initiative Canada-Québec qui vise à comprendre, à protéger et à restaurer l'écosystème du Saint-Laurent.

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Abstract

Swimmer's itch is a short-term immune reaction caused by schistosomes that parasitize aquatic snails and birds. The condition occurs after people are accidentally infected by a free-living transmission stage of the parasite, the cercaria, which emerges from the snail in search of the next host, but is unable to complete its life cycle in humans. The cercaria dies in human skin, causing itchy papules lasting up to ten days. Symptoms are more severe on reinfection and can cause insomnia. Although not known to pose significant risk to public health in Canada, outbreaks elsewhere have resulted in lake closures and affected local economies in recreational lake districts. Given projected demographic and climatic changes in southern Quebec, incidence is likely to increase in this province. Control of swimmer's itch depends on a thorough understanding of the biology of avian schistosomes. The risk of severe cases may be reduced through public awareness of risk factors such as duration of exposure to lake water, sunny conditions, shallow depths, onshore winds, morning exposure, early to mid-summer exposure, prior history of swimmer's itch and exposure to waters known to be periodically infested. It is difficult to screen for cercariae in natural waters, but infections in snails and birds are detectable with the right equipment and expertise. Molluscicides used in the past to extirpate infested snail populations have had mixed results. Mechanical disturbance of snail habitat, which has been used successfully in Quebec, appears to be more effective and to pose less environmental risk. Another promising technique uses the anthelmintic drug Praziquantel to treat hatchling waterfowl resident at infested lakes. Experimental work on N,N-diethyl-*m*-toluamide (DEET) as a topical prophylaxis against cercarial penetration is also cause for hope. Currently, reducing swimmer's itch requires a multipronged approach involving public awareness of risk factors and, potentially, snail habitat disturbance and/or treatment of birds with anthelmintics. The latter strategies require biological and veterinary expertise, specialized equipment, manpower and the notification of provincial authorities.

Résumé

La dermatite du baigneur est une réaction cutanée immunitaire à court terme causée par des schistosomes qui parasitent les escargots et les oiseaux aquatiques. Cette réaction survient lorsque des personnes sont accidentellement infectées par le stade libre du parasite, la cercaire, qui émerge de l'escargot, à la recherche de son prochain hôte, un oiseau. La cercaire ne peut compléter son cycle de vie chez l'être humain parce qu'elle meurt dans sa peau, causant des papules prurigineuses pouvant durer jusqu'à dix jours. Les symptômes sont plus graves lorsqu'il s'agit d'une réinfection et peuvent causer jusqu'à de l'insomnie. Bien que cette infection ne soit pas connue pour présenter un risque important pour la santé publique au Canada, des flambées de cas ont entraîné ailleurs la fermeture de lacs et affecté les économies locales dans les régions de lacs récréatifs. Étant donné les changements démographiques et climatiques prévus dans le sud du Québec, les cas d'infection vont probablement augmenter dans cette province. Le contrôle de la dermatite du baigneur dépend d'une compréhension profonde de la biologie des schistosomes aviaires. Il est possible de réduire le risque de cas graves en sensibilisant la population aux facteurs de risques, comme la durée de l'exposition à l'eau d'un lac, les conditions ensoleillées, les faibles profondeurs, les vents du large, l'exposition matinale, l'exposition au début et au milieu de l'été, ainsi qu'une dermatite schistosomiale antérieure et une exposition précédente à des eaux connues pour être infestées périodiquement. Il est difficile de dépister des cercaires dans les eaux naturelles, mais les infections chez les escargots et les oiseaux sont détectables avec le bon équipement et de l'expertise. Les molluscicides utilisés dans le passé pour éliminer les populations infectées d'escargots ont eu des résultats discutables. Le dérangement mécanique des habitats de l'escargot, employé avec succès au Québec, semble plus efficace et présenter moins de risques pour l'environnement. Une autre technique prometteuse est l'emploi de l'anthelminthique Praziquantel pour traiter les oisillons aquatiques dans les lacs infestés. Sont également prometteurs des travaux expérimentaux sur le N,N-diéthyl-3-méthylbenzamide (DEET) pour une prophylaxie topique contre la pénétration des cercaires. Actuellement, la lutte contre la dermatite du baigneur exige une approche à multiples paliers où est conjuguée la sensibilisation du public aux facteurs de risques avec, si possible, le dérangement mécanique des habitats de l'escargot et/ou le traitement des oiseaux avec des anthelminthiques. Ces dernières stratégies nécessitent une expertise biologique et vétérinaire, de l'équipement spécialisé, de la main-d'oeuvre et la notification des autorités provinciales.

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Definitions

Abundance: The number of parasites divided by the number of hosts, including hosts that are not infected.

Anatid: A member of the family Anatidae: ducks, geese and swans.

Cercaria: A waterborne, free-living developmental stage of a trematode that emerges from the snail intermediate host and, in schistosomes, infects the vertebrate definitive host.

Challenge: The exposure of a host to a parasite in an infective developmental stage.

Definitive host: A host in which sexual reproduction occurs.

Drive trap: A non-harmful, corral-like trap used in bird banding.

Fluke: A parasitic trematode flatworm.

Icterid: A member of the family Icteridae: orioles, blackbirds, grackles, oropendolas, caciques, and cowbirds.

Incidence: The number of hosts newly infected by a given parasite species per unit of time.

Intensity: The number of parasites divided by the number of infected hosts.

Intermediate host: A host in which a parasite develops but sexual reproduction does not occur.

Gigantism: Development to an abnormally large size.

Life cycle: For parasites, all developmental stages of a parasite as well as the intermediate and definitive hosts in which they are found.

Lumen: The internal cavity of an organ.

Miracidium: A ciliated, waterborne, free-living developmental stage of trematodes that emerges from an egg shed by the definitive host and infects the intermediate host.

Murine: A member of the family Muridae: mice and rats.

Naïve: An organism which has not previously been exposed to a parasite.

Patency: The period of infection during which a parasite produces eggs or larvae.

Periphyton: Unicellular algae which attach to a submerged surface.

Platyhelminth: A flatworm, member of the phylum Platyhelminthes.

Prepatency: The period of infection preceding shedding of eggs or larvae by a parasite.

Prevalence: The proportion of hosts infected by one or more individuals of a given parasite species, often expressed as a percentage.

Schistosome: A member of the trematode family Schistosomatidae.

Schistosomiasis: A human disease caused by schistosomes of the genus Schistosoma.

Schistosomulum: A parasitic, sexually immature developmental stage of schistosomes occurring in the vertebrate definitive host.

Sporocyst: A parasitic developmental stage of trematodes occurring in the molluscan intermediate host that generates asexually produced larvae.

Tegument: The outer membrane of a platyhelminth.

Trematode: A member of the subclass Trematoda, in the phylum Platyhelminthes.

Virulence: The propensity of a parasite to cause harm; pathogenicity.

Abbreviations

d	Days
P.I.	Post-infection
wks	Weeks

1 Introduction

Swimmer's itch is a short-term, non-communicable immune reaction occurring in the skin of people infected by a family of waterborne parasites known as schistosomes. Schistosomes are one of several kinds of trematodes, which are a type of flatworm or platyhelminth. The developmental stage of the schistosome that penetrates human skin is the cercaria. The symptoms of the disease and developmental stage of the parasite give swimmer's itch its technical name: cercarial dermatitis.

Schistosomes that cause swimmer's itch have parasitic stages in a snail and a vertebrate — usually a bird — and are unable to complete their life cycles in humans. Bathers commonly develop the condition when they swim in shallow lake waters inhabited by snails infected with the parasites.

Although apparently not a significant risk to public health, as a nuisance, swimmer's itch has the potential to adversely affect recreational activities in lake districts such as those present throughout southern Quebec. People who experience severe episodes subsequently reduce their recreational use of infested lake waters (Verbrugge et al. 2004). Widespread or well publicized outbreaks (e.g. Chamot et al. 1998) are thought to have economic impacts in areas where lake-oriented tourism is significant; indeed, outbreaks have resulted in the closure of lakes to the public (de Gentile et al. 1996).

2 Etiology

An estimated 30–40% of swimmers exposed to avian schistosomes develop symptoms (Blankespoor 1980), which consist initially of mildly itchy red spots on the skin. These develop into larger, raised papules within as little as one hour or as much as 15 hours post-infection (P.I.) and can last up to ten days (Lévesque et al. 1990; Zbikowska 2004). Papules are associated with intense itching, which can cause insomnia (Blankespoor and Reimink 1988) and, in rare cases, may lead to secondary infections with systemic symptoms (Lévesque et al. 1990; Ridenour 2003). Each papule corresponds to the penetration site of a single schistosome. People reporting a tingling or prickling sensation on the skin following exposure are more likely to develop symptoms (Chamot et al. 1998), which generally continue for 3 to 4 days (Blankespoor and Reimink 1988a).

When a human is infected by cercariae for the first time, the immune system mounts a two-fold response: a slower, specific reaction targeting the tegument shed by the cercaria after penetration and the proteins it uses to penetrate the skin (Hoeffler 1982); and a mild, non-specific inflammatory response at the penetration site (Horak and Kolarova 2001). The specific reaction allows the immune system to remember and recognize the invader in the event of subsequent infections. Upon reinfection, the primed immune system triggers a quicker and more severe non-specific inflammatory response, resulting in an overreaction — a phenomenon known as immune hypersensitivity, which is similar to an allergic reaction (Hoeffler 1982; de Gentile et al. 1996; Ridenour 2003). First-time infections are more likely to be asymptomatic; symptoms indicate a person has probably previously been infected by schistosome cercariae.

3 Epidemiology

Swimmer’s itch was first reported in 1928 in a Michigan lake (Cort 1928). In North America, the condition is thought to be more frequent in areas with glacial lakes, particularly the Great Lakes–St. Lawrence Basin (Jarchow and Van Burkalow 1952; Blankespoor 1980). The continent’s glacial lakes and their basins provide good breeding grounds for waterfowl and lymnaeid snails are more diverse in these habitats than regions that were not glaciated during the Pleistocene (Jarchow and Van Burkalow 1952); moreover, the Great Lakes–St. Lawrence Basin lies under the Mississippi Flyway of migratory waterfowl.

In 1988, 74 cases of swimmer’s itch traceable to 28 water bodies were reported in all five regions surveyed within Quebec, namely Rimouski, Rouyn-Noranda, Lake Saint François, Portneuf and Hull (Lévesque et al. 1990). Swimmer’s itch has also been reported in Lake Nairne (Giovenazzo 2002), at two beaches near Quebec City (Giovenazzo et al. 1995), in Lake Beauport (Lévesque et al. 2002) and in Lake Aylmer (R. Chatelain, pers. comm. 2003).

On a global scale, reports of swimmer’s itch are increasing in frequency and some suggest incidence is rising (de Gentile et al. 1996; Kock and Böckeler 1998; Giovenazzo 2002; Hjørngaard Larsen 2004), although this may also be attributed to improved awareness and reporting (Blankespoor and Reimink, 1988a). What little data are available on changes in schistosome populations in birds and snails do not support increases in parasite numbers as a cause for increased incidence. In a Michigan lake, schistosomes have become less prevalent and diverse in birds over the last 50 years (Keas and Blankespoor, 1997) and others have reported no change in the prevalence of trematodes in natural snail populations observed over a 20-year period (Zbikowska 2004). However, the relationship between schistosome prevalence in snails and swimmer’s itch incidence in humans is unclear. Low or even declining prevalence in snails may co-occur with increasing incidence in humans if, for example, increasing numbers of people swim in infested water bodies. This may prove to be the case in southern Quebec, where human populations are predicted to increase by 10–30% between 2001 and 2026 in recreational lake districts (i.e. Eastern Townships, the Laurentians, Lanaudière, Montérégie and Outaouais) (ISQ 2004).

A number of risk factors for swimmer's itch have been proposed. Sunny conditions, warm ambient temperatures, shallow depths, onshore winds, algal abundance and morning swims during early to mid-summer months are frequently associated with increased swimmer's itch incidence, especially if preceded by an overcast, cool period (Blankespoor 1980; Giovenazzo et al. 1995; Chamot et al. 1998; Lindblade 1998; Normandeau 1988; Horak et al. 2002; Verbrugge et al. 2004). Other suggested risk factors include age and previous history of swimmer's itch (Lindblade 1998; Chamot et al. 1998). However, increased risk among children likely reflects their tendency to stay for longer durations in shallow water; otherwise, when taken into account, age and gender have no effect on incidence, while duration of swimming does (Verbrugge et al. 2004). The effect of warm weather on incidence may have several causes, including increased frequency of swimming (Verbrugge et al. 2004) and, via increased water temperatures, altered cercarial behaviour (Chamot et al. 1988), increased rates of schistosome development in the snail host (Lindblade 1988) and increased rates of cercarial shedding (Verbrugge et al. 2004).

At the scale of a lake, swimmer's itch incidence is sometimes associated with endemic 'hot spots' (e.g. Lindblade 1998; Leighton et al. 2000), although it can also be widespread (e.g. Chamot et al. 1998). Free-swimming cercariae are thought to accumulate near the water surface, where they are subject to wind-driven surface currents (Leighton et al. 2000; Blankespoor, 1980; Verbrugge et al. 2004). In theory, this should produce endemic areas and higher concentrations near shore, but it may also cause cercarial drift, resulting in shifting and sporadic endemic areas (Leighton et al. 2000).

Anthropogenic habitat alteration may also affect rates of swimmer's itch in humans. The construction of retaining walls and riprap for bank stabilization may provide favourable egg-laying habitat for schistosome-harbouring snail species (Blankespoor and Reimink 1988a). Three swimmer's itch outbreaks in France were attributed to eutrophication of recreational water bodies as well as a hot, sunny summer. These conditions led to population increases and habitat expansion in the snail *Lymnaea ovata*, the non-migration of local duck colonies and increased swimming (de Gentile et al. 1996). Similarly, an increased risk of swimmer's itch in Moscow was ascribed to snail population increases resulting from the eutrophication of municipal water bodies due to urban waste, as well as colonization by mallards escaped from local farms (Be'er and German 1993). Long-term climate change may also alter swimmer's itch rates in humans. De

Gentile et al. (1996) note that the three outbreaks in France were preceded by several years of unusually mild and rainy winters and hot summers. In southern Quebec, the rising summer temperatures projected to occur over the next 50 years may lengthen growing seasons for snail hosts and prolong the residence time of migrating bird hosts, resulting in increased transmission (Marcogliese 2001) and more widespread swimmer's itch incidence in humans. Some habitat alterations may reduce swimmer's itch rates. A number of contaminants commonly released into aquatic ecosystems — mainly heavy metals, but also herbicides, pesticides and molluscicides — have been experimentally shown to negatively affect the survival or infectivity of cercariae of the human parasite *Schistosoma* (Pietrock and Marcogliese 2003).

4 The Schistosome Life Cycle

The schistosome life cycle is summarized in the following table.

Table 1
The schistosome life cycle

Schistosome developmental stage	Habitat/Host		Reproduction
Egg ↓ Miracidium ↓	Free-living in water		
Mother sporocyst ↓↓↓ Daughter sporocyst ↓↓↓	Aquatic snail	Intermediate	Asexual
Cercaria ↓	Free-living in water		
Schistosomulum ↓ Adult schistosome ↓↓↓	Vertebrate (bird, mammal, fish, reptile)	Definitive	Sexual
Egg	Passed into water with feces		

↓ Developmental change.
↓↓↓ Reproduction.

The schistosome life cycle includes parasitic phases in two hosts, a snail and a vertebrate, and two free-living transmission stages. Asexual reproduction occurs in an aquatic snail (the intermediate host) and sexual reproduction occurs in the vertebrate (the definitive host). From each host a short-lived, non-feeding stage emerges and swims in search of the next host in the cycle. Table 2 provides a list of some North American schistosome species and their hosts.

Table 2
Schistosomes associated with cercarial dermatitis in North America

Genus and species of schisostome	Intermediate host		Definitive host		Other
	Species	Development	Species	Development	
Trichobilharzia					
• *adamsi*	*Physa c.f. coniformis*[1]		Experimental infection of domestic *Anas platyrhynchos* and *A. domesticus*[1]	Maturity in liver in final host > 42 d P.I.[1]	Natural definitive host unknown[1]
• *alaskensis*	*Lymnaea stagnalis*[1]		Twice experimentally in *Anas platyrhynchos*[1]	Maturity in intestinal veins 10–17 d P.I.[1]	Natural definitive host unknown[1]
• *brantae*			Reported once in wild goose[1]	Maturity in mesenteric and renal veins[1]	
• *burnetti*			Reported once in *Aythya collaris*[1]	Maturity in cloacal vein[1]	
• *cameroni*	*Physa gyrina*[1]	Cercariae develop 28–35 d after miracidial penetration[1]	Experimental infection of *Anas platyrhynchos, Columbia livia* and *Serinus canarius*[1]	Maturity in veins in wall of small intestine[1]	
• *elvae*	*Lymnaea palustris, L. stagnalis*[1]		Experimental infection of *Anas platyrhynchos* and *Serinus canarius*[1]	Maturity in intestinal veins 13 d P.I.[1]	*T. elvae*, the first species implicated in swimmer's itch, may be equivalent to *T. ocellata*[1]
• *horiconensis*			Reported once in *Aythya americana*[1]	Maturity in cloacal vein[1]	
• *kegonsensis*			Reported once in *Aythya vallisneria*[1]	Maturity in cloacal vein[1]	
• *ocellata*	*Lymnaea japonica*, *L. limosa*, *L. ovata*, *L. palustris*, *L. peregra* and *L. stagnalis*[1]; does not infect *Physa gyrina*[3], *Radix ovata* or *R. auricularia*; infects *L. stagnalis* and *Stagnicola palustris*[4]	Cercariae emerge 7 wks P.I. at 20°C and 4–5 wks P.I. at 25°C; patency for > 123 d[5]	*Anas platyrhynchos* (wild and domestic), *A. acuta*, *A. clypeata*, *A. crecca*, *A. discors*, *A. falcata*, *A. formosa*, *A. penelope*, *A. poecilorhyncha*, *A. querquedula*, *A. rubripes* (experimentally), *A. strepera*, *Aythya fuligula*, *Netta rufina*, *Sterna hirundo*[1]	Young worms in lungs 2–9 d P.I.; maturity 8–21 d P.I.; eggs in intestinal wall 9–56 d P.I., in feces 13–40 d P.I.; patency continued to 146 d P.I. [1, 6]	*T. ocellata* is probably synonymous with other species and likely comprises distinct species[4]
• *oregonensis*	*Physa ampullacea*[1]	Cercariae emerge 23 d P.I.[1]	Experimental infection of domestic *Anser anser* and *Anas platyrhynchos*[1]	Maturity in hepatic portal veins, veins of intestine and cecal walls[1]	

Genus and species of schisostome	Intermediate host		Definitive host		Other
	Species	Development	Species	Development	
• *physellae*	*Lymnaea japonica*, *Physa gyrina*, *P. parkeri, Physella magnalacustris*, *P. pripinqua*[1]; does not infect *Stagnicola catascopium*[7]	Cercariae emerge 34 d P.I.[1]	*Mergus merganser*[7]; *Anas platyrhynchos* (wild and domestic), *A. acuta*, *A. clypeata*, *A. crecca*, *A. discors*, *A. falcata*, *A. formosa*, *A. penelope*, *A. poecilorhyncha*, experimental infection of domestic *Columbia livia* and wild *Serinus canarius*[1]	Maturity in portal and intestinal veins; males in mesenteric veins, females in venules beneath serosa and intestinal submucosa[1]	
• *stagnicolae*	*Lymnaea emarginata*[1], *Stagnicola emarginata*[8], *S. catascopium*; does not infect *Physa* spp.[7]		Experimental infection of *Serinus canarius*[1]; wild infections in *Aix sponsa*, *Merganser merganser*, *Branta canadensis*, *Anas platyrhynchos*, *Quiscalus quiscula*[8]	Maturity in small intestinal veins less than 6 wks P.I.[1]	
• *waubesensis*			Reported once in *Anas americana*, *A. collaris*[1]	Maturity in intestinal and cloacal veins[1]	
Schistosomatium					
• *douthitti*	*Lymnaea emarginata*, *L. stagnalis* and *L. palustris*[j]	Cercarial shedding is nocturnal[10] and begins 6–8 wks P.I.[9]	Arvicolines: voles, muskrats[11]		
Gigantobilharzia					
• *huronensis*	*Gyraulus parvulus*[7]; *Physa gyrina*, *P. integra*, *P. parkeri* and possibly *Lymnaea palustris*[9]		Mainly icterids: *Quiscalus quiscula*, *Agelaius phoeniceus*[7, 12]; but also fringillids (cardinals and sparrows), sturnids (starlings) and motacillids (wagtails)[9]	Patency 35–45 d P.I.[12]	Usually referred to as *Gigantobilharzia* sp.; *G. huronensis* is the only commonly reported species[9]
Australobilharzia					
• *canadensis*			Reported once in *Aythya valisneria*[1]	Maturity in hepatic portal vein[1]	
• *chapini*			Reported once in *Aythya affinis* and *Mergus serrator*[1]	Maturity in mesenteric veins[1]	
• *manitobensis*			Reported once in *Aythya valisneria*[1]	Maturity in hepatic portal vein[1]	

Genus and species of schisostome	Intermediate host		Definitive host		Other
	Species	Development	Species	Development	
• *variglandis*	*Littorina pintado*, experimentally in *Littorina scabra* and *Nassarius obsoletus*[1]		Experimentally in domestic *Anas platyrhynchos*, *Columbia livia* and *Serinus canarius*, as well as *Gallus gallus*, *Anous stolidus*, *Larus argentatus*, *Sterna fuscata* and *Arenaria interpres*[1]	Mesenteric and (rarely) hepatic veins[1]	

Sources: 1. McDonald 1969. 2. Cort 1928. 3. Loken et al. 1995. 4. Kock 2001. 5. Horak et al. 2002. 6. Smyth and Halton 1983. 7. Leighton et al. 2000. 8. Blankespoor and Reimink 1991. 9. Hoeffler 1982. 10. Ginetsinskaya 1968. 11. Keas and Blankespoor 1997. 12. Guth et al. 1979.

P.I.: Post-infection.

Adults of nonhuman schistosomes live and reproduce in vertebrates, most commonly in the bile ducts of aquatic birds. Unlike other fluke families, which are hermaphroditic, schistosomes have separate sexes and both must be present in the definitive host for the parasite to complete its life cycle. Adult schistosomes release eggs which pass out of the host's body with the feces.

The egg hatches in water, releasing a small free-living stage, the miracidium, which is either male or female. The miracidium swims in search of the intermediate host, a snail. Miracidia cannot infect any snail, but are restricted to a single species or a small number of closely related species, often lymnaeids (Smyth and Halton 1983; Horak et al. 2002).

If successful in locating and penetrating a snail, the miracidium develops into a mother sporocyst in the snail's head-foot region. The mother sporocyst continually produces daughter sporocysts (sacs filled with embryos), which migrate to the snail's hepatopancreas or reproductive organs. Asexual reproduction by the daughter sporocysts produces large numbers of another short-lived, free-living, non-feeding stage known as cercariae. Cercariae are genetically and sexually identical to their miracidial 'parent' and consist of an elongated body and a forked tail, which they use to swim in search of the definitive host.

On locating a compatible host, the cercaria uses suckers to crawl along the surface in search of an opening such as a wrinkle or follicle and sheds its tail as it attempts to penetrate.

After penetration, the parasite casts off its cercarial tegument and is then known as a schistosomulum. The schistosomulum enters the circulatory system, begins feeding and migrates to the lungs and then to the vascular system near or in the intestine. Here the worm matures and mates with another schistosome, after which the female releases eggs to begin the cycle anew.

The definitive host of most species of schistosomes that cause swimmer's itch are birds, particularly waterfowl. The genus most often implicated, *Trichobilharzia*, is the most diverse and best studied of the avian schistosomes. This group is usually found in anatids (ducks, geese and swans), although it also occurs in North American grebes, herons, pigeons and icterids (perching birds: blackbirds, grackles and orioles) (Horak et al. 2002). *Gigantobilharzia*, which also causes swimmer's itch, appears to infect mainly icterids (Guth et al. 1979; Leighton et al. 2000). Another nonhuman schistosome, *Schistosomatium*, infects voles and muskrats (Keas and Blankespoor, 1997). The most medically important genus in the family, *Schistosoma*, parasitizes humans, afflicting over 200 million people in tropical and subtropical regions (Horak et al. 2002). The attraction of cercariae to humans has been attributed to the similarity in lipid composition of bird and human skin (Horak et al. 2002).

Humans are accidental hosts for avian schistosomes, which cannot complete their life cycles in a mammal. Avian schistosomes usually die in the skin of mammals that have previously been infected (Horak and Kolarova 2001). In human skin biopsies, schistosome penetration does not exceed a depth of 1 mm (Hoeffler 1982) and *Trichobilharzia* schistosomula appear intact 3–9 hours post-infection, but show tegument degradation 24 hours post-infection (Horak et al. 2002). However, in naïve mammals, avian schistosomes reach the liver, kidney, heart and lungs of mice, hamsters, guinea pigs and rabbits and the lungs of rhesus monkeys (Penner 1941; Hoeffler 1974). Schistosomula of the European *Trichobilharzia regenti* (which sheds eggs in tears of birds) have been found in mammalian nervous tissue (Horak et al. 2002).

During the parasitic stages in the schistosome life cycle, significant reproduction occurs. A bird infected by a pair of reproductively active adult worms can release many schistosome eggs. Similarly, a snail infected by a single miracidium can shed large numbers of cercariae (e.g. up to 1500 *Trichobilharzia ocellata* cercariae emerge daily from *Stagnicola elrodi* [Graham 2003]). Thus the seemingly low prevalence generally found among snails (< 5%) can be associated with a large number of cases in humans and a higher prevalence may not entail an appreciable increase in human infections (Zbikowska 2004).

4.1 THE BIRD HOST

Avian schistosomes have high mortalities at several points in their migration through the tissues of the definitive host. Most cercariae fail to cross the skin barrier of birds and many schistosomula fail to pass through the lungs to the intestine (Horak et al. 2002). Schistosomula that reach the lungs remain there for 4 to 16 days post-infection (Horak et al. 2002). Those that succeed in continuing on to the intestinal vascular system and mating produce eggs in as little as 9 days post-infection (McDonald, 1969; Smyth and Halton 1983). Patencies of 10 days post-infection have been reported in Quebec (Giovenazzo et al. 1995), while 3 to 4-week periods were observed in Michigan (Blankespoor and Reimink 1991).

The life span of *Trichobilharzia* in the definitive host is generally brief (Guth et al. 1979; Horak et al. 2002). In waterfowl, mature worms usually die soon after depositing their eggs, although live, mature *Trichobilharzia* have occasionally been found over one year post-infection (Horak et al. 2002) and experimental, patent infections with *Gigantobilharzia* in canaries (*Serinus canarius*) have been observed to last over one year (Guth et al. 1979).

The common merganser (*Mergus merganser*), mallard (*Anas platyrhynchos*) and wood duck (*Aix sponsa*) appear to be important hosts for schistosomes that cause swimmer's itch (Guth et al. 1979, Blankespoor and Reimink 1991; Loken et al. 1995; Leighton et al. 2000). Among 14 species of birds at a Michigan lake, the highest prevalence occurred in the wood duck, common merganser, mallard, Canada goose (*Branta canadensis*) and common grackle (*Quiscalus quiscula*) (Blankespoor and Reimink 1991) (Table 3).

Younger waterfowl are more likely to be infected by schistosomes than adults, but this does not appear to be true for perching birds. In a multi-site Michigan survey of 43 species of wild birds, infections were less common (12%) among adult anatids than among hatchlings (46%), but were uniform (≈15%) among adult and hatchling red-winged blackbirds and common grackles (Guth et al. 1979). At a Michigan lake where swimmer's itch had been frequently reported, most of the 89% of common mergansers that were infected were hatchlings (Blankespoor and Reimink 1991). Prevalence among common mergansers in Cultus Lake, B.C., increased as the season continued, with few adults infected in spring, juvenile infections appearing in early summer and all individuals infected by September (Leighton et al. 2000). Higher prevalence in hatchlings in wild anatids (e.g. Guth et al. 1979) suggests that waterfowl die from or are cleared of their infections as they age or that older birds are more resistant to infection (Reimink et al. 1995).

Table 3
Prevalence of schistosome infections in North American birds

		Number examined		Prevalence (%)		
Latin name	English name	Hatchling	Adult	Hatchling	Adult	Source
Aix sponsa	Wood duck	13	6	31	33	1
		2		100		2
Anas discors	Blue-winged teale			60		1
Anas platyrhynchos	Mallard	63	5	63	40	1
		17		24		2
Agelaius phoeniceus	Red-winged blackbird	7	63	14	14	1
Branta canadensis	Canada goose	45		9		2
		137	87	39	8	1
Cyanocitta cristata	Blue jay	26	37	0	3	1
Dumetella carolinensis	Grey catbird	0	28		4	1
Melospiza melodia	Song sparrow	716	528	16.6	9.5	1
Mergus merganser	Common merganser	100 < n < 120		82–98		3
		87		83.9		4
Molothrus ater	Brown-headed cowbird	25	7	0	0	1
Parus atricapillus	Black-capped chickadee	12	8	0	0	1
Parus bicolor	Tufted titmouse	6	14	0	7	1
Passer domesticus	House sparrow	140	39	0	0	1
Quiscalus quiscula	Common grackle	228	129	7	19	1
		29		7		2
Turdus migratorius	American robin	18	36	0	0	1

Sources: 1. Guth et al. 1979. 2. Blankespoor and Reimink 1991. 3. Leighton et al. 2000. 4. Loken et al. 1995.

Schistosomes have also been described in domestic ducks, but these reports usually represent intentional experimental infections (McDonald 1969). For captive ducks to become infected by schistosomes they must be exposed to water inhabited by suitable snail hosts.

Intense schistosome infections are harmful to ducks and can cause swelling of the feet and legs, emaciation, weight loss, stunted growth and death (Horak et al. 2002).

4.2 THE EGG

Eggs shed by adult schistosomes are spindle shaped and pass through the gut wall into the lumen of the intestine and out of the host's body with the feces. Eggs that fail to reach the intestinal cavity and lodge in other organs, such as the liver, are responsible for most pathology associated with avian schistosomiasis. Once shed in the feces and immersed in water, eggs hatch within minutes in response to osmotic pressure (Horak et al. 2002).

4.3 THE MIRACIDIUM

After emerging from the egg, the free-living miracidium uses cilia to swim in search of an intermediate host, a snail. The miracidium can chemically detect snails and distinguish potential intermediate hosts from other species (Smyth and Halton 1983; Kock 2001; Horak et al. 2002). This stage does not feed and must locate and infect a snail quickly; maximum life spans rarely exceed 24 hours (Hoeffler 1982; Horak et al. 2002) and tend to be shorter if miracidia hatch from older eggs (Roberts and Janovy 1996). Miracidia survive better at lower temperatures (e.g. up to 34 hours longer at 4˚C than at 18˚C for *Schistosomatium douthitti* [Ginetsinskaya 1968]).

4.4 THE SNAIL HOST

Avian schistosomes typically use lymnaeid and physid snails as intermediate hosts. In Canada, *Lymnaea catascopium*, *Stagnicola emarginata*, *Stagnicola elodes*, *Stagnicola palustris*, *Physella gyrina* and *Physa* spp. have been implicated in swimmer's itch transmission (Swales 1936; Normandeau 1988; Giovenazzo et al. 1995; Leighton et al. 2000). In North America, reported schistosome prevalence in lymnaeids and physids seldom exceeds 5% (Table 4); several long-term studies in Europe report prevalence of *Trichobilharzia* in these snails near 1% (Hjørngaard Larsen 2004).

Table 4
Prevalence of schistosome infections in snails in North America

Snail	Locality	Schistosome	Prevalence (%)	Source
Aplexa hypnorum tryoni	Clear Lake, Manitoba		0	1
Gyraulus parvus	Cultus Lake, British Columbia	*Gigantobilharzia* sp.	–	2
Helisoma spp.	Clear Lake, Manitoba		0	1
Helisoma trivolvis	Clear Lake, Manitoba		0	1
Lymnaea stagnalis jugularis	Clear Lake, Manitoba		6	1
Lymnaea stagnicola	Nairne Lake, Quebec		31.9	3
Physa sp.	Cultus Lake, British Columbia	*Trichobilharzia physellae*	3.6	2
	St. Lawrence near Quebec		0-5	4
Physella gyrina	Lake Beauport, Quebec	Ocellate cercaria spp.	1.4	5
	Lake Beauport, Quebec	Non-ocellate cercaria spp.*	2.8	5
	Clear Lake, Manitoba		0	1
	St. Lawrence near Quebec		20	4
Stagnicola spp.	St. Lawrence near Quebec		4-50	4
Stagnicola catascopium	Cultus Lake, British Columbia	*Trichobilharzia stagnicolae*	2.6	2
Stagnicola elodes	St. Lawrence near Quebec		12	4
Stagnicola elrodi	Flathead Lake, Montana	*Trichobilharzia ocellata*	2	5
Stagnicola emarginata canadensis	Clear Lake, Manitoba		8	1
	Two lakes in Michigan	*Trichobilharzia stagnicolae*	2.1	6
Stagnicola palustris	Clear Lake, Manitoba		0	1

Sources: 1. Swales 1936. 2. Leighton et al. 2000. 3. Giovenazzo 2002. 4. Giovenazzo et al. 1995. 5. Loken et al. 1995. 6. Keas and Blankespoor 1997.

* Not confirmed to cause dermatitis.

In *Lymnaea stagnalis*, daughter sporocysts of *Trichobilharzia ocellata* emerge from the mother sporocyst 3 to 4 weeks post-infection (de Jong-Brink et al. 1997) and cercarial shedding begins approximately 7 weeks post-infection at 20˚C and 4 to 5 weeks post-infection at 25˚C (Horak et al. 2002). Cercarial shedding in snails has been observed to last up to at least 123 days (Horak et al. 2002).

Moderate schistosome infections do not shorten snail life spans (Horak et al. 2002) and snails are occasionally self-cleared of infection (Minchella 1985). However, low prevalence among snails has also been interpreted as evidence of virulence, in that infected snails tend to die (Zbikowska 2004).

Snail hosts show physical changes after infection by schistosomes. Such changes may represent a benefit to either the host or the parasite and a cost to its counterpart. For example, schistosome infections commonly result in snail castration, an obvious detriment to the intermediate host (Horak et al. 2002). Theoretically, castration profits the parasite by allowing more of the snail's resources to be used to sustain production of cercariae rather than snail eggs. By increasing prepatent egg production, some snails are apparently compensating for the reproductive loss (Minchella 1985). Another phenomenon commonly associated with schistosome infection in snails is gigantism. Gigantism may reflect the snail's reallocation of resources in the hope of outliving the parasite (Minchella 1985), particularly in species that are short-lived and have a single breeding season (Sousa 1983), or it may result from spatial requirements of the parasite (de Jong-Brink et al. 1997). However, recent work shows that gigantism is not linked to the prevalence of schistosome infection, suggesting instead that increased growth reflects the greater likelihood of older, bigger snails being infected (Graham 2003).

Schistosome infection may also alter the behaviour of snail hosts. There is evidence that infected snails aggregate more than uninfected snails (Boissier and Moné 2003), which could increase the likelihood of definitive hosts being infected by both sexes of schistosome. Infected snails show a stronger preference for lower temperatures, which prolongs the survival of both infected snails and emerging cercariae (Zbikowska 2004).

It appears that schistosomes can overwinter in infected snails. Because prevalence in snails peaks mid-summer, it has been suggested that snails acquire infections in spring from newly returning migratory birds (Giovenazzo et al. 1995). However, the mid-summer spike in prevalence more likely reflects a second schistosome generation following the infection of newly arrived and particularly newly hatched birds by cercariae released from infected snails that survived the winter (Hoeffler 1982; Normandeau 1988). Moreover, patency in snails is reported to be much longer lasting than in waterfowl (Guth et al. 1979; Horak et al. 2002) and the life histories of North American snails include an overwintering phase (Thorp and Covich 2001). In general, lymnaeids and physids hatch from eggs in spring and die after a single egg deposition episode the following spring (Thorp and Covich 2001; Giller and Malmqvist 1998).

As the source of infective cercariae that cause swimmer's itch, the distribution and habits of physid and lymnaeid snails are of interest. Generally, lymnaeids feed on periphyton and physids feed on detritus; both groups are usually found in the littoral zone (Thorp and Covich 2001). For example, *Lymnaea emarginata* feeds preferentially on periphyton and is therefore more common on cobble (where periphyton grows year-round) than on macrophytes, although it will feed on the periphyton on macrophytes when snail densities are high (Thorp and Covich 2001). Freshwater snails of all families move into deeper water in the fall (Thorp and Covich 2001).

4.5 THE CERCARIA

The distribution, abundance and longevity of schistosome cercariae are affected by biological and physico-chemical conditions. For example, cercarial survival is negatively influenced by increasing temperatures (Zbikowska 2004). In refrigerated conditions, *Trichobilharzia* cercariae have been reported to live for several days (Ginetsinskaya 1968) and other species survive up to 130 hours at 8˚C (Zbikowska 2004). However, older cercariae are less able to penetrate hosts (Hoeffler 1982). In general, swimmer's itch-causing cercariae survive at most 1 to 1.5 days, with the majority dying in less than 24 hours if a compatible host is not located (Horak et al. 2002; Hoeffler 1982).

The emergence of cercariae from snails is generally associated with morning light. Although three cercariae species in *Stagnicola elodes* and *Physella gyrina alba* collected from the St. Lawrence River near Quebec City did not show diurnal emergence patterns during a 48-hour interval (Giovenazzo et al. 1995), this seems to be an exception. Morning cercarial emergence is indicated both by epidemiological studies of swimmer's itch in humans (Chamot et al. 1998; Lindblade 1998) and experimental work with snails (Blankespoor and Reimink 1991; Leighton et al. 2000). In the case of *Schistosomatium douthitti*, cercarial emergence is inhibited by light (Ginetsinskaya 1968), in keeping with the nocturnal habits of its murine hosts.

On emerging from the snail, *Trichobilharzia* cercariae swim away from the pull of gravity and unsuitable surfaces (e.g. rocks) toward the light, passing shadows and mechanical stimulation (Ginetsinskaya 1968; Smyth and Halton 1983; Horak et al. 2002). These behaviours lead cercariae toward the upper centimetres of the water column, where they intermittently swim and rest (Ginetsinskaya 1968; Roberts and Janovy 1996) and are subject to wind-driven currents. Pockets of high cercarial density can form in littoral areas exposed to onshore winds (Leighton et al. 2000; Verbrugge et al. 2004).

The distribution of host organisms also affects the distribution of cercariae. In Cultus Lake, B.C., *Gigantobilharzia* occurred only in the snail *Gyraulus parvus*, which was confined to a single site where both Eurasian milfoil (*Myriophyllum spicatum*) and overhanging trees were present (Leighton et al. 2000). The trees provided perches for icterids, the definitive host of *Gigantobilharzia*, and milfoil provided habitat for *Gyraulus*. At other sites on this lake, *Trichobilharzia stagnicolae* and *T. physellae* were more prevalent in *Stagnicolae catascopium* and *Physa* spp., respectively, in sheltered areas with floating logs than in exposed areas with no logs. These differences in prevalence were attributed to the habits of the local definitive host for these two species, the common merganser. This bird feeds on fish in open water and was observed to return to roost on logs in sheltered areas in the littoral zone and defecate in the vicinity.

5 Screening

Methods exist for detecting schistosomes at several stages during the parasite's life cycle, some with more challenging technical requirements than others.

In order to identify fluke taxa, it is preferable to extract adult worms from the bird host; however, this is difficult and requires sacrificing the bird (Horak et al. 2002). It is more practical and humane to screen bird feces. Because birds may not be infected at the time of sampling and the feces of infected birds may not always contain eggs, samples should be obtained repeatedly and from many birds. This last requirement is rarely met in wild bird populations, but it is achievable with domestic ducks.

Screening for infections in ducks or other birds may be performed by collecting fresh stool samples from individual birds in a single Petri dish on moist filter paper (adapted from Reimink et al. 1995 and Guth et al. 1979). Samples are kept moist and stored in a cool area until they can be examined with a dissecting microscope, at which point fecal matter is diluted and allowed to settle for 1 to 2 hours. Dilution water should be taken from filtered offshore lake water (to avoid contamination), artificial pond water or some other non-chlorinated source. After settling, miracidia, if present, can be observed in the water with a dissecting microscope, but inexperienced observers may confuse them with ciliated protozoans. A compound microscope is necessary to distinguish between miracidia, which are multicellular and have ciliated plates and specialized internal organs, and ciliated protozoans, which are unicellular and completely covered with cilia.

The presence of fluke eggs or miracidia in feces does not prove that captive birds are infected with swimmer's itch-causing schistosomes; eggs may also be shed by other kinds of flukes in the birds. To verify swimmer's itch-causing capability, local snails should be infected with miracidia from fecal samples and the resulting cercariae used to challenge human volunteers.

To screen the intermediate host, snails are individually housed in clear plastic cups containing filtered lake water or artificial pond water and periodically monitored for cercarial shedding using a dissecting microscope. Snails that do not shed cercariae can be screened for sporocysts with a dissecting microscope by pressing the soft tissues of the snail between glass plates. Again, some expertise is required to distinguish cercariae and sporocysts. In sampling natural snail populations, a power analysis using the variation in prevalence in Table 4 indicates that 120 snails should be collected and screened in order to estimate prevalence with 95% confidence and a precision of 1%.

Screening natural waters for the free-living stages of schistosomes is more technically demanding. Giovenazzo et al. (1995) attempted to measure cercarial abundance by sieving St. Lawrence River water using a variety of mesh sizes, but accumulation of debris and zooplankton prevented reliable results. Hybridization and polymerase chain reaction (PCR) assays have been successfully used to detect *Trichobilharzia ocellata* in water by targeting species-specific, non-coding DNA sequences (Kozak-Cięszczyk and Wędrychowicz 2003). The more powerful and specific of the two techniques, the PCR assay, allows the detection of a single cercaria in 0.5 g of plankton.

6 Control Measures

6.1 THE BIRD HOST

The anthelmintic drug Praziquantel appears to be promising for controlling schistosomes in waterfowl and reducing the incidence of swimmer's itch in humans. The drug arrests the constant regeneration of the tegument of the adult worm and thereby allows the bird's immune system to recognize and attack the pathogen (Roberts and Janovy 1996). Studies in Michigan, discussed below, indicate that appropriate single administrations of the drug can clear waterfowl of schistosomes, after which birds become resistant to reinfection. More importantly, this strategy can lead to a reduction in prevalence in intermediate host populations and diminish swimmer's itch incidence in humans.

Blankespoor and Reimink (1991) used Praziquantel to clear mallards of schistosomes in the lab and administered it to waterfowl resident at a lake during five consecutive summers. Ducks were treated monthly to prevent reinfection. Reports of swimmer's itch at the lake declined and schistosome prevalence in the snail *Stagnicola emarginata* decreased significantly (from a high of 2% to approximately 0.1%).

Reimink et al. (1995) showed it is unnecessary to administer Praziquantel repeatedly. After a single oral dose at 4 weeks of age, mallards had significantly fewer infections a year later than untreated birds. Moreover, the prevalence of naturally infected snails in lakes where Praziquantel was used to treat hatchlings was reduced from between 1–2% to 0.1–0.2% the year following treatment.

Blankespoor et al. (2001) found that single injections of Praziquantel in dosages of 200 mg/kg of body weight were far more effective in reducing fecal schistosome loads in common mergansers than oral dosages of less than 40 mg/kg, which had no discernible effect. (The manufacturer, Bayer, recommends 40 mg/kg.) The low efficacy of orally administered Praziquantel in mergansers was attributed to the shorter gastrointestinal tract of this piscivorous birds, which results in less time for digestion than occurs in herbivorous species.

Although Praziquantel is not inexpensive, as an swimmer's itch control method it was both more effective and less costly than the prevailing use of the molluscicide copper sulphate at these Michigan sites. Moreover, it was not toxic to birds, even at 50 times the normal dose (Blankespoor and Reimink 1991).

Other methods of reducing swimmer's itch incidence that target definitive hosts have not been well studied. Attempts by residents at Lake Nairne, Quebec, to drive away waterfowl during the summer did not produce desired results: the following year cercarial prevalence in snails increased (Giovenazzo 2002). Leighton et al. (2000) suggest removing debris in the littoral zone at lakes where roosting waterfowl such as common mergansers are present, thereby reducing schistosome transmission to snails. Lakeside residents should avoid feeding waterfowl, as this may cause the birds to stay in the area and increase swimmer's itch infection rates (Blankespoor and Reimink 1988a).

6.2 THE SNAIL HOST

Control measures focusing on snail intermediate hosts can be used in a localized area such as a small beach. Although chemical means have been widely used to reduce snail populations, recent work suggests that mechanical disturbance of snail habitat is more effective and economical and poses less environmental risk.

Molluscicides available in North America include copper sulphate, copper carbonate, sodium pentochlorphenate and Baylucide® (niclosamide) (Hoeffler 1982). Copper sulphate, by far the most commonly employed molluscicide in North America, has been used since the 1930s to control swimmer's itch in many Michigan lakes (Blankespoor and Reimink 1991). The chemical has had mixed results, for which several explanations have been suggested.

- Snails reproduce and disperse quickly, making one-time local applications ineffective.
- Molluscicide is often applied to small localities with little scrutiny of local or adjacent snail populations. Reductions in local populations of snail species that do not harbour swimmer's itch-causing schistosomes can allow a site to be colonized by species susceptible to infection.
- Failure to account of local currents, wind conditions and water chemistry can result in unpredictable dispersion or precipitation of the chemical.
- Snails may become resistant to copper sulphate. *Lymnaea catascopium* and *Physa integra* from a lake that had previously been treated with copper sulphate were more resistant to lab exposures of the molluscicide than snails from a pristine lake (Blankespoor et al. 1985). Furthermore, larger snails from both lakes were more resistant than smaller snails. This is significant because older snails, which tend to be

> larger, are more likely to be infected than younger, smaller individuals (Graham 2003).

The biggest drawback to copper sulphate and molluscicides in general may be toxicity to other forms of aquatic life (Madsen 1990; Blankespoor and Reimink 1991).

Several Canadian studies have examined mechanical snail control techniques as a means to combat swimmer's itch. A variety of mechanical methods were used over a three-year period at Lake Nairne, Quebec (Giovenazzo 2002; Giovenazzo 2003). During the summers of 2001–2003, *Lymnaea stagnicola* and planorbid snails were manually removed at some sites, scythes were used to cut emergent vegetation (mainly *Scirpus*) at others and no action was taken where low numbers of snails were observed. These efforts were evaluated by comparing snail densities and the prevalence of schistosome infections in snails at the different sites. Removal of vegetation and/or the associated habitat disturbance appear to have been more effective in culling snail populations than snail removal by hand, which did not affect snail populations consistently. However, it is difficult to assess the comparability of the densities over the 3-year span as presented in Giovenazzo (2002) and Giovenazzo (2003). Densities appear to be based on different numbers of samples per year, collected at different periods each year and by different methods. In 2001, snail densities were based on a single sampling effort using hand collection at an unspecified date; in 2002, on five sampling efforts beginning in June (some collected by hand, some with rakes); and in 2003, on a single sampling effort in May using an unspecified method. Prevalence of schistosome infections in snails was higher at most sites in 2002 than in 2001, but how changes in snail populations due to habitat disturbance would be expected to affect prevalence is unclear. Results regarding swimmer's itch incidence in humans are not presented.

At Cultus Lake, British Columbia, Leighton et al. (2000) studied the effects of weekly mechanical disturbance of cobble snail habitat during the breeding season at three pairs of sites (one treatment site, one control) that were initially similar in terms of snail egg mass densities. After disturbance using a boat-mounted rototiller and tractor-mounted rock rake, densities of *Stagnicola catascopium*, *Physa* spp. and *Gyraulus parvulus* were reduced by 96–99% compared to adjacent control sites, 5 to 20 days after the end of treatment. Local populations of these species were confirmed as the intermediate hosts of *Trichobilharzia stagnicolae*, *T. physellae* and *Gigantobilharzia* sp., which were shown to cause dermatitis in humans. Reductions in snail densities were attributed to the destruction of snail habitat during the breeding and early development phase of the snails, which killed adult snails, destroyed the epilithic periphyton on which they feed and exposed eggs to predation. The authors note that copper sulphate had previously been used in Cultus Lake without appreciable effects. No results were presented concerning the effects of habitat disturbance on swimmer's itch incidence.

Lévesque et al. (2002) used a suction pump to destroy snail habitat inhabited by a well-defined population of *Physella gyrina*, which appeared to be the source of an outbreak of swimmer's itch in Lake Beauport near Quebec City in 1999. No swimmer's itch was reported the following summer.

The usefulness of localized control programs that target snails may be limited by wind and current conditions. Cercariae tend to be found near the surface of the water where they can be transported by wind-generated surface currents into other areas; theoretically, this may lead to concentrated pockets of cercariae along the shoreline. Prevailing winds over a lake could indicate the direction in which cercariae are likely to be carried and, as suggested by Leighton et al. (2000), buoys set afloat in areas of high snail density can be used to model cercarial drift.

Studies of the biological control of schistosomes have focused on the human parasite *Schistosoma* by targeting its intermediate host, *Biomphalaria*. The use of fish that feed on *Biomphalaria* has not proved widely applicable because fish switch prey when snail densities decrease without affecting parasite transmission rates (Madsen 1990). The introduction of snails that compete with *Biomphalaria* has had mixed results because potential competitors often end up coexisting with *Biomphalaria* (Madsen 1990). Another approach is the introduction of parasites that interact with schistosomes within the snail. One candidate group are the echinostome trematodes, which infect snails and develop into rediae. Unlike schistosome sporocysts, rediae possess a mouth and gut which they use to consume host tissue and other parasites, including schistosomes. In controlled conditions, Lie (1973) used echinostome egg dispersal to reduce prevalence of S*chistosoma* in snails, with the added benefit that host snail populations were considerably reduced. The same antagonistic interaction between parasites may be at work at a New Zealand lake, where Davis (1998) recorded that peak annual prevalence in snails of schistosomes coincided with the lowest annual prevalence of two species of echinostome. Similarly, echinostome prevalence peaked during the month when schistosomes were not found in any snails. Biological control strategies are complex and require considerable laboratory and site-specific research before implementation can be attempted.

Caution and restraint should be exercised before conducting a snail control program. COSEWIC (2004) has identified data deficiencies for two molluscs rarely encountered in Quebec, namely the snail *Physella parkeri latchfordi* and the freshwater limpet *Acroloxus coloradensis*. Destruction of aquatic plant communities should not be undertaken lightly, not least because it has not been shown to be effective. Before vegetation is removed, plant species should be surveyed to ensure no species at risk are present (e.g. *Carex lupuliformis* [endangered], *Justicia americana* [threatened], *Cicuta maculata* var. *victorinii* and *Gentianopsis procera* spp. *macounii* var. *victorinii* [threatened] [COSEWIC 2004]). Finally, although disturbance of snail habitat is probably less harmful to the aquatic ecosystem than the application of copper sulphate, it is not "benign", as stated by Leighton et al. (2000). Gastropods perform a crucial function in littoral food webs by converting periphyton into a form useable by other aquatic organisms (Giller and Malmqvist 1998).

6.3 OTHER CONTROL MEASURES

Swimmer's itch can be reliably prevented by avoiding bathing in water where the parasite occurs. However, this imposes unrealistic restrictions on recreational uses of lakes and natural waters.

Preventing swimmer's itch at the level of cercaria-skin interactions has received little attention. It is theoretically possible to prevent infection if the skin is dried off before cercarial penetration takes place, and vigorous and immediate towel-drying after swimming is sometimes recommended for this reason (e.g. Blankespoor 1980; Normandeau 1988). Similarly, some local authorities recommend showering immediately after swimming (de Gentile et al. 1996). The usefulness of these practices, however, has not been demonstrated (Hoeffler 1982; de Gentile et al. 1996) and is suspect, since cercaria can presumably penetrate the skin during the comparatively long period during which the bather remains in water prior to towelling off or showering.

The use of N,N-diethyl-*m*-toluamide (DEET) as a topical prophylaxis against cercarial penetration is more promising. Salafsky et al. (1998) showed that a concentration of 7.5% DEET, which is found in the insect repellent Off®, immobilized *Schistosoma* cercariae within 5 minutes.

However, because of its rapid absorption by the skin, the prophylaxis of DEET is short-lived, ranging from 30 minutes to 6 hours for insects and even shorter durations for cercariae. Salafsky et al. (1999) succeeded in prolonging the anti-cercarial action of DEET in mice by preparing lipid-based compounds of the chemical. Single applications of 10% DEET in three compounds significantly and greatly reduced the number of *Schistosoma* worms that became established in the lungs when mice were challenged with cercariae up to 24 hours after application. By contrast, DEET alone significantly reduced worm establishment in the lungs 4 hours after application, but it had no effect after 24 hours. The most effective compound was 10% DEET in liposome, or "Lipodeet," which conferred 100% protection against cercarial penetration even 48 hours post-application. Lipodeet (10% and 20% DEET formulations) also conferred up to 90% protection if mice were allowed to swim in warm water for 1 hour after application. DEET alone was only slightly effective after a 5-minute swim and its effects were absent after a 1-hour swim. Although DEET-related toxicity is infrequent in topical applications, Salafsky et al. (1999) examined DEET uptake through the skin of Lipodeet versus DEET alone, and found that the liposome matrix significantly reduced the amount of DEET found in mouse urine and blood after application.

To achieve lake-wide reductions in avian schistosome populations, a multipronged approach involving snail habitat disturbance and/or treating birds with anthelmintics is advisable. Both strategies require manpower and the notification of provincial authorities. In addition to biological and veterinary expertise, specialized equipment is also necessary (e.g. dissecting microscopes, Praziquantel, drive-traps, and the ability to identify bird, snail and trematode taxa and to trap and administer drugs to birds). Snail control may be somewhat less technically demanding as it does not involve trapping birds or anthelmintics.

Prevention remains a viable strategy. In the absence of commercially available lipid-based DEET compounds, trials with insect repellents could be conducted with the assistance of a dermatologist or physician and a biologist. Public awareness of risk factors is a safe way to reduce the impact (and, it is hoped, the incidence) of swimmer's itch, particularly if coupled with knowledge of endemic areas in a lake.

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