Fish and ecosystem health as determined by parasite communities of lake whitefish (*Coregonus clupeaformis*) from Saskatchewan boreal lakes

Michael Pietrock and Olesya Hursky

**ABSTRACT**

In northern Canada, there is increasing concern about the potential negative impacts of industrial activities on wildlife and ecosystems. Therefore, a study was conducted on lake whitefish (*Coregonus clupeaformis*) from Montreal and Reindeer lakes, Saskatchewan, to assess fish health and condition, and ecosystem integrity of these northern lakes. In Montreal Lake, all fish were infected by $\geq 2$ parasite species. The most prevalent parasite at this site was the larval trematode *Ichthyocotylurus erraticus*, which was detected in all fish examined. All Reindeer Lake whitefish were shown to harbour $\geq 1$ parasite species. The most prevalent parasite (found in 87.9% of fish) at this locality was the larval trematode *Diplostomum* sp. Macroscopically visible pathogenic changes were not noted. Gross energy values of whitefish were $4.40 \pm 0.88$ MJ/kg and $5.14 \pm 1.14$ MJ/kg for Montreal Lake and Reindeer Lake, respectively, indicating that fish have sufficient energy stores to withstand stressful conditions. The parasite communities were species-rich and diverse, with Shannon diversity indices of 2.12 (Montreal Lake) and 2.02 (Reindeer Lake). The ratios of allogenic/autogenic as well as planktonic/benthic parasite species did not indicate atypical environmental conditions. Together the findings suggest that in both lakes there is currently no significant anthropogenic impact on the whitefish populations and ecosystem health.

**Key words** | boreal lakes, ecosystem integrity, fish health, lake whitefish, parasites, Saskatchewan

**INTRODUCTION**

Saskatchewan is one of Canada’s Prairie Provinces which, in its northern parts, has thousands of relatively pristine lakes and other water bodies of various sizes. Aboriginal fishers and hunters as well as sport fisherman are the predominant users of these aquatic resources. In the recent past, concerns were expressed by First Nations representatives that, as in other Canadian provinces (Timoney & Lee 2009; Kelly et al. 2010), accelerating industrial activities such as metal mining and oil sands exploration in Saskatchewan’s north may affect aquatic ecosystem integrity and can compromise fish health. Recent studies have linked impairment of fish health, as indicated by increased occurrence of tumors, deformities and pathogens, to mining and milling operations (van den Heuvel et al. 2000; Muscatello et al. 2006; Timoney & Lee 2009). A potentially negative impact on fish, wildlife and ecosystems due to anthropogenic activities in the north, therefore, is a topic of concern as well as major public and scientific debate (Muscatello et al. 2008; Northwatch & MiningWatch Canada 2008; Kelly et al. 2009, 2010; Droitsch & Simieritsch 2010).

Fish are at the upper end of the aquatic food web and thus may biomagnify chemical substances present in the ecosystem. Both organic and inorganic chemicals have been demonstrated to impair fish health (Overstreet 1993; Lawrence & Hemingway 2005). Changes in fish population health, or fish community structure and composition may indicate anthropogenic impacts on the environment.
Therefore, a number of studies use fish as indicator organisms for ecosystem health and integrity (Simon 1999).

A relatively new and elegant approach to obtaining information on both fish and ecosystem health is the study of fish parasite communities. Parasites, on one hand, may directly compromise fish health, growth, condition and fecundity, and often enhance host responses to pollution stress (Marcogliese & Pietrock 2011). Moreover, they are known causes for fish diseases and mortalities (Schäperclaus 1990). On the other hand, a tremendous amount of valuable ecological information on the state of an ecosystem can be derived through the study of parasite communities (Marcogliese 2004). As the complex life-cycle of many helminth parasites includes several invertebrate and vertebrate taxa acting as intermediate or final host, the presence of a parasite in or on an organism shows that other host species necessary for parasite life-cycle completion (temporarily) occur in the habitat of interest as well. Parasites, thus, are indicative of the general biodiversity of an ecosystem. Moreover, many parasitic organisms (or stages thereof) are trophically transmitted through predator-prey interactions. Parasites thus reflect the host’s position in a food web as well as trophic relationships (Marcogliese & Cone 1997). In environmental studies parasites have furthermore been used to identify population biology, niche shifts and migrations of their hosts (Williams et al. 1992; Bergeron et al. 1997; MacKenzie 2002), environmental pollution (MacKenzie et al. 1995; Lafferty 1997) and deterioration of aquatic habitats (Cone et al. 1995; D’Amelio & Gerasi 1997). Not only have parasite communities been shown to respond to changes in ecosystem conditions, but also indicators based on parasite communities have been developed to provide environmental managers and decision makers with tools to assess and classify habitat quality (Landsberg et al. 1998; Palm & Rückert 2009).

In 2008/2009 a study on lake whitefish (Coregonus clupeaformis) parasites was conducted in two Canadian lakes in the Boreal Plains and Boreal Shield ecozones, respectively. Whitefish are widely distributed in northern boreal lakes and, in Canada, play a significant role in the diet of Indigenous people. The specific objectives were to investigate whether there is a potential anthropogenic impact on whitefish health and aquatic ecosystem integrity. Specifically, lake whitefish metazoan parasites were identified and infection parameters were calculated to obtain information on the health of the fish from both waters. Additionally, gross energy content of the whitefish was assessed in order to determine fish condition. Finally, the parasite community of C. clupeaformis was analysed with regard to diversity and species composition to attain knowledge on current habitat quality and potential human influences on the aquatic environment.

MATERIALS AND METHODS

Sampling sites

This study was conducted in Montreal and Reindeer lakes, both of which are located in northern Saskatchewan, Canada. Montreal Lake is situated at 54°40′N and 105°40′W within the Boreal Plain ecozone. Located at an elevation of 490 m, Montreal Lake covers an area of 447 km² (Natural Resources Canada 2010). The lake is relatively shallow with a depth of 8.5 m at its deepest spot (mean depth 2.2 m). The fish community consists of northern pike (Esox lucius), walleye (Sander vitreus), lake whitefish (C. clupeiformis), cisco (Coregonus artedii), yellow perch (Perca flavescens) and burbot (Lota lota) (Anonymous 2009). Reindeer Lake is an oligotrophic lake of early Precambrian age. It is located near the northern limit of the coniferous forest (57°0′N, 102°0′W). At an elevation of 337 m, it is Saskatchewan’s second largest lake, covering 5,569 km² with maximum length of 245 km, maximum width of 56 km and maximum depth of 215 m (Dean 1975; Guildford et al. 2008). Common fish from this lake include lake trout (Salvelinus namaycush), lake whitefish (C. clupeiformis), cisco (C. artedii), northern pike (E. lucius), walleye (S. vitreus), white sucker (Catostomus commersonii), yellow perch (P. flavescens) and burbot (L. lota) (Dean 1975; Houde et al. 2008).

Water samples

In summer 2009 physicochemical water parameters (Table 1) were measured in both lakes using the U-10 (Horiba) water quality checker for determination of pH, conductivity, dissolved oxygen concentration, temperature, salinity and turbidity. Measurements were conducted
about 1 (Reindeer Lake) and 3 (Montreal Lake) metres below water surface.

For determination of alkalinity, hardness and ammonia concentrations, water samples were taken from both lakes on the same day as above. Samples were stored in dark plastic bottles, put on ice and transported to the laboratory where the samples were analysed by an Auto Titrator (Man-Tech Inc.).

Fish sampling

Adult lake whitefish from both lakes were sampled between October 2008 and October 2009 using gill nets. Fishing was conducted by local fishermen. In Montreal Lake a total of 71 fish (mean body mass (±S.D.) of 0.990 (0.27) kg, mean body length (±S.D.) 42.9 (4.60) cm) were sampled. The Reindeer Lake fish sample comprised 91 individuals (mean body mass (±S.D.) 1.14 (0.22) kg, mean body length (±S.D.) 45.3 (3.20) cm). All fish were sacrificed in the field, put on ice and transported to the laboratory, where the fish were frozen until further examination.

Parasitological examination

Parasitological examination of fish was conducted according to standard techniques. After thawing, length and weight of fish were determined. External inspections of skin and fins were conducted to detect infections by ectoparasites and presence of metacercarial cysts. The eyes of the fish were removed and dissected; the lens and vitreous humour of the eye were examined separately. Gills were removed and inspected for occurrence of parasites. Subsequently the body cavity was opened and the following organs were dissected and examined for pathological changes and parasitic infections: intestine, liver, gall bladder, spleen, gonads, swimbladder, heart, kidney, and urinary ducts and bladder. Subsequently the fish skin was removed and the muscle was analysed for presence of parasites. Muscles from both sides of the fish were cut into 5-cm slices which were placed between glass plates and squashed for further examination. Finally, the cranium of the fish was opened to dissect and examine the brain for parasitic infections.

All unencysted parasites found were counted, removed from the organs, cleaned in 0.68% saline solution and transferred into 4% formalin. For species identification, parasites were either cleared in glycerol or stained with acetocarmine (Pietrock 1998). Encysted parasites were counted as well and subsamples were removed from the respective organs, opened with the help of fine needles and processed (fixed, stained) as described.

Parasite measurements and identifications were performed with the help of a stereomicroscope SZX10 (Olympus) and research microscope VANOX-T (Olympus), respectively. Parasites were identified using the keys of Bauer (1985, 1987), Arai (1989), Moravec (1994), Gibson (1996), Scholz & Hanzelová (1998) and Parker (2010).

Determination of fish condition and gross energy content

A Fulton-type condition factor ($K$) was calculated according to the formula:

$$K = \frac{\text{weight (g)}}{\text{length (cm)}^3} \times 100$$

As the condition factor can be affected by many variables, fish condition was furthermore assessed based on the gross energy content, which reflects the available energy resources of fish (Schreckenbach et al. 2001). Briefly, approximately 5 g of muscle was taken from every fish, weighed to the nearest 0.001 g and dehydrated in an oven for 24 h. Subsequently, the dry weight of the sample was measured and the gross energy content was calculated using the formula:

$$\text{Gross energy (MJ/kg)} = 0.0255 \times \text{dry matter (\%)}^{1.6785}$$

Schreckenbach et al. 2001.

### Table 1 | Selected water parameters of Montreal and Reindeer lakes, Saskatchewan, Canada, measured in July 2009

<table>
<thead>
<tr>
<th>Water parameter</th>
<th>Montreal Lake</th>
<th>Reindeer Lake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>Conductivity (μS/cm)</td>
<td>270</td>
<td>32.3</td>
</tr>
<tr>
<td>Oxygen concentration (mg/L)</td>
<td>11.1</td>
<td>12.5</td>
</tr>
<tr>
<td>pH</td>
<td>7.7</td>
<td>6.96</td>
</tr>
<tr>
<td>Salinity (%)</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Alkalinity (mg/L as CaCO$_3$)</td>
<td>663.0</td>
<td>26.0</td>
</tr>
<tr>
<td>Hardness (mg/L as CaCO$_3$)</td>
<td>133.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Total ammonia (mg/L as N)</td>
<td>0.047</td>
<td>0.137</td>
</tr>
</tbody>
</table>
Analysis of parasite community

The parasite community was both quantitatively and qualitatively described by the number of species and species composition. Overall diversity of the parasite community was determined by calculating the Shannon index ($H'$) (Magurran 1988). In order to determine levels of parasite infection, the prevalence (i.e. percentage of infected fish) and mean intensity (i.e. mean number of parasites per infected fish) were calculated separately for each parasite species (Bush et al. 1997). The Berger–Parker dominance index ($1/d$) was calculated to identify the most common species (Magurran 1988). Parasites were furthermore assigned into being either autogenic or allogenic, depending on whether they mature in fish or in vertebrates other than fishes, respectively (Esch et al. 1988). Additionally, parasite species were divided into planktonic and benthic species based on whether fish-infective stages develop in planktonic or benthic intermediate hosts (Zander & Kesting 1996).

Statistical analyses

Differences in prevalence were statistically compared using the Chi-square test. For comparison of the mean intensity of infection the Mann-Whitney $U$-test was applied to identify statistically significant differences between the two lakes. Gross energy content and condition factor of the test groups were analysed by $t$-test. Unless otherwise stated, differences between test groups were considered statistically significant at $p < 0.05$. All calculations were conducted by means of SPSS 17.0.

RESULTS

Fish health and condition

All whitefish from Montreal Lake were infected by at least two parasite species (range 2–7). Prevalence and mean intensities of infection were variable between species (Table 2). The most prevalent parasite in this lake was *Ichthyocotylurus erraticus*, which was found in cysts around the heart of all fish. This trematode showed the highest infection intensities with individual fish harbouring up to 2,200 metacercarial cysts. The gastro-intestinal tract was the organ (system) with the highest number of parasite species (*Proteocephalus longicollis*, unidentified cestode species, *Neoechinorhynchus tumidus*, *Pomphorhynchus bulbocelli*, *Raphidascaris acus*). Macroscopically, however, there were no visible pathological changes in either this organ system or any other organs.

All Reindeer Lake whitefish harboured at least one parasite species (range 1–8). Prevalence and mean intensities of infection are given in Table 2 for each species. With a total prevalence of 87.9%, the most prevalent parasite species of lake whitefish from this locality was *Diplostomum* sp., which was detected in the eye lenses. Highest infection intensities were recorded for *Cyathocephalus truncatus*. Up to 1,355 specimens of this cestode were counted in the pyloric caeca of individual fish. Again the gastrointestinal tract was the organ harbouring the highest number of parasite species (*P. longicollis*, *C. truncatus*, *Acanthocephalus dirus*, *Echinorhynchus* sp., *Raphidascaris acus*). No macroscopically visible pathological changes were observed.

Whitefish from Montreal and Reindeer lakes were generally in good condition. During fish dissections, small deposits of body fat were found in the body cavity of most of the fish examined. Mean condition factor (Table 3) was not significantly different between the whitefish samples from the two lakes. However, the mean gross energy content of the Reindeer Lake fish was slightly (but statistically significantly) higher than the gross energy value of the Montreal Lake fish (Table 3).

Parasite community analyses

The parasite community of *C. clupeaformis* from Montreal Lake consisted of 15 species belonging to the taxa Cestodes, Trematoda, Acanthocephala, Nematoda, Copepoda and Hirudinea (Table 2). The Shannon diversity index of the parasite community was 2.12. *Ichthyocotylurus erraticus* was the dominant species in this locality with a Berger–Parker index of 1.22. The parasite community consisted of six allogenic and eight autogenic species. The ratio of benthic to planktonic parasite species was 9:3 (Table 2). The unidentified cestode was not assigned to either the allogenic or autogenic group, nor to the benthic or planktonic group as its life-cycle is unknown.
The parasite community of Reindeer Lake whitefish was composed of a total of 12 species belonging to the taxa Cestoidea, Trematoda, Monogenea, Acanthocephala, Nematoda and Copepoda (Table 2). Its Shannon diversity index was 2.02. The dominant species of the parasite community was the cestode *C. truncatus* with a Berger–Parker index of 2.19. Overall, the community consisted of three allogenic and nine autogenic parasite species. The ratio of benthic to planktonic species was 7:3 (Table 2).

**DISCUSSION**

The current study yielded similar results in Montreal and Reindeer lakes and thus it seems applicable to discuss the...
data from both sampling sites together. Overall, dissections and parasitological examinations revealed that the fish are in good health state despite the variety and number of parasite species found. Many of the identified species (Tryaenophorus crassus, Diplostomum sp., Tylocephalus scheuringi, Uvulifer ambloplitis, Pomphorhynchus bulbo-collis, Raphidascaris acus, Piscicola geometra) are generalists which have been found in various fish from other localities as well (Margolis & Arthur 1980). Prevalence and intensities, in particular, of some parasites were very high. This was particularly evident for I. erraticus in Montreal Lake and C. truncatus in Reindeer Lake fish. However, it is not uncommon that widely distributed parasites with a broad host spectrum reach high prevalence and intensity in their host populations. This holds especially for larval stages such as metacercariae (e.g. Diplostomum sp., I. erraticus) or nematode larvae (e.g. R. acus) which are long-lived in their hosts. Larval parasites detected in the adult whitefish may therefore originate from infections that took place in former years and which, along with annually occurring new infections, result in high prevalence and intensities. High infection intensities, in combination with other stressors may lead to disease and mortality within the host population. Typically, in a given host population only a few individuals are heavily infected while the majority of hosts carry moderate or low parasites numbers (Esch & Fernandez 1993). In the current investigations, several species (e.g. Diplostomum sp., Acanthocephalus dirus and T. crassus from Montreal Lake) follow this typical pattern. In other cases (e.g. I. erraticus metacercariae from Montreal Lake, C. truncatus from Reindeer Lake) high mean intensity values were caused by many fish being heavily infected rather than only a few individuals.

In the present study, no macroscopically visible pathogenic changes were found. It is nevertheless well conceivable that pathogenic effects did occur at the microscopic level as was described in earlier studies on, for example, Coregonus spp. infected with I. erraticus metacercariae (Orecka-Grabda 1991; Dezfuli et al. 2008) or the nematode Cystidicola farionis (Faisal et al. 2010). Pathogenic effects are the result of complex processes and depend on several factors, such as host and parasite species, age of host, target organ and number of invading parasites per time unit. Furthermore, pathogenic effects may manifest themselves after a given period of infection. Lack of macroscopic pathologies thus may not be uncommon, in particular as diseased or otherwise weakened fish under natural conditions may easily be removed from the population by predation. In terms of fish population health, the highly abundant Diplostomum sp. and I. erraticus pose a risk to larval whitefish in Reindeer and Montreal lakes, as single cercariae while migrating to the target organ are capable of killing small fish (Schäperlaus 1990). Whether or not and to what degree parasite-mediated mortalities among fish larvae currently occur, however, requires further investigation.

Coregonus clupeaformis from both localities had a condition factor similar to their conspecifics in many other lakes of North America (Rennie & Verdon 2008). However, the Fulton-type condition factor can be affected by gonad mass, stomach filling and other variables, potentially leading to misinterpretations of the true fish condition. For this reason, fish condition can be evaluated by assessment of gross energy stores (Schreckenbach et al. 2001; Simon 2007), which in the sum are available to the fish to cope with stressful conditions. Healthy fish should reveal gross energy contents of 4–7 MJ/kg to resist long-term natural and anthropogenic stressors (Schreckenbach et al. 2001; Schreckenbach 2002). Lake whitefish from Montreal and Reindeer lakes had gross energy values of around 5.0 MJ/kg. These values are thus at the lower end of the recommended ‘energy store scale’. However, taking into account both the inconspicuous condition factor and fat deposits noticed in the fish during dissections it is concluded here that the fish from Montreal and Reindeer lakes on average were in sufficient condition to withstand chronic stressors.

Table 3 | Mean condition factor (K) and gross energy content of lake whitefish (Coregonus clupeaformis) from Montreal and Reindeer lakes, Saskatchewan, Canada

<table>
<thead>
<tr>
<th></th>
<th>Montreal Lake</th>
<th>Reindeer Lake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean condition factor K* (^±S.D.)</td>
<td>1.20 (0.13)</td>
<td>1.18 (0.16)</td>
</tr>
<tr>
<td>Mean gross energy content (MJ/kg) (^±S.D.)</td>
<td>4.40 (0.88)</td>
<td>5.14 (1.14)</td>
</tr>
</tbody>
</table>

*Statistically significant differences (t-test, p < 0.05).
^Fulton factor.
"calculated according to Schreckenbach et al. (2001).
Parasite communities have repeatedly been used to assess the integrity of aquatic ecosystems (Blanar et al. 2009; Vidal-Martínez et al. 2010). The wide distribution and ability to respond to a variety of anthropogenic stressors make parasites useful tools in ecosystem health assessments. Overall, owing to the significance of parasites for, for example, trophic energy flow, host population dynamics and interspecific competition, it is now increasingly accepted that healthy ecosystems are those with diverse parasite communities (Marcogliese 2005; Hudson et al. 2006). Compared with parasitological investigations on whitefish from other localities (Dechtiar 1972; Arthur et al. 1976; Watson & Dick 1979; Goater et al. 2005) the parasite community data do not suggest that integrity of the two lakes under study is currently negatively impacted. With 15 and 12, respectively, parasite species of a variety of taxa, whitefish from Montreal and Reindeer lakes had a species-rich community of parasites. Taking into account that each parasite species has a more or less complex life-cycle which comprises various invertebrate and vertebrate hosts and specific transmission pathways, the parasitological findings suggest that environmental conditions in the two localities support a diverse and interactive biocoenosis.

As depicted in Figure 1, comparison of conceptual food webs derived from whitefish parasite surveys from both the literature and the present investigations shows no fundamental differences in web structure metrics such as number of trophic levels, chain lengths and connectance. It should be mentioned though that, although present in real life, two taxa (insects, mammals) could not be included in the parasite-based webs of Montreal and Reindeer lakes, as the parasites (Diphyllobothrium sp., Crepidostomum sp.) indicating trophic links between whitefish and mammals and insects, respectively, were not detected in these localities. This, however, is not unusual as Diphyllobothrium sp. and Crepidostomum sp. have not been found in each individual whitefish parasite survey either. The Shannon-index of the lake whitefish was around 2.0 in both lakes and thus higher than or as high as those of fish from other waters (Marcogliese & Cone 1998; Sammartín et al. 2000; Lamková et al. 2007; Li et al. 2009). This fact, however, should not be overrated, as richness of parasite communities is also influenced by host phylogeny, although local processes are important determinants of species richness (Poulin 1998), and ultimately diversity.

The ratio of allogenic to autogenic parasite species has been used to assess habitat quality. Generally, there is evidence that the proportion of autogenic species within parasite communities decreases from oligotrophic to eutrophic waters (Esch 1971), although there are exceptions (Leong & Holmes 1981). The present results on whitefish parasite communities from oligotrophic Montreal and Reindeer lakes follow this general pattern with autogenic species outnumbering allogenic ones. The allogenic/autogenic ratios in the current study thus do not suggest any significant anthropogenic impact on the respective aquatic ecosystem. Furthermore, a well-balanced ratio of planktonic and benthic species has been suggested to be indicative of good habitat quality (Zander & Kesting 1996). While acknowledging that a well-balanced ratio may suggest non-extreme conditions, we urge caution with use of a defined planktonic/benthic ratio as an indicator of undisturbed environments. Parasite community structure is affected not only by environmental variables but also by host characteristics (in addition to evolutionary constraints). A host specialized in terms of food or habitat choice may easily end up with an unbalanced planktonic/benthic ratio of its parasite community, even in the most pristine environment. Host biology, therefore, needs always to be taken into consideration when applying the planktonic/benthic parasite concept in environmental assessments. Additionally, a large proportion of benthically transmitted parasites in the parasite community may reflect suitable conditions for the existence of a diverse benthic invertebrate fauna. In view of the fact that many anthropogenically affected aquatic systems suffer from permanent or temporary oxygen depletion near the bottom zone, a higher percentage of benthic parasite species (as found in the current investigations) may actually be a stronger indicator for good habitat conditions than a well-balanced ratio of benthic and planktonic species.

Information on parasite communities or health of lake whitefish from western Canada is fragmentary and largely restricted to the studies of Leong & Holmes (1981) and Goater et al. (2005), who investigated whitefish parasites in several lakes of Alberta, Canada. A few additional studies on whitefish specifically focus on either a single parasite species (Ashcroft et al. 2006), or list the occurrence of parasitic organisms without providing details on the respective species or genus (Waite et al. 1990). Leong & Holmes (1981)
and Goater et al. (2005) found 12 and 10, respectively, helminth species in their samples. A closer look at their findings reveals that there appears to be a set of parasites (I. erraticus, Cyathocephalus truncatus, Cystidicola farionis) which are common in whitefish and may reach high prevalence and/or intensities in this host. Other species contribute to a varying degree to the whitefish parasite community which, in consequence, displays varying complexity and diversity. Depending on local conditions, pathological changes may occur with potential health effects on host individuals and populations, as was shown in lake whitefish from other localities (Orecka-Grabda 1991; Faisal et al. 2010). At a global scale, northern aquatic ecosystems currently face multiple threats, such as eutrophication, acidification, global warming, overexploitation, reservoir construction and introduction of non-native species, all of which may lead to changes in fish parasitism (Lafferty 1997; Lafferty & Kuris 1999; Marcogliese 2001; Morley 2007). With regard to

Figure 1 | Schematic of parasite transmission through a conceptual food web (above) based on life-cycles of common lake whitefish (Coregonus clupeaformis) parasites. Solid lines symbolize trophic transmission of parasites while dashed lines indicate pathways of free-living parasite stages. Each arrow potentially represents transmission of several parasite taxa. Further complexity through inclusion of paratenic hosts and post-cycle parasitism is possible. Below are the conceptual web and parasite transmission pathways based on present data on parasites of lake whitefish from Montreal (ML) and Reindeer (RL) lakes, Saskatchewan, Canada.
Montreal and Reindeer lakes, however, the current parasitological findings are consistent with results on parasites of lake whitefish across its whole geographical range. It therefore is suggested that, at present, there are no significant anthropogenic impacts on these two water bodies.

ACKNOWLEDGEMENTS

The authors would like to thank Tina Giroux from the Federation of Saskatchewan Indian Nations (FSIN) for her help in establishing the contacts to local Indigenous communities in northern Saskatchewan. Noland Henderson (Montreal Lake Cree Nation) and Tom Bird (Peter Ballantyne Cree Nation) deserve our most sincere gratitude for collecting the fish. Juliane Deubner (University of Saskatchewan) is greatly acknowledged for the fish drawings. We are thankful to Larisa Matwee (University of Saskatchewan) and Tonio Pieterek (Humboldt University Berlin, Germany) who helped in the lab. Valuable comments by Dr David Marcogliese and two anonymous reviewers are greatly appreciated. The project was financially supported by grants from the Indigenous Peoples’ Health Research Centre (IPHRC, grant number SCDP0919) and the Natural Sciences and Engineering Research Council of Canada (NSERC, grant number 371538-09) to M.P.

REFERENCES

Anonymous 2009 Fish Stock Assessment: Montreal Lake. Saskatchewan Ministry of Environment, Regina, SK.
Dean, E. L. 1975 Aquatic Ecology and Fisheries in Reindeer Lake. Saskatchewan Fisheries Laboratory, Department of Tourism and Renewable Resources, Regina, SK.
Droitsch, D. & Simieritsch, T. 2010 Canadian Aboriginal Concerns with Oil Sands. The Pembina Institute, Drayton Valley, AB.

Marcogliese, D. J. 2004 Parasites: small players with crucial roles in the ecological theater. *EcoHealth* 1, 151–164.


Northwatch and MiningWatch Canada 2008 *The Boreal Below: Mining Issues and Activities in Canada’s Boreal Forest*. MiningWatch Canada, Ottawa, ON.


Pietrock, M. 1998 Faunistic-ecological investigations on the endohelminth infection of blue bream (Abramis ballerus) and ruffe (Gymnocephalus cernuus) from the Lower Oder River. Wissenschaft und Technik Verlag, Berlin (in German).


Simon, J. 2007 Age, growth, and condition of European eel (Anguilla anguilla) from six lakes in the River Havel system (Germany). J. Mar. Sci. 64, 1414–1422.

Simon, T. P. 1999 Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities. CRC Press, Boca Raton, FL.


First received 16 January 2011; accepted in revised form 20 September 2011