Parasites are key components of Arctic ecosystems. The current rate of climate and landscape changes in the Arctic is expected to alter host-parasite interactions, creating a significant concern for the sustainability of Arctic vertebrates. In addition to direct effects on host populations, changes in parasite loads on wildlife can have significant impacts on the people who depend on these organisms for food. Parasites play important roles in maintaining ecosystem stability through the regulation of host populations, and can provide unique insights into the historical and current status of ecosystems. Parasites can, for example, provide information on the presence of direct or indirect interactions among species present in the ecosystem as well as information about the host habits (Hoberg 2010). Healthy ecosystems typically have a high diversity of parasites, reflecting the number of definitive (ultimate) and intermediate host species and vectors. As a result, the detection of a “normal” complement of parasites can be indicative of a healthy ecosystem. Conversely, the detection of “new” (invasive) parasites or very few parasite species can suggest otherwise (Hudson et al. 2006).

To use parasites as indicators of environmental health and to track or predict changes in parasitism and animal health, comprehensive data on parasite diversity, health, distributions, and life cycles are essential (Hoberg et al. 2003; Hoberg and Brooks 2008; Hoberg et al. 2008). Although considerable progress has been made in defining the diversity and ecology of parasites found in Arctic vertebrates (Rausch 1974; Hoberg et al. 2012a), there remain substantial knowledge gaps.

### Methodology

The present review considers all available literature on the parasites of country food of animal origin in the Canadian North, defined as the land- and ocean-based territory of Canada that lies north of the southern limit of discontinuous permafrost, from northern British Columbia in the west to northern Labrador in the east (IPY, 2007–2008). We consulted three academic databases, Web of Science, JSTOR, and Google Scholar.
with the search words parasite + arctic + Canada; further searches were conducted with the scientific and common names of the hosts + parasite. Studies out of the defined geographic range or without parasite identification to family or lower level were excluded. We also revised the cited literature of the publications found in the searches. For host species with high mobility, we included records from other regions, such as Alaska, Greenland, Iceland, Russia, and the Canadian Subarctic, when no parasitological studies have been conducted in the Canadian North. In addition, the databases of the Canadian Museum of Nature Parasite Collection and the United States Parasite Collection were searched for records of the host species in the Yukon, Northwest Territories, Nunavut, northern Quebec, and Newfoundland and Labrador; only records within the Canadian North were considered.

We considered vertebrate species regularly hunted for food in the Canadian North (Table 1). We also considered the wolf (Canis lupus) and wolverine (Gulo gulo), although rarely consumed, because they are reservoirs of parasites that transmit to humans and are frequently hunted for their fur. For parasite nomenclature, we followed the Encyclopaedia of Life (http://eol.org) and specialized literature for each taxon.

## Results

We found records for 248 species of macroparasites in vertebrate species of harvested wildlife in the Canadian North (Appendix 1, https://www.polardata.ca/pdcsearch/?doi_id=12962). Of these, 185 species were recorded within the Canadian North, and 63 were recorded outside this region; the 63 recorded outside this region were parasitizing species (mainly birds) that are also distributed in the Canadian North but have not been studied for parasites. The record includes flatworms (flats of the classes Monogenea, Digenea, and Cestoda); nematodes (roundworms); acanthocephalans (thorny-headed worms); acari (ticks); insects (lice, fleas, and flies); and pentastomids (tongue worms). The most diverse groups are roundworms and tapeworms (Cestoda), with 80 and 78 species respectively. Birds are the group of vertebrates with the largest number of recorded parasite species, with 115; although many of these taxa were extraterritorial, they are also likely to occur in the Canadian North because of the high mobility of their hosts. Mammal and fish parasite records comprise 88 and 59 species respectively. It is interesting that no parasites have been documented for the Arctic hare, Lepus arcticus (Table 1). Among the 248 species of parasites, only 133 are represented by voucher specimens in existing collections. Importantly, no vouchers are available for parasites of polar bears or walruses from the Canadian North. Conversely, there are numerous records in these collections for species that have not been reported in the literature (Appendix 2, https://www.polardata.ca/pdcsearch/?doi_id=12962). Of these, 185 species have not been reported in the literature (Appendix 2, https://www.polardata.ca/pdcsearch/?doi_id=12962). Of these, 185 species have not been reported in the literature (Appendix 2, https://www.polardata.ca/pdcsearch/?doi_id=12962).

## Table 1: Number of macroparasite species known from species of harvested wildlife in the Canadian North.

<table>
<thead>
<tr>
<th>Host species</th>
<th>P</th>
<th>N</th>
<th>A</th>
<th>C</th>
<th>Ac</th>
<th>I</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Salvelinus alpinus (Arctic char)</td>
<td>21</td>
<td>8</td>
<td>4</td>
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<td></td>
<td>35</td>
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<td>Salvelinus namaycush (Lake trout)</td>
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<td>Coregonus clupeaformis (Whitefish)</td>
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<td>2</td>
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<td></td>
<td>12</td>
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<tr>
<td>Boreogadus saida (Polar cod)</td>
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<td>4</td>
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<td></td>
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<tr>
<td>Arctogadus glacialis (Arctic cod)</td>
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<td></td>
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<tr>
<td>Birds</td>
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<td></td>
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<tr>
<td>Uria aalge (Common murre)</td>
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<td>6</td>
<td>2</td>
<td>4 (1)</td>
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<tr>
<td>Anasa acuta (Northern pintail)</td>
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<td></td>
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<tr>
<td>Anser alibrons (Greater white-fronted goose)</td>
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<td>2 (2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anser caerulescens (Snow goose)</td>
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<td>5</td>
<td></td>
<td>1</td>
<td>11 (1)</td>
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## Host species

**Host species**

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<thead>
<tr>
<th>Host species</th>
<th>P</th>
<th>N</th>
<th>A</th>
<th>C</th>
<th>Ac</th>
<th>I</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anser anser (Ross’s goose)</td>
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<td>Branta canadensis (Canada goose)</td>
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<td>5 (4)</td>
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<td>2</td>
<td>14 (10)</td>
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<td>Branta bernicla (Brant goose)</td>
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<tr>
<td>Clangula hyemalis (Long-tailed duck)</td>
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<td>Cygnus olor (Trumpeter swan)</td>
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<td></td>
<td></td>
<td>4 (2)</td>
<td>8 (6)</td>
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<td>Dendrocygna autumnalis (Barrow’s goldeneye)</td>
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<tr>
<td>Somateria spectabilis (King eider)</td>
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<td>1</td>
<td>9 (7)</td>
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<td>Gavia pacifica (Pacific loon)</td>
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<td>Gavia stellata (Red-throated loon)</td>
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<td></td>
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<tr>
<td>Gavia adamsi (Yellow-billed loon)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lagopus lagopus (Willow ptarmigan)</td>
<td>7 (6)</td>
<td>6 (5)</td>
<td>1 (1)</td>
<td>5 (5)</td>
<td>7 (5)</td>
<td>25 (21)</td>
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</tr>
<tr>
<td>Lagopus muta (Rock ptarmigan)</td>
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<td>3 (3)</td>
<td></td>
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## Mammals

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<th>C</th>
<th>Ac</th>
<th>I</th>
<th>TOTAL</th>
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<tr>
<td>Rangifer tarandus (Caribou)</td>
<td>7</td>
<td>15</td>
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<td>27</td>
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<td>Ovibos moschatus wardi (Muskox)</td>
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<td></td>
<td></td>
<td>17</td>
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<td>Vulpes lagopus (Arctic fox)</td>
<td>4</td>
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<td></td>
<td></td>
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<td>8</td>
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<tr>
<td>Canis lupus (Wolf)</td>
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<td>5</td>
<td></td>
<td></td>
<td></td>
<td>17</td>
<td></td>
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<tr>
<td>Gulo gulo (Wolverine)</td>
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<tr>
<td>Ursus arctos horribilis (Grizzly bear)</td>
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<td>5</td>
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<td></td>
<td></td>
<td>7</td>
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<tr>
<td>Ursus maritimus (Polar bear)</td>
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<td>3</td>
<td></td>
<td></td>
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<td>5</td>
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<tr>
<td>Cystophora cristata (Hooded seal)</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Erignathus barbatus (Bearded seal)</td>
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<td></td>
<td></td>
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<td>3</td>
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</tr>
<tr>
<td>Pagophilus groenlandicus (Harp seal)</td>
<td>1</td>
<td>7</td>
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<td></td>
<td></td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Phoca vitulina (Harbour seal)</td>
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<td>8 (2)</td>
<td>1 (1)</td>
<td>1 (1)</td>
<td>11 (5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pusa hispida (Ringed seal)</td>
<td>5</td>
<td>9</td>
<td>3</td>
<td></td>
<td>1</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Odobenus rosmarus (Walrus)</td>
<td>2</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Delphinapterus leucas (Beluga whale)</td>
<td>2</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Monodon monoceros (Narwhal)</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

## Fishes

The Arctic char (Salvelinus alpinus) is the fish species with the largest number (35) of known parasite species (Table 1). Reflecting its anadromous nature, these parasites include some species acquired in the marine environment and others in fresh water. However, its high diversity of parasites also reflects the fact that the Arctic char is, by far, the most intensively studied fish species in the Arctic. Other Arctic fish species are known to host from 5 to 18 parasite species.

Several of these species are of zoonotic importance. Larvae of roundworms in the genus Contracaecum and other related genera live in mesenteries and body cavity of fish. However, once a fish is dead, they rapidly migrate into the muscle, reducing the quality of the meat, and some species represent a potential source of infection for humans if they ingest raw, smoked, or undercooked fish (McCarty and Moore 2000). Although in most cases the infection is asymptomatic, patients may experience nausea, vomiting, diarrhea, abdominal pain, and hypersensitivity reactions (Jenkins et al. 2013). In the same way, larval tapeworms of the genus Diphyllobothrium live in the muscle or viscera of fish and are transmitted to their definitive host when ingested. In the wild, the definitive hosts are polar bears, marine mammals, and other carnivores, but humans can be infected by zoonotic diphyllobothriid tapeworms if they eat raw or undercooked fish (Desvives et al. 2013).
Diphyllobothriasis is rarely associated with clinical disease and is not considered a major public health problem in Canada (Jenkins et al. 2013). High infection levels with *Diphyllobothrium* species can also inhibit gonadal development in fish, reducing their reproductive potential (Gallagher et al. 2009). Monogenean and copepod parasites on fish gills can cause delays in growth and sexual maturation as well as hypoxia in heavy infections (Gallagher, et al. 2009; Winger et al. 2008). Although no epizootic events caused by *Tetraonchus* spp. or *Salmincola* spp. have been reported in the Canadian North, these species are present in this area, and it is important to be aware of their potential effects on fish populations.

### Birds

A total of 99 species have been documented in Arctic birds, although 55 of these records are extraterritorial (Appendix 1). The list is dominated by tapeworms and roundworms of the digestive tract, and no parasites of zoonotic importance have been reported. Mortality events in geese have been documented in other regions, in which heavy infections with roundworms of the upper digestive tract (*Echinuria uncinata*) in Poland (Cornwell 1963), heartworms (*Sarcocme eurycoe*) in the United States (Holden and Sladen 1968), or schistosomes (*Anserobilharzia brantae*) in the United States (Lynch et al. 1987) were reported, and might have contributed to mortality. A negative correlation between parasite and interfere with neurological or muscular function, increasing susceptibility to predation (Kutz et al. 2012).

Caribou and muskoxen are natural intermediate hosts for the tapeworms *Echinococcus canadensis*, *Taenia hydatigena*, and *T. krabbei*, which complete their life cycle in canids (dogs, foxes, and wolves) and release their eggs in the feces of the definitive host. *Taenia hydatigena* and *T. krabbei* are considered as a parasite of zoonoses [various diseases that can be transmitted from animals to humans]; in contrast, *Echinococcus canadensis* is the cause of a recurrent zoonosis in the Arctic. People, like caribou and muskoxen, get infected when eggs of this tapeworm are accidentally ingested (Jenkins et al. 2013).

### Mammals

The caribou, *Rangifer tarandus*, and muskoxen, *Ovibos moschatus*, both harbour diverse parasite assemblages, 27 and 17 species respectively. These parasites include various taxonomic groups, including digeneans, tapeworms, roundworms, flies, and mites, although the roundworms are most diverse. Nematodes of the subfamily *Trichostrongylinae* (*Ostertagia, Marshallagia, and Teladorsagia*) are common parasites of the abomasum (the fourth stomach compartment in ruminants), whereas they can cause serious effects on nutrition when present in high numbers. However, these two unguolate species are most seriously impacted by internal parasites, such as the lungworms (*Dictyocaulus, Varestrongylus, Protostrongylus, and Umingakstrongylus*) or the muscle-dwelling worms (*Parelaphostrongylus*). Infection with these parasites can affect respiratory function and interfere with neurological or muscular function, increasing susceptibility to predation (Kutz et al. 2012).

The consumption of raw or undercooked meat from an infected animal, producing trichinellosis, which causes edema, fever, rash, and myalgia. Outbreaks of human trichinellosis remain a public health concern in the Canadian North (Jenkins et al. 2013).

Few parasitological studies have been conducted with bears in the Canadian North, and some of the studies in polar bears are from captive specimens. Seven parasite species have been recorded from grizzly bears and five from polar bears (four of these from captive specimens). The tapeworm *Diphyllobothrium uris* completes its life cycle in the intestine of bears after they feed on fish, the intermediate host. Humans can accidentally be infected with this species by consuming raw or undercooked fish (Jenkins et al. 2013). *Trichinella* spp. roundworms (*T. nativa* and genotype T6) are common in both grizzly and polar bears in the Canadian North (Brown et al. 1949; Choquette et al. 1969; Gadahar and Forbes 2010; Jenkins et al. 2013; Larter et al. 2011; Rah et al. 2005; Smith 1978; Thorshaug and Rusted 1956), and at least one human outbreak has been linked to the consumption of grizzly bear (Houezé et al. 2009).

The ringed seal has considerably more species of parasites than the other seal species, which have from 3 to 11 species (Table 1). Among the parasite species are the heartworms (*Acanthocheilonema spirocauda*) and the lungworms (*Ostertagius circumcatus* and *Parafilaroides bipidus*), which can cause damage to the lungs in high numbers, especially to seal pups (Measures and Gosselin 1994; Ondreka 1989). Both tapeworms and roundworms occur in the intestinal tract as *Anisakis sp.*, *Contracaecum ocellatum* and *Pseudoterranova roundworms of the genus *Trichinella*. These roundworms possess a unique life history, as a single vertebrate species serves as both definitive and intermediate host. Alpslive in the intestine, where females produce larvae that migrate to the skeletal muscle. Transmission to other species, including humans, can occur when the original host is eaten. The genus *Trichinella* includes nine species and three genotypes (Krivokapich et al. 2012); only *T. nativa* (T2) and genotype T6 have been reported from northern Canada (Larter et al. 2013). These roundworms have been recorded from many vertebrate species in the Arctic, including carnivores (polar and grizzly bears, Arctic fox, wolf, and dog) and pinnipeds (walrus and ringed seal) (Appendix 1; https://www.polardata.ca/pdcssearch/?doi_id=12962). People get infected through the consumption of raw or undercooked meat from an infected animal, producing trichinellosis, which causes edema, fever, rash, and myalgia. Outbreaks of human trichinellosis remain a public health concern in the Canadian North (Jenkins et al. 2013).

The caribou, *Rangifer tarandus*, and muskoxen, *Ovibos moschatus*, both harbour diverse parasite assemblages, 27 and 17 species respectively. These parasites include various taxonomic groups, including digeneans, tapeworms, roundworms, flies, and mites, although the roundworms are most diverse. Nematodes of the subfamily *Trichostrongylinae* (*Ostertagia, Marshallagia, and Teladorsagia*) are common parasites of the abomasum (the fourth stomach compartment in ruminants), whereas they can cause serious effects on nutrition when present in high numbers. However, these two unguulate species are most seriously impacted by internal parasites, such as the lungworms (*Dictyocaulus, Varestrongylus, Protostrongylus, and Umingakstrongylus*) or the muscle-dwelling worms (*Parelaphostrongylus*). Infection with these parasites can affect respiratory function and interfere with neurological or muscular function, increasing susceptibility to predation (Kutz et al. 2012).
decipiens. Larvae of these ascarids are transmitted by fish, and humans can become infected by consuming raw or undercooked fish (Jenkins et al. 2013). Sucking lice (family Echinophthiridae) are mostly specialized on seals. Echinophthirius horridus, in particular, is found on many seal species in the Northern Hemisphere, including the ringed seal. It is most prevalent on young animals because of their higher body temperature and thinner skin. There is evidence that this ectoparasite is the intermediate host for the heartworm Acanthocheloneema spirocauda, which often has serious consequences for young seals (Geraci et al. 2018; Leidenberg et al. 2007).

At least 16 species of parasites (tapeworms, roundworms, and acanthocephalans) have been reported from walrus in the Bering Strait (Rausch et al. 2007). However, few studies have been completed in the Canadian North, where only two species of parasites have been recorded, an ascarid, Pseudoterranova decipiens, from the stomach and Trichinella sp. in muscle. This latter species has caused several outbreaks of trichinellosis in humans after eating walrus meat (Jenkins et al. 2013).

The beluga whale hosts at least seven species of parasites in the Canadian North, five roundworms and one ascarid, Contracaecum osculatum (Houde, et al. 2003). The ascarids recorded from beluga whale parasites in the Canadian North, five roundworms and one ascarid, Contracaecum osculatum (Houde, et al. 2003). The ascarids recorded from beluga whale parasites in the Canadian North, five roundworms and one ascarid, Contracaecum osculatum (Houde, et al. 2003). The ascarids recorded from beluga whale parasites in the Canadian North, five roundworms and one ascarid, Contracaecum osculatum (Houde, et al. 2003). The ascarids recorded from beluga whale parasites in the Canadian North, five roundworms and one ascarid, Contracaecum osculatum (Houde, et al. 2003). The ascarids recorded from beluga whale parasites in the Canadian North, five roundworms and one ascarid, Contracaecum osculatum (Houde, et al. 2003). The ascarids recorded from beluga whale parasites in the Canadian North, five roundworms and one ascarid, Contracaecum osculatum (Houde, et al. 2003). The ascarids recorded from beluga whale parasites in the Canadian North, five roundworms and one ascarid, Contracaecum osculatum (Houde, et al. 2003). The ascarids recorded from beluga whale parasites in the Canadian North, five roundworms and one ascarid, Contracaecum osculatum (Houde, et al. 2003). The ascarids recorded from beluga whale parasites in the Canadian North, five roundworms and one ascarid, Contracaecum osculatum (Houde, et al. 2003). The ascarids recorded from beluga whale parasites in the Canadian North, five roundworms and one ascarid, Contracaecum osculatum (Houde, et al. 2003). The ascarids recorded from beluga whale parasites in the Canadian North, five roundworms and one ascarid, Contracaecum osculatum (Houde, et al. 2003). The ascarids recorded from beluga whale parasites in the Canadian North, five roundworms and one ascarid, Contracaecum osculatum (Houde, et al. 2003). The ascarids recorded from beluga whale parasites in the Canadian North, five roundworms and one ascarid, Contracaecum osculatum (Houde, et al. 2003). The ascarids recorded from beluga whale parasites in the Canadian North, five roundworms and one ascarid, Contracaecum osculatum (Houde, et al. 2003). The ascarids recorded from beluga whale parasites in the Canadian North, five roundworms and one ascarid, Contracaecum osculatum (Houde, et al. 2003). The ascarids recorded from beluga whale parasites in the Canadian North, five roundworms and one ascarid, Contracaecum osculatum (Houde, et al. 2003). The ascarids recorded from beluga whale parasites in the Canadian North, five roundworms and one ascarid, Contracaecum osculatum (Houde, et al. 2003).


Suzanne E. Tank1 *, David Olefeldt2, William L. Quinton3, Christopher Spence4, Nicole Dion5, Caren Ackley5, Katherine Burd5, Ryan Hutchins1, and Samson Mengistu5

1 Department of Biological Sciences, University of Alberta, Edmonton, Alberta, Canada
2 Department of Renewable Resources, University of Alberta, Edmonton, Alberta, Canada
3 Centre for Cold Regions and Water Science, Wilfred Laurier University, Waterloo, Ontario, Canada
4 Environment and Climate Change Canada, Saskatoon, Saskatchewan, Canada
5 Water Resources Department, Government of Northwest Territories, Yellowknife, Northwest Territories, Canada
* suzanne.tank@ualberta.ca

Abstract

During the summer of 2014, the southern Northwest Territories (NWT) experienced an unprecedented wildfire season, with burned areas spread across two ecoregions (the Taiga Plains and Taiga Shield) and a landscape underlain by a mosaic of permafrost coverage, vegetation type, and previous fire history. Our study was conducted across the Dehcho, Tłı chǫ Wek’èezhii, and Akaítchò Regions of the NWT, which encompass the most significantly burned areas from the 2014 fire season. Within these regions, we worked in paired burned–unburned catchments on the Taiga Plains and Taiga Shield to examine responses to fire within ground and surface waters. We additionally examined water quality across a series of 50 catchments that were stratified across ecoregion and by fire history, and varied in within-catchment characteristics such as wetland extent. This sampling scheme — which covers as significant a range of landscape variability as possible — is allowing us to differentiate the effects of wildfire from other landscape variables that cumulatively impact aquatic ecosystem health. While wildfire had a clear effect on the chemical composition of pore waters, this effect was diminished at the stream outlet and at the landscape scale. Rather than having an overriding effect on water quality, wildfire appears to be one of many landscape variables that act in concert to determine water quality in the southern NWT.

Résumé


Suggested citation: