POTENTIAL DISPERSAL OF AQUATIC INVASIVE SPECIES INTO HUDSON BAY FROM BALLAST WATER FROM SHIPS TRAVELLING FROM PORTS IN EUROPE AND NORTH AMERICA

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EXECUTIVE SUMMARY

Widespread and numerous invasions of exotic or nonindigenous species have occurred worldwide, facilitated by human activities such as recreation, agriculture, commerce, and habitat disturbance and alteration. Aquatic habitats appear particularly vulnerable to species invasions with hundreds occurring in North America during the past century and increasing invasion rates during recent decades mainly as a consequence of expanding global trade and ship ballast water transport of organisms. The aquarium industry has also resulted in the introduction of hundreds of foreign species into North America. There are multiple potential impacts from invasions, some of which can have detrimental effects on the native flora and fauna. Impacts include, but are not limited to, introductions of new parasites/diseases, alteration of physical and/or chemical abiotic conditions, displacement or extirpation of native species through competition, predation, or genetic alterations, or effects at multiple levels of ecological organization. In many cases it is difficult to identify direct impacts from successful invasions. The direct and indirect economic costs associated with introductions can also be significant (e.g., an estimated $137 billion annual costs associated with invaders in the U.S.). Though inherently difficult, attempting to predict successful potential invasions can assist in developing prevention and mitigation techniques to minimize invasive risks. The specific objectives of this project were to: 1) assess the risk of aquatic invasive species dispersing into Hudson Bay; and 2) compile baseline information on the distribution of indigenous fish, invertebrates, and other aquatic flora and fauna in the Churchill River estuary and Hudson Bay proper that may be at risk should invasive species become established. In addition, the potential effects of climate change on the invasion of exotic species into Hudson Bay will be examined.

Species at risk of invading Hudson Bay were identified from potential sources of dispersal (particularly those with similar climatic regimes to the Churchill region), biological characteristics that facilitate invasiveness (multiple modes of reproduction, tolerant of wide ranges in temperature, salinity, etc.), invasion history (those with an extensive history of invasions are more likely to continue invading new regions), and strong associations with human-facilitated modes of dispersal (e.g., shipping traffic). Potential invaders were classified as low, medium, or high risk. Exotic species that were assessed as having no risk of invasion were not included in further analyses. The classification of high risk was assigned to those species that were predicted, on the basis of existing information, the use of established prediction methods, and professional judgement, of having a high probability of being introduced into the Churchill River estuary and/or Hudson Bay and become successfully established. Those designated as medium risk typically have at least one barrier (e.g., climate, dispersal methods, etc.) preventing

invasion while those designated as low risk typically have multiple barriers preventing invasion. A total of 24 species were predicted as high-risk invaders.

The main limiting factor preventing widespread invasions into Hudson Bay is the present climate of the region, particularly the relatively low maximum and the small range in water temperatures compared to most, if not all, potential source regions. Climate change could therefore have a significant impact on the ecosystem of the region. Even modest estimates from multiple climate change models predict an increase in mean annual air temperature of 2-5°C (with higher latitudes potentially incurring increases as high as 8°C). The resulting increases in water temperatures by only a few degrees could be sufficient to remove the barrier preventing potential invasion of many exotic species and would facilitate northward range expansion of several native North American species that may impact on the existing aquatic ecosystem. Several of the species currently identified as medium risk of invasion into Hudson Bay could likely be upgraded to high risk with increasing local temperatures while there are likely no species that would decrease in risk status. Climate change must therefore be factored in invasive species risk assessment.

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1.0 INTRODUCTION

Contract background

Fisheries and Oceans Canada, Environmental Sciences Division – Central and Arctic Region (DFO) contracted North/South Consultants Inc. to compile a list of aquatic invasive species (AIS) and assess the vectors and risk of their potential dispersal into Hudson Bay from the ballast water of ships travelling from ports in Europe and North America to Hudson Bay, specifically to the Port of Churchill. The specific objectives of the project are to: 1) assess the risk of aquatic invasive species dispersing into Hudson Bay; and 2) compile baseline information on the distribution of indigenous fish, invertebrates, and other aquatic fauna in the Churchill estuary and Hudson Bay proper that may be at risk should invasive species become established.

Exotic species

Worldwide, the establishment of nonindigenous species (NIS, see Colautti & MacIsaac 2004 for terminology) across regions and continents is facilitated by human activities, such as recreation (e.g., tourism, boating, fishing,), agriculture and commerce (e.g., pest control, pet trade, transport of goods), and those that lead to habitat disturbance and alteration (e.g., reservoir construction, forest clear cutting). Anywhere from 100-10,000 NIS have been documented for most countries and their numbers are still increasing (Lodge 1993). Aquatic habitats are particularly vulnerable to species invasions (Mills et al. 1993a) and hundreds of aquatic invasive species (AIS) have become established in North America during the past century (Mills et al. 1993a, 1996a; Cohen & Carlton 1998). Expanding global trade and ship ballast water in particular (Holeck et al. 2004), continues to increase the volume of flora and fauna transported between geographical regions (Carlton & Geller 1993). The aquarium industry alone has resulted in the introduction of thousands of foreign species into North America (Welcomme 1984) and continues to be a source for future invaders (Rixon et al. 2005). These introductions are a serious threat to native aquatic ecosystems and may include unexpected disease transmission (e.g., Gozlan et al. 2005), changes in the genetic structure of native populations (e.g., Ferguson 1990; Berg et al. 2002), alterations of the physical/chemical habitat (e.g., Olenin & Leppäkoski 1999; Simberloff & Von Holle 1999; Ojaveer et al. 2002), changes in species diversity, reduced abundance or extinction of native species (e.g., Haag et al. 1993; Ketelaars & van Breemen 1993; Leppäkoski & Olenin 2000; Bernauer & Jansen, in press), or effects at multiple levels of ecological organization (e.g., Simon & Townsend 2003). However, in most cases the ecological consequences of AIS on the native biota and habitat are unknown.

Despite this general lack of information and the fact that typically only a small proportion of NIS (<10%) cause significant impacts (Williamson & Fitter 1996), the direct and indirect economic costs associated with NIS can be very large. Environmental damages and losses caused by NIS in the U.S. have been estimated at $137 billion (U.S. dollars) annually (Pimentel et al. 2000). Colautti et al. (2006) have calculated the direct costs incurred by 10 NIS in Canadian fisheries, agriculture, and forestry industries at $187 million Can per year, and estimated the indirect impacts on natural resources (e.g. reduced yield) of 16 NIS to be between $13.3-34.5 billion Can per year. Given these financial consequences, NIS have increasingly become the subject of high profile court cases. The Norwegian Supreme Court, for example, fined the Norwegian Ministry of the Environment US $640,000 payable to the owner of the water rights of several lakes into which *Mysis relicta* had been introduced (Josefsson & Andersson 2001).

Yet despite obvious ecological and economic damage caused by invasive species, there have been few formal attempts to identify methods for predicting success rates of potential invaders into North America (Ricciardi & Rasmussen 1998). This is likely a result of the perceived impracticality or difficulty of predicting which species can become established in new geographical regions and the effects these invasions may have on the existing environment (Rejmanek 1996). Advance information could be used to develop means of preventing introductions and to develop management plans for the control of AIS (Bailey et al. in press a). The identification of potential invasions should be a priority among the scientific community and policy makers (Ricciardi & Rasmussen 1998).

The objective of this report is to identify AIS that may be transported to Hudson Bay and the Churchill River estuary in ballast water of ships entering the port of Churchill and to assess the risk of their establishment in Hudson Bay and its tributary rivers.

2.0 APPROACH

Data were compiled by reviewing relevant literature and datasets and through key person interviews (see Section 4.1) with biologists who have collected organisms in the marine and estuarine environments of the region or who have done extensive research in the area of AIS. Literature was obtained from these biologists, from DFO and university libraries, the Internet (see Section 4.2 for key websites), and the personal collections of study team members. In a first approach, species lists were compiled from potential source regions of AIS that were based on an analysis of the ship traffic into Churchill harbour from 1999-2003. There are hundreds of aquatic species that could potentially be introduced into the region with the ships that enter Churchill Port. It was impractical to create a comprehensive species list from all geographical areas and to describe the biology of each potential invader. Instead we followed the approach of Ricciardi & Rasmussen (1998) who developed a more effective method for the risk assessment of AIS and which has likely stimulated many recent studies that attempt to model or otherwise address the ecological (Ricciardi 2003; Wonham et al. 2005; Stepien et al. 2005) and economical (Leung et al. 2002) risks associated with AIS. Potential invaders were then classified as low, medium, or high risk. Exotic species that were assessed as having no risk of invasion were not included in further analyses. The classification of high risk was assigned to those species that were predicted on the basis of the approach of Ricciardi & Rasmussen (1998) and professional judgement of having a high probability of being introduced into the Churchill River estuary and/or Hudson Bay and become successfully established. Those species designated as medium or low risk typically have one or more barriers (e.g., climate, dispersal methods, distribution, etc.) preventing invasion. This approach is described in the following paragraphs.

2.1 IDENTIFICATION OF POTENTIAL SOURCES OF DISPERSAL

Since the most likely source of AIS in the Churchill River estuary and Hudson Bay is ship ballast water and sediment, we focused on source regions represented in the shipping record that are known to contribute a disproportionate amount of invasive fauna and flora to regions currently significantly impacted by AIS: a) the Laurentian Great Lakes, b) the North and Baltic Seas, including some connected inland waters, and c) the Atlantic coasts of Europe and North America. There were some difficulties associated with analyzing the shipping traffic at Churchill, because the records did not provide the locations of the ports of call prior to the last port visited before reaching Churchill (i.e., the port of origin in the records). However, many transoceanic vessels operate globally and load ballast water from diverse regions (see Holeck et al. 2004 for an example).

When determining potential donor regions and their importance it was assumed that, for example, ships flying flags from some European countries (e.g., Poland, Russia; see Section 3.1) had visited North Sea and/or Baltic Sea ports within a reasonable amount of time before their arrival in Churchill and represented potential sources of the respective AIS. Although few ships arrived at Churchill directly from a Great Lakes port (see Section 3.1), many more ships may have visited Great Lakes ports before arriving in Churchill from other ports of origin. Therefore, aquatic organisms from the Great Lakes area were included as potential AIS, particularly those species that are widely distributed and show a wide range of environmental tolerances.

Donor regions with climate similar to that of Hudson Bay were not well represented among the harbours of origin. Although predictions of invasive potential based solely on climatic criteria have produced mixed results (Mack 1996), climate would be a limiting factor when identifying certain donor regions (e.g., tropical and subtropical regions). Europe and Asia have been key donor regions for many AIS. For example, high volume shipping between Europe and the Great Lakes region since construction of the St. Lawrence Seaway has resulted in the introduction of more than 30% of the region's AIS (Mills et al. 1993a). In addition, increasing trade with east Asia in the last decade has coincided with the introduction of several Asian invertebrates to estuarine environments on the Pacific coast of North America (Cordell et al. 1992; Cohen & Carlton 1998). Known invaders from other regions were also considered since those species have already demonstrated an ability to become successfully established in new environments.

In addition to the number and location of ports that are visited by ships, ballast exchange practices at each are another important consideration when determining the risk of invasion/establishment of AIS. Although recent shipping regulations in North America requiring oceanic exchange of ballast water should theoretically reduce the number of potentially successful invasions, these regulations are not foolproof. Not all ships necessarily comply with the regulations since Canadian guidelines for ballast exchange are voluntary (Kerr et al. 2005), incomplete ballast water exchanges are common, and ships declaring no ballast on board (NOBOB) can still have residual ballast water and sediments (Locke et al. 1993; Bailey et al. 2003; Bailey et al., in press b). Organisms with saline-tolerant life cycle stages, such as those that frequent estuarine habitat, or those with dormant resting stages, can survive these incomplete exchanges (Locke et al. 1993; MacIsaac et al. 2002; Colautti et al. 2003; Bailey et al. 2003; Bailey et al. 2004; Bailey et al. 2005 a, b; Bailey et al. in press b). It is therefore likely that AIS will continue to become established in North America via ship ballast water.

2.2 IDENTIFICATION OF THE BIOLOGY OF THE INVADERS

Once potential donor regions were identified, species lists of potential AIS were compiled. These lists were compared to the list of organisms (mainly zooplankton, macroinvertebrates, and fish) known to occur in Hudson Bay and two of its major tributaries. Species identified as non-indigenous to the Hudson Bay region were ranked according to potential risk of invasion as determined through compilation of data on distribution, environmental tolerances/requirements, and dispersal abilities. Rankings were established from literature reviews of ecological requirements of AIS compared with present and predicted climate in the regions of potential invasion and recent trends in the spread of these AIS to other regions.

Ricciardi & Rasmussen (1998) described some general characteristics that could facilitate invasion of a species (Table 1). Though few of these characteristics have been thoroughly tested, they are applicable to a wide variety of potential invaders and were thus used for our predictions. Zebra mussel (*Dreissena polymorpha*), for example, has high genetic variability, wide physiological tolerance limits, and possesses natural mechanisms for rapid dispersal (Garton & Haag 1991). As a result it has already colonized a large geographic range and is likely to continue expanding that range (Groves & Burdon 1986). We also considered species with large natural ranges, which are often good predictors of invasive skills (Roy et al. 1991, Rejmanek 1996). For example, several invasive species with large natural ranges have already become established in North America (e.g., brown trout, *Salmo trutta*, the cladoceran *Daphnia lumholtzi*, and the snail *Potamopyrgus antipodarum*).

The most consistent characteristic of invaders and the one factored most strongly into our assessment of invasion/establishment potential was commensalism with humans, since most AIS appear to use some human-driven dispersal mechanism (Groves & Burdon 1986; Morton 1979, 1997; Bailey et al., in press b). Though a wide variety of AIS can and have been transported in ship ballast (Duggan et al. 2005; Bailey et al. 2005 b), we placed emphasis on those species that can remain dormant in ballast sediment or are otherwise tolerant to saltwater flushing (Bailey et al. 2004, 2005 a, in press b). Additional emphasis was placed on organisms that can, during at least part of their life cycle, parasitize hosts that have biological characteristics suitable for dispersal and where potential new hosts (taxonomically or biologically similar) currently exist.

Table 1. Some hypothesized general characteristics of AIS (modified from Ricciardi & Rasmussen 1998).

1.	Abundant and widely distributed in native range
2.	Broad environmental tolerances
3.	High genetic variability
4.	Short life cycle
5.	High growth rates
6.	Sexual maturity early in life
7.	High reproductive capacity
8.	Generalized, opportunistic diet
9.	Living in dense aggregations
10.	Natural, rapid dispersal mechanisms
11.	Show human commensalism (e.g., use ship ballast water for transport)

2.3 HISTORY OF INVASION

The invasion history of species in our assessment was also considered. It has been shown that many successful AIS that have invaded one geographic area will continue to invade other areas as opportunities present themselves (Ricciardi & Rasmussen 1998). When combined with the first two steps (identification of likely source regions of invasion and invader characteristics such as human commensalism), predictions of invasion potential should become more accurate. We further tried to enhance predictive power by examining dispersal patterns of recent invaders into areas that are similar to Hudson Bay and the Churchill River estuary, and for which further dispersal into our target region is more likely (Ricciardi & Rasmussen 1998). In particular, the northern Baltic Sea was seen as a potentially key donor region. This source region is relatively isolated, has a short development period, low salinity, and experiences large fluctuations in temperature (Kotta et al. 2003). A large number of successful invasions into the Baltic Sea have occurred within the last few decades and this area could act as a source for other northern habitats (Kotta et al. 2003). However, since there were few other such examples of colder potential donor regions (e.g., Lake Superior [Grigorovich et al. 2003a]), habitat similarities were not a limiting factor. Lists of current invasive species in two potentially key donor regions (the

North and Baltic seas and the Great Lakes) used for our assessments are presented in Appendix 1.

Using a similar approach as later formalized in Ricciardi & Rasmussen (1998), Mills et al. (1993b) were able to predict the invasion of *P. antipodarum* into the Great Lakes (since reported in Lake Ontario [Zaranko et al. 1997]). Ricciardi (1998) similarly predicted that *Limnoperna fortunei*, an Asian freshwater mussel that is currently expanding its range in the western Pacific and South America, would soon invade North America if it hasn't already. Furthermore, the majority of invasions of species into the Great Lakes from the Ponto-Caspian region (Black, Caspian, and Azov seas), such as the zebra mussel, could likely have been predicted if this approach had been applied. Ricciardi & Rasmussen (1998) predicted that an additional 17 species of invertebrates and fish from the Ponto-Caspian region could become established in the Great Lakes.

2.4 IMPACT ASSESSMENT

Following the identification and relative potential of likely AIS into the Hudson Bay region, we attempted to predict the potential ecological impact of these species. Again, species that have had significant ecological impacts during earlier invasions into other regions were emphasized, assuming that AIS that have caused significant impacts in other areas will do the same in any new area they invade. According to Ricciardi & Rasmussen (1998) there probably will be some degree of uncertainty associated with such predictions, particularly given the differences in climate between Hudson Bay and most source regions. However, the same authors also argued that this approach could have predicted the large-scale impacts to the Great Lakes ecosystem resulting from introductions of Eurasian species such as the zebra mussel, ruffe (*Gymnocephalus cernuus*), and the cladoceran *Bythotrephes* sp. prior to their arrival in North America. In addition, based on impact history, Ricciardi & Rasmussen (1998) identified two species of amphipods, five species of mysids, and one fish species that could potentially have significant impacts if they were to invade the Great Lakes. The above approach was applied to predict potential impacts from AIS in the Hudson Bay region while factoring in climatic differences.

3.0 RESULTS AND DISCUSSION

3.1 SHIP TRAFFIC INTO CHURCHILL

A total of 194 ships from 11 distinct geographical regions were recorded entering Churchill harbour from 1999-2003 (Table 2). Of these vessels, 107 were identified as having ballast or cargo while the remainder were other vessel types. With 18 ships, the Atlantic coast of Europe and northern Africa was the source region of most of the ballasted ships, followed by the North Sea, the United Kingdom and Ireland, and the Northwest Territories and Nunavut which each contributed 15-16 ships (Table 2). Seven ships entered Churchill from ports in the Great Lakes Area and five ships came from the Baltic Sea.

Table 2. Number of ships entering Churchill harbour in 1999-2003 according to port of origin. Cargo ships (bulk carrier, dry cargo barge, general cargo) have been separated into those carrying ballast and those carrying cargo.

Source Region	**Ballast**	**Cargo**	**Other**
Atlantic Coast, Europe/Northern Africa	18	0	0
Atlantic Coast, North America	8	0	6
Baltic Sea	5	0	0
Great Lakes / St. Lawrence River	7	0	0
Greenland/Iceland	5	0	2
Gulf of Mexico	1	0	1
Mediterranean	10	0	0
North Sea	16	0	0
Northwest Territories/Nunavut	15	5	78
South America	1	0	0
United Kingdom and Ireland	15	1	0
Total	**101**	**6**	**87**

Ballast or Cargo = bulk carrier, other bulk carrier, dry cargo barge, general cargo
Other = cruise, passengers, crude/products tanker, oil tankers, chemical tanker, tugs

Of all 194 ships, 19 ballasted ships and nine other ships were identified as entering Churchill from a port of origin or country (often in Canada or Greenland) other than its registered country and for which the country of registration is located in a known AIS source region (Table 3). Although some of these countries offer a flag state of convenience and the respective ships rarely or never make port in one of the countries' harbours, the possibility exists that some ships sailing under the flags listed in Table 3 have made port in known AIS source regions before entering Churchill via a port in a country that would not be considered an AIS source region. Thus the risk of AIS transfer into Churchill harbour may be somewhat higher than indicated by the number of ships listed in Table 1. Specific ports of origin identified for each geographical region are presented in Table 4.

Table 3. Vessel flag of ships that entered Churchill harbour from a port of origin in a country/region other than in its registered country. Only countries from potential AIS source regions are included.

Vessel Flag	Ballast	Cargo	Other
United Kingdom	1	0	5
France	0	0	2
Norway	0	0	1
Estonia	1	0	0
Russia	3	0	0
Poland	1	0	0
Turkey	1	0	1
Greece	5	0	0
Malta (including Gozo)	7	0	0
Sum	**19**	**0**	**9**

Table 4. List of ports of origin for the geographical regions identified in Table 2. Geographical regions other than port cities are listed in brackets.

NWT/Nunavut	Gr Lakes/ StLR	Greenland and Iceland	Atlantic Coast, North America	Gulf of Mexico	UK and Ireland	Atlantic Coast, Europe/North Africa	North Sea	Baltic Sea	Mediterranean	South America
Akpatuk island	Alexandria Bay	(Greenland)	Argentia	Freeport	Aughinish	Brest	Amsterdam	Brevik	Algeciras	Maracaibo
Arviat	Baie- Comeau	(Iceland)	Halifax	Houston	Avonmouth	Dunkirk	Antwerp	Copenhagen	Barcelona	
Baker Lake	Hamilton	Nuuk	Rigolet		Belfast	Lisbon	Flushing	(Denmark)	Gibraltar	
Chesterfield inlet	Montreal		St. John's		(Ireland)	Bilbao	Fredrikstad	Klaipeda	Savona	
Coral harbour			St. Pierre Miquelon		Falmouth	Gijon	Gothenburg		Trieste	
Erik's Cove			Cementon		Glasgow	Huelva	(Norway)			
Hall Beach			Georgetown		Hull	Gijon	Rotterdam			
Lake Harbour/Kimmirut			New York		Immingham	Rouen	Terneuzen			
Marble Island			Norfolk		Ireland	Annaba	Uddevalla			
Northwest Territories			Wilmington		Liverpool	Casablanca				
Rankin Inlet					London	Morocco				
Repulse Bay					Londonderry	Dakar				
Sanikiluaq					Southampton					
Whale Cove										

NWT= Northwest Territories, Gr Lakes= Great Lakes, UK= United Kingdom, StLR= St. Lawrence River

3.2 SPECIES NATIVE TO HUDSON BAY AND SOME TRIBUTARY STREAMS

Appendix 1 lists aquatic species native to or already present in the furthest downstream reaches of the Churchill (~15 km reach) and Nelson (~100 km reach below the Limestone Generating Station) rivers, the downstream portions of their major tributaries, their associated estuarine environments, and in nearby marine habitat in western Hudson Bay (figures 1 and 2). More than 115 species of crustacean zooplankton, macroinvertebrates, fish, phytoplankton, algae, and macrophytes have been documented from freshwater habitat in the Churchill and Nelson rivers immediately upstream of the zone of salt-water influence (Appendix 1). More than 300 species of crustacean zooplankton, macroinvertebrates, fish, phytoplankton, algae, and macrophytes have been documented from brackish water habitats of the Churchill and Nelson River estuaries, Hudson Bay and Hudson Strait (Appendix 1).

3.3 INVASIVE SPECIES POTENTIAL IN THE HUDSON BAY REGION

In a literature review to evaluate the dependence of plant and animal invasion on disturbance, Lozon & MacIsaac (1997) concluded that most animal introductions are into aquatic habitats near urbanized areas and are often facilitated by ballast water discharge. Dormant resting stages (diapausing eggs, dormant buds, quiescent juveniles, and anhydrobiotic adults) are produced by many different aquatic organisms, particularly those in freshwater (Cáceres 1997). Ballast sediments can therefore be a potentially important source of NIS. Transfer of resting stages in sediment relocations has often been implicated in zooplankter introductions (Schrimpf & Steinberg 1982; Koste & Shiel 1989; Hairston et al. 1999). Bailey et al. (2005b) measured the density and viability of resting stages of 21 AIS (all rotifers and cladocerans) from residual ballast sediment samples in ships claiming “no ballast on board” (NOBOB). Viable resting stages were found in about one third of examined ships at a mean density of 300,000/ship. The salinity of residual ballast and the ship’s port of origin were useful predictors for identifying potential invasions from NOBOB vessels. One of the most important aspects of an invasion event and the one that often determines its success seems to be the introduction effort or, as identified by Colautti & MacIssac (2004), the propagule pressure. In the Great Lakes, for example, NOBOB ships are exempt from ballast water exchange legislation (Bailey et al. 2005b). However, NOBOB ships still carry an average of 60 t of residual water and sediment that can harbour dormant resting stages of many invertebrates (Bailey et al. 2003). In fact, these ships may even carry more live freshwater organisms and participate in a greater number of inoculation events than ballasted (BOB; with sea water) ships (MacIsaac et al. 2002; Colautti et

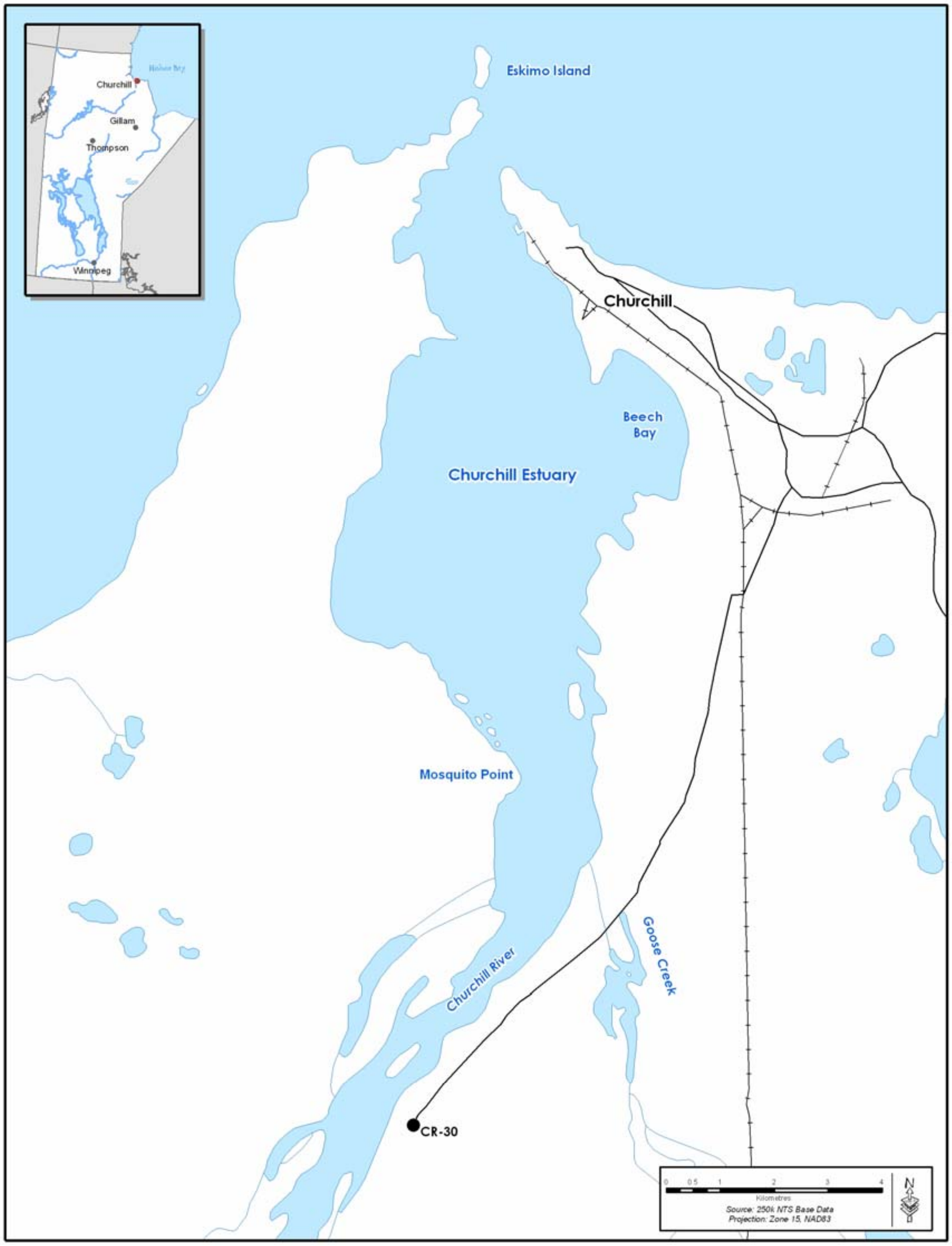

Figure 1. Map of the lower reaches of the Churchill River and nearby estuarine and marine habitat.

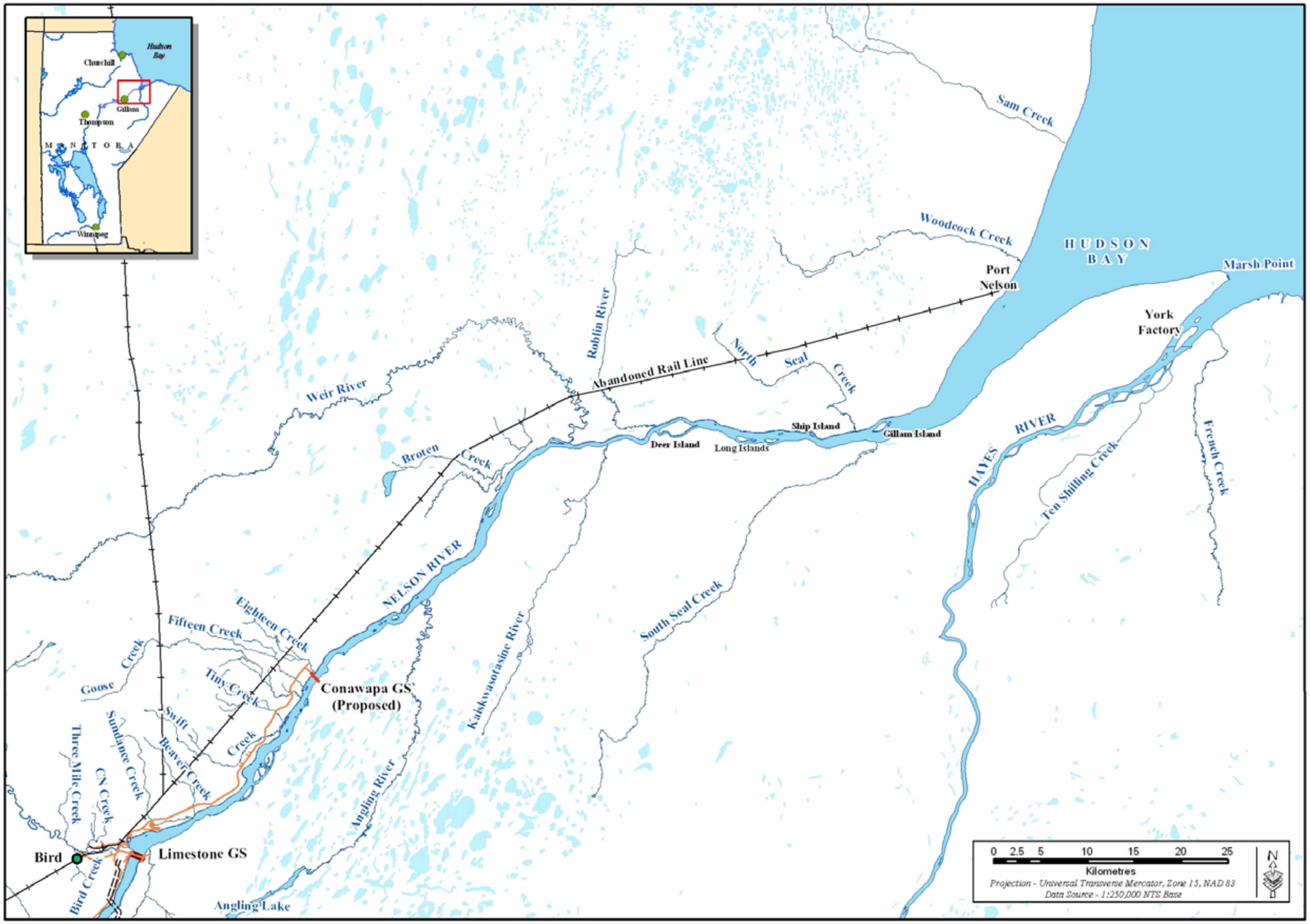

Figure 2. Map of the lower reaches of the Nelson River and nearby estuarine and marine habitat.

al. 2003). It can be assumed that NOBOB ships arriving in Churchill will have similar proportions of residual ballast water and sediment with similar densities of invertebrate resting stages to those documented from the Great Lakes. However, since most ships arrive BOB in Churchill (Table 2), there is an additional risk of invasion by species that don't necessarily have dormant resting stages (e.g., fish) or that require adults of another species as a transportation vector (e.g., some parasites using invertebrate intermediate hosts). Therefore, ballasted ships entering the Port of Churchill still pose a large threat for inoculations with AIS.

3.4 SPECIES MOST LIKELY TO INVADE HUDSON BAY

By selecting species from our pool of potential invaders (Table 5) that are widely distributed, have broad environmental tolerances that would include adaptive potential to the Hudson Bay region, have a history of successful invasions, and generally rely on humans as invasion vectors, we identified 24 species that were considered at highest risk of invasion. Species identified as having moderate or low risk of invasion are limited by one or more of the factors we identified as necessary for invasion. However, the potential for invasion of the two lower risk groups cannot be completely ruled out, particularly should (climatic) conditions change. Species with no risk of invasion were excluded from the table. Current temperature and salinity regimes recorded from the Hudson Bay region are presented in tables 6 and 7.

Table 5. List of non-indigenous aquatic species with potential for invasion and establishment in the Hudson Bay area. Species considered at high risk are highlighted in red.

Taxon/Species	**Common Name**	**Risk of Invasion**[1]	**Factors limiting potential invasion into Hudson Bay**[2]
		ZOOPLANKTON	
ARTHROPODA			
Cladocera			
Bythotrephes longimanus	**Spiny water flea**	**High**	
Cercopagis pengoi	**Fishhook water flea**	**High**	
Cornigerius maeoticus maeoticus	-	Medium	Poor invasion history - This species only recently (2003) invaded the Baltic from the Ponto-Caspian region with no other recorded invasions, but cannot be ruled out for Hudson Bay since environmental conditions are acceptable
Daphnia lumholtzi	-	Low	Climate - warm temperate to tropical species
Eubosmina coregoni	-	Medium	Habitat and salinity - This species is not adapted for estuarine conditions and is actually more likely to invade the Nelson and Churchill river systems from Lake Winnipeg where it's recently (1994) been discovered
Eubosmina maritima	**-**	**High**	
Evadne anonyx	-	Medium	Climate - even this might not be a sufficient barrier for this species
Copepoda			
Acartia tonsa	**-**	**High**	
Ameira divagans	-	Low	Climate
Cyclops strenuus	-	Medium	Invasion history - climate is likely suitable (it's in Lake Superior) but this species has not been an aggressive invader in general
Heteropsyllus cf. *nunni*	-	Medium	Distribution - Relatively small distribution compared with most invasive species

Table 5. Continued.

Taxon/Species	**Common Name**	**Risk of Invasion**[1]	**Factors limiting potential invasion into Hudson Bay**[2]
Megacyclops viridis	-	Low	Climate and habitat - Not adapted for colder estuarine habitat
Nitokra hibernica	-	Medium	Climate
Nitokra incerta	-	Medium	Climate
Onychocamptus mohammed	-	Medium	Invasion history - climate is likely suitable but despite a large native range, this species does not appear to readily invade new regions (Great Lakes only, so far)
Schizopera borutzkyi	-	Low	Climate and habitat - Not adapted for colder estuarine habitat
Skistodiaptomus pallidus	-	Low	Climate and habitat - Not adapted for colder estuarine habitat
	MACROINVERTEBRATES		
PORIFERA			
Demospongiae			
Eunapius carteri	-	Low	Primarily climate
ECTOPROCTA (bryozoans)			
Lophopodella carteri	-	Low	Primarily method of dispersal (on imported aquatic plants) but also climate
Victorella pavida	-	Low	Climate and dispersal mechanisms
CNIDARIA			
Anthozoa			
Diadumene cincta	Orange anemone	Low	Primarily climate
Hydrozoa			
Cordylophora caspia	**Freshwater hydroid**	**High**	
Craspedacusta sowerbyi	Freshwater jellyfish	Medium	Climate only, despite worldwide invasion success, it has not yet established in more northern habitats
Nemopsis bachei	-	Medium	Primarily climate

Table 5. Continued.

Taxon/Species	Common Name	Risk of Invasion[1]	Factors limiting potential invasion into Hudson Bay[2]
PLATYHELMINTHES			
Turbellaria			
Dugesia polychroa	-	Medium	Primarily climate, invasion could be facilitated should *D. polymorpha* (a commensal relationship) ever invade
ANNELIDA			
Oligochaeta			
Branchiura sowerbyi	-	Low	Climate and dispersal mechanisms
Gianius aquaedulcis	-	Medium	Climate
Ripistes parasita	-	Medium	Climate
Polychaeta			
Ficopomatus enigmaticus	-	Medium	Climate, this species is thought to be close to its temperature minimum for reproduction and survival in southern Britain
Hypania invalida	-	Medium	Climate
Marenzelleria* cf. *viridis	**-**	**High**	
Marenzelleria* cf. *wireni	**-**	**High**	
ARTHROPODA			
Insecta			
Acentropus niveus	Aquatic moth	Medium	Likely to invade only if *Myriophyllum spicatum* facilitate invasion
Tanysphyrus lemnae	Duckweed weevil	Low	Likely to invade only if *Lemna* spp. invade and even then climate may limit invasiveness
Amphipoda			
Caprella mutica	**Skeleton shrimp**	**High**	
Chelicorophium curvispinum	**-**	**High**	
Chelicorophium robustum	-	Medium	Climate
Chelicorophium sextonae	-	Low	Climate - even warmer water than other *Chelicorophium* spp.

Table 5. Continued.

Taxon/Species	Common Name	Risk of Invasion[1]	Factors limiting potential invasion into Hudson Bay[2]
Dikerogammarus haemobaphes	-	Medium	Climate - slightly warmer water temperatures near Churchill would facilitate invasion
Dikerogammarus villosus	**Killer shrimp**	**High**	
Echinogammarus berilloni	-	Medium	Climate
Echinogammarus ischnus	-	Medium	Climate - though highly invasive in Europe and the Great Lakes from ballast water transfer, its distribution does appear limited in Lake Superior only to the warmest areas (Grigorovich et al. 2003). Invasion would be facilitated by *D. polymorpha* (Ricciardi 2001)
Echinogammarus trichiatus	-	Medium	Climate
Echinogammarus warpachowskyi	-	Medium	Climate and to a lesser extent, lack of widespread invasion success
Gammarus fasciatus	-	Medium	Climate - Should *Dreissena* spp. invade with increased temperatures, invasion of this species could be facilitated
Gammarus tigrinus	-	Medium	Climate
Gmelinoides fasciatus	**-**	**High**	
Obesogammarus crassus	-	Medium	
Obesogammarus obesus	-	Medium	Climate
Pontogammarus robustoides	**-**	**High**	
Cumacea			
Stenocuma graciloides	-	Medium	Though tolerant of a wide range of temperatures and salinities, this species has only recently invaded the Gulf of Finland but has not yet become established suggesting it's not a particularly potent invader
Decapoda			
Astacus leptodactylus	Galician crayfish	Low	Climate and dispersal mechanisms (primarily aquaculture and live food)

Table 5. Continued.

Taxon/Species	**Common Name**	**Risk of Invasion**[1]	**Factors limiting potential invasion into Hudson Bay**[2]
Atyaephyra desmaresti	-	Low	Climate and dispersal mechanisms (primarily aquaculture and live food)
Eriocheir sinensis	**Chinese mitten crab**	**High**	
Pacifastacus leniusculus	Signal crayfish	Medium	Typical invasion pathways (aquaculture) less likely to facilitate invasion in Hudson Bay (though climate conditions may be suitable)
Rhithropanopeus harrisii	Estuarine mud crab	Medium	Climate
Isopoda			
Jaera istri	-	Medium	Climate
Proasellus coxalis	-	Low	Climate
Proasellus meridianus	-	Medium	Climate
Mysidacea			
Hemimysis anomala	**-**	**High**	
Limnomysis benedeni	-	Medium	Climate
Mysis relicta	-	Low	Primarily habitat - needs cold, deep, slow-moving water not present near the Hudson Bay estuaries
Paramysis lacustris	-	Medium	Climate and possibly also habitat
Cirripedia			
Balanus improvisus	**Acorn barnacle**	**High**	
Elminius modestus	Small barnacle	Low	Climate
MOLLUSCA			
Bivalvia			
Congeria leucophaeta	False mussel	Medium	Climate - Has been observed in Sweden but was unable to establish
Corbicula fluminalis	Asian clam	Medium	Climate - more sensitive to feezing than *C. fluminea*
Corbicula fluminea	**Asian clam**	**High**	
Crassostrea gigas	Giant oyster	Medium	Climate and dispersal mechanisms

Table 5. Continued.

Taxon/Species	Common Name	Risk of Invasion[1]	Factors limiting potential invasion into Hudson Bay[2]
Dreissena bugensis	**Quagga mussel**	**High**	
Dreissena polymorpha	Zebra mussel	Medium	Climate - though temperatures in the Churchill region are likely suitable for adult survival, larval survival requires warmer temperatures
Ensis americanus	Jackknife clam	Medium	Climate
Ensis directus	Atlantic jackknife	Medium	Climate
Lasmigona subviridis	Green floater	Low	Climate and habitat
Limnoperna fortunei	Asian freshwater mussel	Medium	Climate
Mytilopsis leucophaeta	Brackish water zebra mussel	Medium	Climate
Petricola pholadiformis	American piddock	Low	Climate and habitat
Pisidium amnicum	Greater European peaclam	Low	Climate
Pisidium henslowanum	Henslow pea clam	Low	Climate
Pisidium supinum	Humpback pea clam	Low	Climate
Sphaerium corneum	European fingernailclam	Medium	Climate
Tapes phillipinarum	Manila clam	Low	Invasion history - climate may be suitable in the Churchill region but this species does not appear to have a strong history of successful invasions
Teredo navalis	Shipworm	Medium	Dispersal mechanisms - seems to require wooden ships for attachment which are in uncommon use presently
Unio mancus	-	Low	Climate
Gastropoda			
Bithynia tentaculata	Spire snail	Medium	Climate may limit invasion but if *Myriophyllum* were to successfully invade, this could facilitate invasion of *Bithynia*
Cipangopaludina chinensis malleata	Chinese apple snail	Low	Climate and habitat
Cipangopaludina japonica	Japanese mystery snail	Low	Climate and habitat

Table 5. Continued.

Taxon/Species	**Common Name**	**Risk of Invasion**[1]	**Factors limiting potential invasion into Hudson Bay**[2]
Crepidula fornicata	Slipper limpet	Medium	Climate
Gillia altilis	Buffalo pebblesnail	Low	Climate and habitat
Lithoglyphus naticoides	Gravel snail	Medium	Climate
Physella acuta	European physa	Medium	Climate
Potamopyrgus antipodarum	New Zealand mud snail	Medium	Climate - though highly invasive in Europe and the Great Lakes from ballast water transfer, its distribution does appear limited in Lake Superior only to the warmest areas
Radix auricularia	Big-eared radix	Low	Climate, dispersal methods, and habitat preferences are all potentially limiting
Valvata piscinalis	European stream valvata	Medium	Climate - invasion can be facilitated by *D. polymorpha*
Viviparus georgianus	Trap door snail	Low	Climate, dispersal methods, and habitat preferences are all potentially limiting
Viviparus viviparus	River snail	Low	Climate, dispersal methods, and habitat preferences are all potentially limiting
UROCHORDATA			
Ascidiacea			
Styela clava	Rough sea squirt	Medium	Climate though likely only marginally
		FISHES	
Actinopterygii (ray-finned fishes)			
Clupeidae			
Alosa aestivalis	Blueback herring	Low	Climate and dispersal mechanisms
Alosa chrysochloris	Skipjack herring	Low	Climate and dispersal mechanisms
Alosa pseudoharengus	Alewife	Low	Climate and dispersal mechanisms

Table 5. Continued.

Taxon/Species	Common Name	Risk of Invasion[1]	Factors limiting potential invasion into Hudson Bay[2]
Cyprinidae			
Carassius auratus	Goldfish	Low	Dispersal mechanisms and possibly also climate though this species is highly adaptive
Pseudorasbora parva	Topmouth gudgeon	Low	Climate
Scardinius erythrophthalmus	Rudd	Low	Climate
Gasterosteidae			
Apeltes quadracus	Fourspine stickleback	Low	Climate
Gobiidae			
Neogobius melanostomus	Round goby	Low	Climate
Proterorhinus marmoratus	Tubenose goby	Low	Climate
Moronidae			
Morone americana	White perch	Low	Climate and dispersal mechanisms
Morone mississippiensis	Yellow bass	Low	Climate and dispersal mechanisms
Odontobutidae			
Percottus glenii	Amur sleeper	Medium	Dispersal mechanisms
Osmeridae			
Osmerus mordax	**Rainbow smelt**	**High**	
Percidae			
Gymnocephalus cernuus	**Ruffe**	**High**	
Oncorhynchus gorbuscha	Pink salmon	Low	Dispersal mechanisms
Oncorhynchus kisutch	Coho salmon	Low	Dispersal mechanisms
Oncorhynchus mykiss	Rainbow trout	Low	Dispersal mechanisms
Oncorhynchus nerka	Kokanee salmon	Low	Dispersal mechanisms
Oncorhynchus tshawytscha	Chinook salmon	Low	Dispersal mechanisms
Salmo salar	Atlantic salmon	Low	Climate and dispersal mechanisms
Salmo trutta	Brown trout	Low	Climate and dispersal mechanisms

Table 5. Continued.

Taxon/Species	**Common Name**	**Risk of Invasion**[1]	**Factors limiting potential invasion into Hudson Bay**[2]
PARASITES, DISEASE VECTORS, AND COMMENSALS			
MYXOZOA			
Microsporea			
Glugea hertwigi	**-**	**High**	
Myxosporea			
Myxobolus cerebralis	Whirling disease	Medium	Invasiveness depends entirely on invasion of infected hosts, *S. fontinalis* can act as hosts
Sphaeromyxa sevastopoli	-	Low	Host, *N. melanostomus*, is an unlikely invader
CILIOPHORA			
Suctoria			
Acineta nitocrae	-	Medium	Invasiveness depends on potential invasion success of its commensal partners, the *Nitokra* spp. copepods
SARCOMASTIGOPHORA			
Zoomastigophora			
Trypanosoma acerinae	-	Medium	Invasiveness depends entirely on invasion success of infected host *G. cernuus*
BACTERIA			
Schizomycetes			
Aeromonas salmonicida	-	Medium	Invasiveness depends on invasion success of infected host salmonids for which dispersal mechanisms may limit invasion
PLATYHELMINTHES			
Cestoda			
Amphilina foliacea	**-**	**High**	

Table 5. Continued.

Taxon/Species	**Common Name**	**Risk of Invasion[1]**	**Factors limiting potential invasion into Hudson Bay[2]**
Monogenea			
Dactylogyrus amphibothrium	-	Medium	Invasiveness depends mostly on invasion success of infected host *G. cernuus,* though this parasite can survive detached from the host
Dactylogyrus hemiamphibothrium	-	Medium	Invasiveness depends mostly on invasion success of infected host *G. cernuus,* though this parasite can survive detached from the host
Trematoda			
Acanthostomum sp.	-	Medium	Invasiveness depends on invasion success of infected definitive host *G. cernuus*, or infected intermediate host snails
Clinostomum complanatum	-	Low	Invasiveness depends on unlikely invasion of infected *Radix* spp. (snails) intermediate hosts
Ichthyocotylurus pileatus	-	Medium	Invasiveness depends mostly on invasion success of infected host *N. melanostomus*, but may also use native or introduced intermediate hosts
Neascus brevicaudatus	-	Medium	Invasiveness depends mostly on invasion success of infected host *G. cernuus*, but may also use native or introduced intermediate hosts
Pseudobacciger harengulae	-	Low	Invasiveness depends on unlikely invasion of infected Clupeidae definitive hosts
ANNELIDA			
Hirudinea			
Barbronia weberi	-	Low	Climate and dispersal mechanisms
Caspiobdella fadejewi	-	Low	Climate and dispersal mechanisms
Piscicola haranti	-	Low	Climate and dispersal mechanisms

Table 5. Continued.

Taxon/Species	Common Name	Risk of Invasion[1]	Factors limiting potential invasion into Hudson Bay[2]
ARTHROPODA			
Branchiura			
Argulus japonicus	Japanese fishlouse	Medium	Invasion could be facilitated with invasion of goldfish (can infect native cyprinids once established)
Neoergasilus japonicus	-	Medium	Climate - but only because current hosts are unlikely to tolerate climate
Salmincola lotae	-	Medium	Dispersal mechanisms - though suitable host is already present (*Lota lota*) in the Churchill region, this parasite is only occasionally free-swimming and would have to be transported with host *L. lota* from Eurasia which is unlikely in ballast water
FUNGI			
Aphanomyces astaci	Crayfish plague	Medium	Hosts (several crayfish species) are not generally dispersed by shipping traffic but by means not likely to occur in the Hudson Bay region
	PHYTOPLANKTON, ALGAE, AND MACROPHYTES		
PHYTOPLANKTON			
Bacillariophyta (diatoms)			
Coscinodiscus wailesii	**-**	**High**	
Odontella sinensis	**-**	**High**	
Thalassiosira punctigera	-	Medium	Though successfully established in the North and Baltic seas it remains only a minor component of the phytoplankton possibly due to northern limit of its range

Table 5. Continued.

Taxon/Species	**Common Name**	**Risk of Invasion**[1]	**Factors limiting potential invasion into Hudson Bay**[2]
Pyrrophycophyta (dinoflagellates)			
Alexandrium minutum	-	Low	Primarily climate, more of a warm temperate to tropical species though it has been observed in south Sweden
Chattonella antiqua	-	Medium	Primarily climate
Chattonella marina	-	Medium	Primarily climate
Chattonella cf. verruculosa	-	Medium	Possibly more tolerant of lower temperatures than other *Chattonella* species but invasiveness in other regions still appears relatively limited
Fibrocapsa japonica	-	Medium	Though successfully established in the North Sea, climate is likely still limiting invasion further north
Gymnodinium mikimotoi	-	Medium	Primarily climate, more of a temperate to tropical species
Prorocentrum minimum	**-**	**High**	
ALGAE			
Chlorophyta (green algae)			
Codium fragile* ssp. *tomentosoides	**Oyster thief**	**High**	
Phaeophyta (brown algae)			
Colpomenia peregrina	Oyster thief	Medium	Climate may limit dispersal of this species further north than it has currently invaded; additionally shipping does not appear to be a significant invasion pathway
Fucus evanescens	Wrack	Medium	Invasiveness appears limited though it cannot be ruled out since it seems adaptive to different climates and can use shipping for invasion
Sargassum muticum	-	Medium	Climate

Table 5. Continued.

Taxon/Species	**Common Name**	**Risk of Invasion**[1]	**Factors limiting potential invasion into Hudson Bay**[2]
Rhodophyta (red algae)			
Bonnemaisonia hamifera	-	Medium	Invasiveness is restricted by temperature requirements for reproduction and shipping appears to be of minimal importance as a vector
Dasya baillouviana	Chenilleweed	Low	Primarily climate
Gracilaria vermiculophylla	-	Medium	Though it has invaded Sweden, its occurrence is rare and it doesn't appear that climate is ideal
Heterosiphonia japonica	-	Medium	Though it can survive temperatures from 0-30ºC, optimal growth, particularly of young, only occurs at warmer temperatures
Polysiphonia harveyi	-	Low	Primarily climate, though also dispersal mechanisms
MACROPHYTES			
Magnoliophyta (flowering plants)			
Butomus umbellatus	Flowering rush	Low	Climate will likely limit its distribution further north than southern Canada
Carex acutiformis	Lesser pond sedge	Low	Climate
Carex disticha	Tworank sedge	Low	Climate
Carex flacca	Heath sedge	Low	Climate
Crassula helmsii	New Zealand Pigmyweed	Low	Though a successful invader elsewhere, climate will probably restrict more northern invasions
Elodea nuttallii	Nuttall's waterweed	Medium	Climate
Epilobium hirsutum	Hairy willow-herb	Low	Climate is likely limiting (this species co-exists with *Lythrum salicaria*)
Epilobium parviflorum	Hoary willow-herb	Low	Climate is likely limiting (this species co-exists with *Lythrum salicaria*)

Table 5. Continued.

Taxon/Species	**Common Name**	**Risk of Invasion[1]**	**Factors limiting potential invasion into Hudson Bay[2]**
Glyceria maxima	Reed sweet-grass	Medium	Climate may be suitable although shipping does not appear to be a potential vector
Hydrocharis morsusranae	Frogbit	Low	Climate and dispersal mechanisms
Juncus compressus	Roundfruit rush	Medium	Climate
Juncus gerardii	Saltmarsh rush	Medium	Climate
Juncus inflexus	European meadow rush	Medium	Climate
Lycopus asper	Rough bugleweed	Medium	Climate may be suitable although shipping does not appear to be a potential vector
Lycopus europaeus	Gypsywort	Low	Climate and dispersal mechanisms
Lythrum salicaria	Purple loosestrife	Low	Primarily dispersal mechanisms though climate may also be limiting
Myriophyllum spicatum	Eurasian watermilfoil	Medium	Though it can tolerate a wide variety of salinities and temperatures it has not yet been successful in climates approximating Churchill and invasion pathways are primarily via the aquarium trade
Najas minor	Brittle waternymph	Medium	Climate and dispersal mechanisms
Najas marina	Spiny naiad	Low	Climate and dispersal mechanisms
Nymphoides peltata	Yellow floating heart	Low	Dispersal mechanisms (mostly through ornamental plant trade) in particular
Potamogeton crispus	Curly pondweed	Low	Though tolerant of lower temperatures, they are only found in Ontario in Canada; shipping does not appear to be a potential vector
Puccinellia distans	Weeping alkaligrass	Low	Climate and dispersal mechanisms
Spartina anglica	Common cordgrass	Low	Climate
Sparganium glomeratum	Clustered bur-reed	Medium	Climate and dispersal mechanisms
Trapa natans	Water chestnut	Low	Climate, dispersal methods, and habitat preferences are all potentially limiting
Typha angustifolia	Narrowleaf cattail	Medium	Climate

Table 5. Continued.

Taxon/Species	Common Name	Risk of Invasion[1]	Factors limiting potential invasion into Hudson Bay[2]
Pteridophyta			
Marsilea quadrifolia	European waterclover	Low	Climate, dispersal methods, and habitat preferences are all potentially limiting

1 - Low risk = several factors (climate, dispersal mechanisms, etc.) likely would prevent establishment in Hudson Bay or its tributaries; Medium risk = generally only one factor preventing invasion of Hudson Bay and it may only be marginally preventing invasion; High risk = conditions in Hudson Bay are suitable for potential invasion

2 - Brief summaries for low and medium risk invaders

Table 6. Water temperature and salinity measurements recorded from the Nelson River Estuary and a 100-km long freshwater section of river immediately upstream (i.e. south of Gillam Island) from 1979-1999.

Habitat	Year	Month	Location	Temperature (°C)	Salinity (‰)	Reference
Freshwater	1988	July	surface	16.2 − 19.5	0	Baker 1989
	1988	August	surface	17.5 − 20.0	0	Baker 1989
	1988	September	surface	9.6 − 10.1	0	Baker 1989
Estuary	1979	July	--	18	0	Gaboury 1980
	1979	July	--	14	3	Gaboury 1980
	1979	July	--	11	16	Gaboury 1980
	1979	July	--	9	23	Gaboury 1980
	1979	July	--	9	24	Gaboury 1980
	1988	July	surface	12.6 − 14.5	0.0 − 5.5	Baker 1989
	1988	August	surface	8.1 − 18.1	0.1 − 28.5	Baker 1989
			bottom	6.9 − 10.0	22.2 − 29.7	Baker 1989
	1992	August	surface	6.0 − 16.0	0, 0.59 − 26.0	Baker et al. 1993
			bottom	4.9 − 16.0	0, 1.8 − 27.7	Baker et al. 1993
	1995	July	surface	12.1 − 17.4	0.0 − 10.5	Baker 1996
			bottom	6.4 − 17.1	0.1 − 22.8	Baker 1996
	1996	July	surface	13.6 − 23.5	--	Horne 1997
			bottom	5.9 − 20.1	--	Horne 1997
	1997	July	surface	14.6 − 22.1	0, 4.5 − 13.8	Horne and Bretecher 1998
			bottom	6.9 − 20.9	0, 17.3 − 35.2	Horne and Bretecher 1998
	1998	July	surface	10.7 − 18.6	0, 0.1 − 27.1	Zrum 1999
			bottom	7.0 − 18.6	0, 0.9 − 36.6	Zrum 1999
	1999	July	surface	18.3 − 20.6	0, 2.7 − 13.3	Zrum 2000
			bottom	11.1 − 17.3	2.7 − 32.0	Zrum 2000

Table 7. Water temperature and salinity measurements recorded from the Churchill River Estuary and a 15-km long freshwater section of river immediately upstream (i.e. south of Mosquito Point) from 1993-1996.

Habitat	Year	Month	Location	Temperature (°C)	Salinity (‰)	Reference
Freshwater	1996	June	--	5.0 − 21.0	0	Fazakas and Remnant 1997
		August	--	8.0 − 20.0	0	Fazakas and Remnant 1997
		September	--	2.0 − 19.0	0	Fazakas and Remnant 1997
Estuary	1993	Aug/Sept	surface	6.0 − 13.0	2.5 − 31.0	Baker et al. 1994
			bottom	7.0 − 11.0	10.0 − 32.0	
	1993	Aug/Sept	--	7.5 − 9.5	0, 0.1 − 27.0	Baker et al. 1994
	1994	July	--	-0.4 − 12.2	4.8 − 31.6	Lawrence and Baker 1995

In the following sections we discuss the potential for invasion and the potential ecological impacts should a successful invasion occur for each of the high-risk species. Zooplankton, macroinvertebrate, and fish species will be treated first. A few key parasite species are also identified as potential invaders. However, sufficient information concerning the native and potential invasive parasite species and their respective life cycles is largely unavailable. There could be a large pool of parasites that may co-invade with high-risk invertebrate intermediate hosts with potentially severe impacts when these parasites are transmitted to definitive hosts (native fish fauna). Further work would need to be done to assess this particular risk in the region.

ZOOPLANKTON

3.4.1 *Acartia tonsa*

3.4.1.1 Invasion potential

Likely originally from the Mediterranean Sea, this copepod was first noticed in northern Europe in England in the early part of the 20th century (Conover 1957) and it has since spread to the Gulf of Finland (Brylinski 1981). This brackishwater, euryhaline and eurythermic species can tolerate salinities from 1-13‰, and temperatures from 0-29.5°C, though warmer temperatures produce higher densities (Kurashova and Tinenkova 1988). Though not certain, ballast water seems a likely dispersal mechanism for this species. Therefore, there is potential for establishment in the Hudson Bay region.

3.4.1.2 Potential impacts

There appear to be no significant negative impacts from invasion of this species into other areas though more work needs to be done to confirm the relatively innocuous presence of *A. tonsa*. Impacts in the Churchill region could be expected to be low.

3.4.2 Bythotrephes longimanus (Spiny water flea)

3.4.2.1 Invasion potential

This predatory cladoceran is native to Asia and Europe (including Scandinavia and Russia) and has recently invaded the Great Lakes and other inland lakes in Ontario and the U.S. (Therriault et al. 2002) with the port of St. Petersburg as the likely source of most introductions. This species was probably introduced into the Great Lakes via ballast water (Berg et al. 2002) and as resting eggs from mud (Evans 1988). *B. longimanus* is a cold and freshwater adapted species and is limited to regions where water temperature ranges between 4 and 30°C and salinity values between 0.04 and 8.0‰, but prefers temperatures between 10 and 24°C and salinity between 0.04 and 0.4‰ (Grigorovich et al. 1998) and should therefore find suitable conditions near Churchill. This species has highly plastic reproductive strategies and the eggs are even capable of surviving passage through fish digestive systems (Jarnagin et al. 2000). The only factor that may limit establishment in the Churchill region is the absence of its preferred habitat of cool, deep lakes (MacIsaac et al. 2000).

3.4.2.2 Potential impacts

Multiple impacts from invasion of *B. longimanus* into the Great Lakes include fouling of fishing gear, predation on smaller, native zooplankton, and direct competition with planktivorous fish (larval and adult) for food (Berg & Garton 1988; Evans 1988; Vanderploeg et al. 1993). This species has also been implicated as a factor in the decline of alewife (*Alosa pseudoharengus*) in Lakes Ontario, Erie, Huron, and Michigan (Evans 1988) likely due to competition and a decline in *Leptodora kindtii* from competition and possible predation (Branstrator 1995). There is also speculation that *B. longimanus* may control the abundance of another invasive species *Cercopagis pengoi*, through competition and predation (Vanderploeg et al. 2002). There is potential for this species to compete with local planktivores (e.g., cisco, *Coregonus artedi*) and impact native zooplankton population structure in the Churchill region.

3.4.3 Cercopagis pengoi (Fishhook water flea)

3.4.3.1 Invasion potential

This cladoceran is native to the Ponto-Caspian basin and via ship ballast water has become successfully established in eastern Europe, the Baltic Sea, the Laurentian Great Lakes, and other parts of North America (Leppäkoski & Olenin 2000; Therriault et al. 2002; Vanderploeg et al. 2002). Churchill abiotic conditions are suitable (Table 7) since *C. pengoi* is euryhaline and eurythermic, occurring in both fresh and brackish waters with salinities ranging up to 17‰ and at temperatures from 3-38°C (Gorokhova et al. 2000). Reproductive strategies (parthenogenesis and gamogenesis) would also facilitate invasion via ballast water.

3.4.3.2 Potential impacts

Similar to *B. longimanus*, *C. pengoi* is a potential competitor with young stages of planktivorous fish (Vanderploeg et al. 2002) and may affect resident zooplankton communities through selective predation (Uitto et al. 1999; Benoit et al. 2002; Ojaveer et al. 2004). Reductions in herbivorous zooplankton from predation by this species could result in algal blooms. Additionally, *C. pengoi* attach to fishing gear, clogging nets and trawls, which results in economic losses to fishermen (Leppäkoski & Olenin 2000). Predation on native zooplankton communities and competition with planktivorous fish (e.g., juvenile cisco) are the most likely impacts resulting from successful establishment of this species in the Churchill region.

3.4.4 Eubosmina maritima

3.4.4.1 Invasion potential

This typically marine cladoceran is native to Eurasia, in particular in the Baltic Sea/Gulf of Finland region where it is one of the most abundant species (Viitasalo & Viitasalo 2004). This species can also survive freshwater conditions and it was first discovered in the Great Lakes in 1988 (De Melo and Hebert 1994), likely introduced via ship ballast water. This euryhaline, eurythermic species is adapted for potential invasion into Hudson Bay.

3.4.4.2 Potential impacts

No significant impacts from *E. maritima* have been reported in the Great Lakes. Though there is potential for it to become abundant in the marine/brackish environment near Churchill and possibly displace some native marine cladocerans, impacts are generally expected to be relatively minimal.

MACROINVERTEBRATES

3.4.5 Balanus improvisus (Acorn barnacle)

3.4.5.1 Invasion potential

Originally from the east coast of North America, the acorn barnacle is now established throughout Europe, including the Baltic Sea/Gulf of Finland region (Weidema 2000). It is thought to have invaded most of its current area of occurrence by the 1870s (Jansson 1994), likely travelling largely on the hulls of wooden ships. The acorn barnacle is highly euryhaline and is the most freshwater tolerant species of barnacle (optimal salinity range of 6-30‰) though it cannot reproduce in freshwater (Leppäkoski 1999; Weidema 2000). It is also highly eurythermic and survives at temperatures ranging from 1.8-22.7°C in the Baltic Sea (Jarvekiulg 1979 in Zaiko 2005). However, optimum temperature for free-swimming larvae is approximately 14°C (Leppäkoski 1999), which may limit the potential success of *B. improvisus* in the Churchill region. Ship fouling and ballast water are both potential vectors for transmission to new regions.

3.4.5.2 Potential impacts

Though there appear to be no significant impacts from invasion of this species, there is potential competition for food and space with bivalves and other sessile organisms (Jarvekiulg 1979 in Zaiko 2005). Since *B. improvisus* in the Hudson Bay region would likely be at their northern limit of distribution, abundance and thus potential impacts could be relatively small.

3.4.6 Caprella mutica (Skeleton shrimp)

3.4.6.1 Invasion potential

This large caprellid amphipod is native to marine and estuarine habitat in the northwest Pacific including Siberian and Japanese coastal waters. It invaded several locations along the Pacific coast of North America during the 1970s and 1980s (Cohen & Carlton 1995) and the east coast of North America by the 1990s. It was first discovered in Europe in the Netherlands in 1995 (Platvoet et al. 1995) and has since spread throughout the North Sea and into the U.K. (Willis et al. 2004; Buschbaum & Gutow 2005). Importation of Japanese oysters for aquaculture and ship ballast water are suspected invasion pathways (Willis et al. 2004). Relatively little work appears to have been done on the biology of this species but distributional data suggest that salinity and temperature conditions in the Churchill region could be suitable for establishment. It is unlikely that this species would be tolerant of freshwater conditions in the lower reaches of Hudson Bay tributaries.

3.4.6.2 Potential impacts

There is relatively little information on potential impacts of this invader. Buschbaum and Gutow (2005) noted large concentrations of *C. mutica* in harbours in the North Sea but there is no indication that any native species are being affected. There is potential for competition with native grazing amphipod species in Hudson Bay estuaries. This species can also be found in large numbers attached to aquaculture cages (Willis et al. 2004) so there may be potential for fouling of fishing gear. It is suspected that potential impacts from a successful invasion of *C. mutica* would be relatively minimal to the native ecosystems of the Hudson Bay region.

3.4.7 Chelicorophium curvispinum

3.4.7.1 Invasion potential

This Ponto-Caspian amphipod has been spreading across Europe since about 1900 (Jazdzewski 1980; Bij de Vaate et al. 2002), has recently invaded the Baltic Sea (Leppakoski et al. 2002), and is predicted to be a potential future invader into the Great Lakes via ballast water (Ricciardi & Rasmussen 1998). This species has been found in both estuaries and freshwater and can tolerate salinities up to 18‰ (Birshtein et al. 1968). Based on its wide distribution (Ponto-Caspian to Baltic and North seas), this amphipod seems to be tolerant of a range of temperatures, suggesting that conditions near Churchill and the Nelson rivers (tables 6 and 7) may be suitable for establishment.

3.4.7.2 Potential impacts

This filter-feeding crustacean can attain densities exceeding 100,000 individuals per square meter, altering benthic habitats by building massive networks of mud tubes on rocky substrata (Van den Brink et al. 1993). This alteration of habitat displaced filter feeding caddisflies and zebra mussels in the lower Rhine River (Van der Velde et al. 1994). Also attributed to this species were reductions in total organic carbon and suspended material in the lower Rhine (Van den Brink et al. 1993). There could therefore be significant impacts to the local ecology should *C. curvispinum* successfully invade Hudson Bay estuaries and tributaries.

3.4.8 Corbicula fluminea (Asian clam)

3.4.8.1 Invasion potential

This clam is native to southeastern China, Korea, southeastern Russia, and the Ussuri Basin (Aguirre and Poss 1999). First introduced on the west coast of North America around 1924, *C.*

fluminea, by the 1970s and 1980s, had occupied most of the Mississippi Basin, the Gulf Coast and the eastern United States (Balcom 1994). This species can tolerate salinities of up to 13‰ for short periods (Aguirre and Poss 1999) and temperatures between 2 and 30°C (Balcom 1994). Janech and Hunter (1995) also identified low temperature tolerance in *C. fluminea*. These data suggest the Asian clam is not likely limited by conditions in Hudson Bay (tables 6 and 7). Various invasion pathways have been identified including aquarium trade and ship ballast water transport of larvae.

3.4.8.2 Potential impacts

Ecologically, *C. fluminea* has outcompeted many native North American clam species for food and space (PNNL 2003). Additionally, this species has been known to clog water intake pipes, affecting power, water, and other industries and costing billions of dollars in repairs and cleanup (Balcom 1994).

3.4.9 Cordylophora caspia **(Freshwater hydroid)**

3.4.9.1 Invasion potential

This colonial freshwater hydroid from the Ponto-Caspian region has been a prolific invader, becoming successfully established on both coasts of North America, the Great Lakes region, South America, Australia and New Zealand, and throughout north-western Europe (including Sweden and parts of Russia). Additionally, because this species has already exhibited very successful, widespread invasions throughout northern Europe, it is a high risk invader from these source locations to new areas. Invasion pathways include both the aquarium trade (Mills et al. 1993a) and ballast water (Ruiz and Hines 1997). *C. caspia* can invade a variety of habitats from estuarine to completely freshwater and appears tolerant of different temperature regimes. Though most successful invasions appear to occur in more temperate and tropical locations, the presence of *C. caspia* in the Baltic Sea region cannot rule out the possibility of invasion into Hudson Bay. Invasiveness of this species can also be facilitated with invasion of zebra mussels (Ricciardi 2001), should conditions change enough (i.e. climate change) to suit the biological requirements of zebra mussels. *C. caspia* prey upon larval *D. polymorpha* and use their shells as substrate (Ricciardi 2001).

3.4.9.2 Potential impacts

This species preys upon chironomids and other larval insects in the Connecticut River (Smith et al. 2002) and it may contribute to a restructuring of benthic and pelagic communities (Folino 1999), however, the ecological impacts of this invader have still not been thoroughly studied.

More studies would be required before making an accurate prediction of this species' impacts on the aquatic environments in the Churchill region.

3.4.10 Dikerogammarus villosus (Killer shrimp)

3.4.10.1 Invasion potential

This freshwater amphipod is native to the Ponto-Caspian region and has recently invaded most of western Europe, in particular the Rhine River (Van den Brink et al. 1991). Though it has not yet invaded North America, it is predicted that invasion is highly likely in the near future in ship ballast water (Dick & Platvoet 2001). Though optimal metabolic temperatures are ~20°C, *D. villosus* can tolerate a wide range of temperature changes (Bruijs et al. 2001). However, invasion success may still be limited in the Hudson Bay region without further impacts from climate change since current average temperatures are significantly less than optimum for *D. villosus*. This species can also tolerate low oxygen conditions and, though it prefers salinities of 0‰-10‰, it can adapt to salinities as high as 20‰ but is intolerant of salinities higher than 24‰ (Bruijs et al. 2001), which would enable it to survive typical conditions in the Churchill or Nelson River estuaries (tables 6 and 7).

3.4.10.2 Potential impacts

If successfully established, *D. villosus* can have significant negative impacts on the local environment. This large, predatory amphipod has caused severe reductions in populations of other species of native and exotic amphipods in the Rhine River (Dick & Platvoet 2000; Van der Velde et al. 2000). Similar impacts could be expected on native amphipods in freshwater and estuarine environments in western Hudson Bay.

3.4.11 Dreissena bugensis (Quagga mussel)

3.4.11.1 Invasion potential

A euryhaline native of the Dnieper-Bug estuary in the Ukraine (Mills et al. 1996b), this mussel invaded the Great Lakes in the late 1980s early 1990s (Vanderploeg et al. 2002) most likely from ship ballast water and has begun to replace another invader, the zebra mussel, in several areas (Mills et al. 1996b). Like the zebra mussel, the quagga mussel is tolerant of a wide range of temperatures, however it can spawn at lower temperatures than *D. polymorpha*, (9°C compared with 12°C) and has been observed to proliferate in the profundal zones of the lower Great Lakes where temperatures are constantly 4-9°C (Claxton & Mackie 1998; Vanderploeg et al. 2002).

Current environmental conditions in the Churchill region should therefore be more suitable for establishment of this species than for the zebra mussel.

3.4.11.2 Potential impacts

Quagga mussels, in large concentrations in the Great Lakes region, have negatively affected zooplankton abundance, biomass, and species composition (Grigorovich & Shevtsova, 1995) and have caused upwards of a 95% reduction in the numbers of native unionid clams and have caused some local extirpations (Schloesser et al. 1998; Schloesser & Masteller 1999). Similar impacts could occur in the Churchill region.

3.4.12 Eriocheir sinensis (Chinese mitten crab)

3.4.12.1 Invasion potential

The Chinese mitten crab is native to China and Korea and through widespread invasions is now established across northern Europe including the Baltic Sea region and the San Francisco Bay, Gulf of St. Lawrence, and Great Lakes areas of North America (including Thunder Bay) where it appears to be expanding its range further (Gollasch 1999; Veldhuizen 2001; Franzin, B. pers. comm.). Several invasion pathways have been identified for larvae and adults of this species including ship ballast water. Although currently established only in temperate regions of the world, *E. sinensis* can tolerate a wide range of temperatures (Anger 1991) and it has been observed in the Gulf of Finland region and in Lake Lagoda (Panov 2006) suggesting that establishment in the Churchill region is not unlikely though it may only be a marginally high risk species. A catadromous crab, *E. sinensis* requires both brackish and freshwater habitats to complete its life cycle and can, therefore, tolerate wide variations in salinity (Anger 1991).

3.4.12.2 Potential impacts

This crab has been known to contribute to local extirpations of native invertebrates, modify habitats due to its burrowing activities, interfere with water intake pipes, and cost fish and aquaculture industries (due to gear entanglement, bait stealing, etc.) hundreds of thousands of dollars a year worldwide (Rudnick & Resh 2002). Habitat modification and impacts to native invertebrate fauna can be expected should this species invade Hudson Bay.

3.4.13 Gmelinoides fasciatus

3.4.13.1 Invasion potential

Gmelinoides fasciatus is a gammaridean amphipod of Baikalian origin and is widespread throughout the Lake Baikal basin. Large scale intentional introduction efforts from 1960-1980 introduced this species into many new watersheds within Russia (Zadoenko et al. 1985). Once established in these new regions, *G. fasciatus* quickly spread to new regions via its own dispersal mechanisms, successfully colonizing the entire littoral zone of Europe's largest lake (Lake Ladoga) by 1996 (Panov et al. 1999) and the brackish waters of the Gulf of Finland by 2000 (Panov & Berezina 2001). This amphipod can survive temperatures from 0.2-32°C, withstand variable oxygen levels, and, though primarily freshwater, can establish in brackish environments at salinities below 2‰ (Bekman & Bazikalova 1951; Panov et al. 1999; Berezina et al. 2001). Higher salinity resistance has been observed at lower water temperatures (Verbitsky & Berezina 2003), which may facilitate dispersal in Hudson Bay estuaries. In general, conditions in the Churchill area are likely suitable for successful invasion of this species (Table 7). Though ballast water has not yet been an important invasion vector for this species, it has only recently established in an area (Gulf of Finland) with significant ballasted shipping traffic. Environmental tolerances of this species suggest ballast water transfer would be a viable means of introduction into new regions.

3.4.13.2 Potential impacts

Following successful invasion, this amphipod has outcompeted and replaced native amphipods (e.g., *Gammarus lacustris*) to become the dominant invertebrate in the littoral zone of many freshwater and brackish habitats (Panov and Berezina 2001; Berezina and Panov 2003, 2004). Similar replacement of native *Gammarus* spp. could be expected in the Hudson Bay region.

3.4.14 Hemimysis anomala

3.4.14.1 Invasion potential

This Ponto-Caspian mysid shrimp was intentionally introduced into reservoirs and lakes in the former USSR during the 1950s and 1960s where it quickly formed dense populations (Mordukhai-Boltovskoi 1964; Salemma and Hietalahti 1993). It has since spread into the Gulf of Finland (1992) and has been found in large numbers along the southwest and southern coast of Finland (Salemma 1998). A euryhaline organism, *H. anomala* can survive salinities from 0.5-18.0‰ (Bacescu 1969) and could therefore establish in freshwater or estuarine habitat near

Churchill. Ballast water is thought to be a key vector for future invasions into new regions (Ricciardi & Rasmussen 1998).

3.4.14.2 Potential impacts

Though no significant impacts have been noted for European invasions, Ricciardi & Rasmussen (1998) predict that should *H. anomala* establish in North America, there could be some effects. Native North American mysids (e.g., *Mysis relicta*) are generally restricted to cold, deep lakes but *H. anomala* can invade shallower, warmer aquatic habitats (shallow lakes, margins of large rivers etc.) that are currently devoid of any mysids. Impacts in these new habitats would likely include a reduction in zooplankton and subsequent negative impacts on zooplanktivorous fish and higher consumers (Spencer et al. 1991). Biomagnification of contaminants at higher trophic levels has been observed in North American lakes that contain mysids (Rasmussen et al. 1990). Similar effects could be expected in *Mysis*-free areas near Churchill.

3.4.15 Marenzelleria **cf.** *viridis and M.* **cf.** *wireni*

3.4.15.1 Invasion potential

These two marine polychaetes are often difficult to distinguish from one another based solely on morphology and they share similar ecological characteristics so potential invasiveness will be considered together. Both species are originally from the east coast of North America and were first introduced to Europe in the late 1970s and early 1980s (Atkins et al. 1987; McLusky et al. 1993). *M. viridis*, in particular, quickly spread throughout most of northern Europe, including the North and Baltic seas (Kotta et al. 2003). *M. wireni* has been found in the European Arctic in Spitsbergen (Bick 2005). These species have not yet been recorded from the Churchill region (tables 4 and 5). Though *M. viridis* has established in many coastal regions of the northern Baltic, it has been most successful in more eutrophicated regions or more uniform habitats and is considered one of the most influential exotics in the region. Though primarily marine, *M. viridis* is euryhaline and can survive in near freshwater conditions, preferring sediments enriched with organic matter at river mouths (Maximov & Panov 2002). Conditions in Hudson Bay estuaries would be suitable (Table 7). Invasiveness of these polychaetes is augmented by an exceptionally high reproductive potential (Sarda et al. 1995). These species were most likely introduced to Europe via ballast water as larvae and/or adults.

3.4.15.2 Potential impacts

Concurrent with the invasion of *M. viridis* into the Baltic, densities of some native amphipods (*Chelicicorophium volutator* and *Monoporeia affinis*) and a polychaete (*Nereis diversicolor*) have decreased considerably (Kotta et al. 2003). Similar effects on native benthic invertebrates have been observed in estuaries in Britain and the Netherlands (Atkins et al. 1987; Essink and Kleef 1993). Maximov and Panov (2002) predict that similar replacement of native freshwater species of chironomids and oligochaetes will occur in estuaries and river mouths in the eastern Gulf of Finland. Additional experiments have shown that *M. viridis* increased benthic production and decreased growth and survival of *N. diversicolor* and *M. affinis* (Kotta et al. 2003). Competition with a native Baltic bivalve (*Macoma balthica*) reduced the negative impacts and successful establishment of this species (Kotta et al. 2003). It is unknown if similar competition with native bivalves in Hudson Bay would limit invasiveness of these polychaetes, however, it seems likely that they could have significant negative impacts on native marine and freshwater fauna.

3.4.16 Pontogammarus robustoides

3.4.16.1 Invasion potential

This amphipod originates from the lower sections of large Ponto-Caspian rivers but can also be found in some inland brackish and freshwater lakes (Jazdzewski 1980). Initially intentionally introduced into multiple watersheds in Europe and Russia in the 1960s, *P. robustoides* has subsequently spread to other regions in Europe including the Baltic Sea (Jazdzewski 1980). Though the migration route is not clear, it is likely that ballast water is the primary invasion vector for *P. robustoides*. This species is oligohaline and can establish in fresh or brackish water and, from its distribution, appears tolerant of a wide range of temperatures so that conditions in the Churchill and Nelson river regions should be suitable (tables 6 and 7).

3.4.16.2 Potential impacts

Similar to *G. fasciatus*, *P. robustoides* has been observed replacing native and previously introduced gammarids in the littoral zone of both fresh and brackish waters due to competition and predation (Jazdzewski et al. 2004). Additionally, it is an important intermediate host of the potentially pathogenic sturgeon parasite *Amphilina foliacea* (Section 3.4.18).

FISHES

3.4.17 Gymnocephalus cernuus (Ruffe)

3.4.17.1 Invasion potential

This native European and Asian percid has successfully invaded the Great Lakes region in North America primarily in ship ballast water (Gunderson et al. 1998; Lappalainen and Kjellman 1998). It can tolerate a wide range of ecological conditions including salinities up to 12‰, depths up to 85 m, and eutrophic conditions (Gunderson et al. 1998; Lappalainen and Kjellman 1998). Survival and even spawning can occur over a wide range of temperatures (4.9-30°C) and, in general, *G. cernuus* appears more tolerant of colder temperatures than European perch, *Perca fluviatilis* (Bergman 1987). Conditions in the Churchill region should permit establishment of this species.

3.4.17.2 Potential impacts

This fish is a strong competitor with native fish species such as yellow perch (*Perca flavescens*), *Coregonus* spp., lake sturgeon (*Acipenser fulvescens*), and walleye (*Sander vitreus*) for benthic invertebrate prey (Gunderson et al. 1998). Early maturation and high fecundity have facilitated expansion of this species' introduced range and combined with flexible foraging abilities and egg predation, invasion of *G. cernuus* has caused decreased abundance of some native species in the Great Lakes region such as yellow perch. Species in the tributaries of Hudson Bay that are more exclusively benthivorous would likely be more susceptible to competition from the ruffe and impacts could be quite significant to local fish and invertebrate communities.

3.4.18 Osmerus mordax (Rainbow smelt)

3.4.18.1 Invasion potential

This fish, native to the Atlantic and northwest Pacific coasts of North America, has successfully invaded many lakes in the interior of the continent and established landlocked populations. Rainbow smelt were introduced into the Great Lakes in the 1930s and were first observed in Lake Winnipeg in 1991 (Franzin et al. 1994). They have since dispersed northwards in the Nelson River watershed reaching the estuary by 1998. They have also been recorded from the Hayes River estuary (Stern 2005). These fish are unlikely to invade the Churchill region in ship ballast water, instead they will probably disperse from populations already present in Hudson

Bay at the mouths of the Nelson and Hayes rivers. In fact, there are recent reports that suggest smelt are already present in the Churchill region (Stewart and Watkinson 2004; Bernhardt and Holm 2005) though they may not yet be established.

3.4.18.2 Potential impacts

Smelt compete with and prey upon many native species in areas where they have already become established. For example, in Wisconsin, smelt are the most likely cause, via predation, of the extirpation of cisco from one lake and, via competition, a decrease in condition of adult yellow perch in another (Hrabik et al. 1998). They were predicted to have similar effects on native fish species in Manitoba (Franzin et al. 1994). Though initially predicted to also cause an increase in mercury bioaccumulation in piscvivores that switch to a smelt diet, recent evidence suggests that this is not a significant potential impact of smelt invasions (Johnston et al. 2003). Similar effects are expected in the Churchill region.

PARASITES, DISEASE VECTORS, AND COMMENSALS

3.4.19 Amphilina foliacea

3.4.19.1 Invasion potential

This widely distributed cestode is a natural parasite of several species of Eurasian sturgeon (*Acipenser* spp.). Invasion success of this parasitic cestode depends entirely on the invasion potential of infected intermediate hosts such as *Pontogammarus robustoides* (see Section 3.4.16), and subsequent feeding on these gammarids by lake sturgeon. Additionally, only the adult life cycle stages of gammarids can harbour and transfer this parasite, which may further limit invasion potential.

3.4.19.2 Potential impacts

A. foliacea in the body cavity of the sturgeon host penetrate the liver, gonads, and muscles, leading to hyperaemia and haemorrhages followed by extensive inflammation (Popova & Davydov 1988). Haemoglobin levels, red blood cell counts and body fat content of the host are also affected. The host will form capsules around the parasites but these do not prevent continued growth nor do they effectively contain the parasite. Should this parasite become established in the Churchill region there is also potential that intermediate life cycle stages could infect native gammarids. Potential effects on new intermediate hosts cannot be accurately predicted.

3.4.20 Glugea hertwigi

3.4.20.1 Invasion potential

A natural host of this parasite is the invasive rainbow smelt, *Osmerus mordax*, which has already become established in the Nelson River (Remnant et al. 1997), its estuary, and coastal Hudson Bay (see Appendix 1) and is likely to establish in the Churchill River system in the near future. It is unknown if smelt in the region already possess the parasite since relatively few parasitological studies have been conducted on the Nelson River. However, it has been observed in smelt in the Great Lakes (Mills et al. 1993a). Since a natural host is already present, invasion of this species could be facilitated.

3.4.20.2 Potential impacts

Heavy infections of this parasite may cause mortality, particularly in young-of-the-year smelt (Pekcan-Hekim et al. 2005). *G. hertwigi* can also infect capelin (*Mallotus villosus*) a native species that is an important prey item of beluga and other marine organisms in Hudson Bay. There could, therefore, be impacts on several trophic levels if this species invades Hudson Bay.

FUNGI, PHYTOPLANKTON, ALGAE, AND MACROPHYTES

3.4.21 Odontella sinensis

3.4.21.1 Invasion potential

This diatom is believed to have originated from the Red Sea or Indian Ocean. *O. sinensis* was first noted in the North Sea in 1903 and rapidly spread to become widely distributed throughout northern European waters, including the Baltic Sea (Boalch 1987). This marine or brackish water species can survive a wide range of climatic conditions from tropical to cold temperate. It is now considered an important part of the winter and spring diatom assemblage around Britain (Boalch 1987). Though not well understood, the method of initial invasion was likely ballast transport.

3.4.21.2 Potential impacts

Though a successful invader in Europe, there appears to be no significant local environmental or economic impacts from *O. sinensis*. Diatom blooms of other species have been known to, in high numbers, produce copious amounts of mucilage, resulting in insoluble skeletons of planktonic organisms and mineral particles that can blanket the seabed. Additionally, this mucilage can foul fishing gear. Similarly low impacts should be expected following a successful invasion in Hudson Bay.

3.4.22 Coscinodiscus wailesii

3.4.22.1 Invasion potential

Also thought to have originated from the Indo-Pacific region, this marine diatom was first observed in the English Channel in 1977 (Boalch & Harbour 1977) and within two years had dispersed to Norway and Sweden (Wallentinus in press). It can survive a wide range of climatic conditions as demonstrated by its natural and invasive distributions. Like *O. sinensis*, *C. wailesii* has become an important part of the winter diatom assemblage around Britain since its invasion (Boalch 1987). The method of introduction to Europe is unknown but ballast water transport cannot be ruled out (Rincé & Paulmier 1986).

3.4.22.2 Potential impacts

This species can reach high numbers in European waters and is known to produce large amounts of mucilage that can accumulate insoluble skeletons of planktonic organisms and mineral particles. These particles subsequently increase the density of the mucus and cause it to blanket the seabed. This could potentially bury benthic marine organisms and interfere with filter feeders. Additionally, the heavy mucus slime has been observed to clog or damage fishing trawls and even with extensive cleaning and drying may never be completely removed (Boalch & Harbour 1977).

3.4.23 Codium fragile **ssp.** *tomentosoides* **(Oyster thief)**

3.4.23.1 Invasion potential

This marine alga, originally from the Asian Pacific region (Provan et al. 2005), has successfully invaded Africa, the Australasia-Pacific region, Europe (including the North and Baltic seas), North America, and South America. This species can tolerate wide variations in salinity and temperature enabling invasion of many environments and habitats such as tide pools, wave-swept intertidal shores, and man-made structures (Begin & Scheibling 2003). In particular, *C. fragile* seems to thrive in harbours and bays, which may facilitate its transport by human dispersal mechanisms. Several dispersal mechanisms have been noted for this species including aquaculture (shellfish), and ship hull fouling (Begin & Scheibling 2003). Its invasion of the northwest Atlantic is thought to have resulted from transport by European ships (Begin &

Scheibling 2003). Invasion success of this species can also be attributed to various life history characteristics and physiological ecology including various modes of reproduction.

3.4.23.2 Potential impacts

C. fragile has had serious environmental and economic impacts where introduced. One of the most detrimental effects of this alga is fouling of shellfish beds (Trowbridge 1999). They can smother mussels and scallops by preventing opening of the valve. They can also increase local sedimentation rates and, due to its low-lying profile, obstruct movements of large benthic invertebrates (Benthic Ecology Lab 2001). If this alga were to replace kelp beds, species that normally occupy the understory habitat beneath the canopy would likely be negatively affected.

3.4.24 Prorocentrum minimum

3.4.24.1 Invasion potential

Though the specific origin of this marine dinoflagellate is unknown, it was first observed in Europe in 1976 and is believed to be highly invasive in the North and Baltic seas and Scandinavia (Olenina 2004). It appears to be tolerant of a variety of environmental conditions. Dispersal is known to occur in ballast water and sediments (Hajdu et al. 2000)

3.4.24.2 Potential impacts

Blooms of *P. minimum* cause reddish-brown or mahogany tides and have been reported to have toxic, harmful effects on benthic marine invertebrates, particularly shellfish (Steidinger & Tangen 1996). High biomass during blooms may also locally reduce oxygen resulting in fish and invertebrate kills.

3.5 HUDSON BAY, AN INVASION COLDSPOT, AND POTENTIAL IMPACTS OF CLIMATE CHANGE ON AIS INVASIONS INTO THE HUDSON BAY REGION

The present climate of Hudson Bay near estuaries of the Churchill and Nelson rivers, particularly the relatively low maximum and the small range in water temperatures (tables 6 and 7) compared to most, if not all, potential source regions, is the primary barrier preventing successful invasion of many aquatic species listed in Table 5. Lake Superior can serve as a useful comparison to evaluate the effect of current water temperature regimes of the Churchill area on the potential invasion and establishment of AIS. As the largest and northernmost of the Great Lakes, Lake Superior has fewer AIS than the lower Great Lakes despite the fact that it receives disproportionately more ballast water discharges (Grigorovich et al. 2003b). Grigorovich et al. (2003c) suggested that one possible explanation might be the much colder open water temperatures (rarely higher than 12°C) in Lake Superior relative to most source regions and to the lower Great Lakes. Several species of AIS that require slightly warmer temperatures for survival or reproduction (e.g., *Potamopyrgus antipodarum*, *Echinogammarus ischnus*, and *Dreissena polymorpha*) are found in Lake Superior but only in shallow regions and estuaries where local temperatures warm significantly during summer (Grigorovich et al. 2003c). For example, although adult *D. polymorpha* can survive temperatures ranging from 2-30°C, and could therefore theoretically survive in the Churchill region, larval development of this species requires temperatures from 12-24°C (Ricciardi 1998). Temperatures at the lower end of this range are only reached in the Churchill and Nelson river estuaries for relatively short periods of time and these conditions are likely to prevent establishment of a successfully reproducing population of *D. polymorpha*. In contrast, the quagga mussel can spawn and proliferate at lower temperatures (Claxton and Mackie 1998; Vanderploeg et al. 2002) and is far more likely to invade given the current environmental regime in the Churchill region (see Section 3.4.11).

Climate change models have predicted an increase in mean annual air temperature of 2-5°C with higher latitudes potentially incurring increases as high as 8°C (Manabe & Wetherald 1980; Maarouf 1985; Boer et al. 1992). Resulting increases in water temperatures by only a few degrees could have significant and potentially severe, negative impacts to aquatic ecosystems. Northward range expansion of native and currently established exotics in North America could be expected from increased temperatures. In addition, a large increase in the number of new exotics invading not only the Great Lakes but also areas further north such as Churchill can be expected. Mandrak (1989) predicted range extensions of 21 species of fish into the Great Lakes region with an increase of annual water temperatures by only a few degrees. Climate warming is expected to make the Great Lakes ecosystem more hospitable for additional exotic species, many of which could negatively affect the already impacted indigenous fish fauna (Regier et al. 1996).

Range expansion of native taxa and already introduced taxa as a result of climate change is also expected to have some severe ecological consequences. For example, northward expansions of both native (smallmouth bass, *Micropterus dolomeiu*) and exotic species (carp, *Cyprinus carpio*) are expected in Ontario and would likely profoundly alter species composition in many ecosystems (Minns & Moore 1995). Jackson & Mandrak (2002) predicted that as many as 25,000 populations of four cyprinid species in Ontario may be extirpated with climate change and expanding range of smallmouth bass. Meisner et al. (1987) predict climate change would allow range extensions of cyprinids, esocids, centrarchids, and ictalurids concurrent with shrinking populations of salmonines and coregonines. Changes are also expected for phytoplankton and invertebrate communities. Phyto- and zooplankton biomasses are expected to increase with more complex community interactions and increased invasiveness of exotics occurring with increasing average temperatures (Magnuson et al. 1997; Schindler 1997). This would include already established exotics and future invaders. Salinities in estuarine environments could also change with reduced freshwater input from rivers. There could be adverse biological effects on estuarine habitat including increased risk of invasion of certain species (Coutant 1981).

Climate change and increasing water temperatures in the north would remove the only barrier preventing successful invasion of several species that require only slightly warmer average temperatures for survival and/or reproduction. For example, there are several species in Table 5 currently considered at medium risk of invasion that are only limited by average temperatures that are slightly colder than needed for certain physiological processes or for survival of certain life cycle stages. Should local temperatures increase by only a few degrees due to climate change, several additional species could be considered as high-risk invaders (e.g., *P. antipodarum*, *E. ischnus*, *D. polymorpha*, *Crepidula fornicata*, *Styela clava*, *Obesogammarus crassus*, *Evadne anonyx*, *Nitokra* spp.). In addition, it is unlikely that an increase in temperature by only a few degrees would impose a barrier to invasion by those species currently considered high risk since they can all tolerate wide variations in temperature. Warming temperatures would only increase the number of potential invaders into Hudson Bay.

4.0 REFERENCES AND CONTACTS

4.1 CONTACTS

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4.2 WEB SOURCES (EACH ACCESSED MULTIPLE TIMES IN JANUARY AND FEBRUARY 2006)

Baltic Alien Species Database - http://www.ku.lt/nemo/mainnemo.html

FIGIS (Fisheries Global Information System) - http://www.fao.org/figis/servlet/static?dom=root&xml=introsp/introsp_search.xml

Global Invasive Species Database - http://www.issg.org/database/welcome/

Great Lakes Nonindigenous Aquatic Species List - http://www.glerl.noaa.gov/res/Programs/invasive/

Institute for Biological Invasions - http://invasions.bio.utk.edu/Default.htm

ITIS (Integrated Taxonomic Information System) - http://www.itis.usda.gov/

Invasive Species in the Great Lakes Region - http://www.great-lakes.net/envt/flora-fauna/invasive/invasive.html

NEMESIS (National Exotic Marine and Estuarine Species Information System) - http://invasions.si.edu/nemesis/index.html

NEOCOA - http://www.neocoa.de.

NOBANIS (Northern European and Baltic Network on Invasive Alien Species) - http://www.artportalen.se/nobanis/

Regional Biological Invasions Centre - http://www.zin.ru/rbic/

SGNIS (Sea Grant Nonindigenous Species) - http://www.sgnis.org/

4.3 REFERENCES

Aguirre, W. and Poss, S. G. 1999. Non-indigenous species in the Gulf of Mexico ecosystem: *Corbicula fluminea* (Muller, 1774). Gulf States Marine Fisheries Commission (GSMFC).

Anger, K. 1991. Effects of temperature and salinity on the larval development of the Chinese mitten crab *Eriocheir sinensis* (Decapoda: Grapsidae). Mar. Ecol. Prog. Ser. 72: 103-110.

Anonymous. 1988. Whirling disease management in North America: an emergency conference, Denver, Colorado, 12-14 April 1988. Fish Disease Subcommittee, Colorado River Wildlife Council.

Atkins, S.M., Jones, A.M., and Garwood, P.R. 1987. The ecology and reproductive cycle of a population of *Marenzelleria viridis* (Annelida: Polychaeta: Spionidae) in the Tay Estuary. Proc. R. Soc. Edinburgh 92B: 311-322.

Bacescu, M. 1969. Order Mysidacea. *In*: Opredelitel fauny Chernogo i Azovskogo morey (Key of Black Sea and Sea of Azov fauna). Kiev: Naukova dumka Publ., 2, p. 363-381.

Bailey, R.M. and Smith, G.R. 1981. Origin and geography of the fish fauna of the Laurentian Great Lakes basin. Can. J. Fish. Aquat. Sci. 38: 1539-1561.

Bailey, S.A., Duggan, I.C., van Overdijk, C.D.A., Jenkins, P.T., and MacIsaac, H.J. 2003. Viability of invertebrate diapausing eggs collected from residual ballast sediment. Limnol. Oceanogr. 48: 1701-1710.

Bailey, S.A., Duggan, I.C., van Overdijk, C.D.A., Johengen, T.H., Reid, D.F., and MacIsaac, H.J. 2004. Salinity tolerance of diapausing eggs of freshwater zooplankton. Fresh. Biol. 49: 286-295.

Bailey, S.A., Nandakumar, K., Duggan, I.C., van Overdijk, C.D.A., Johengen, T.H., Reid, D.F., and MacIsaac, H.J. 2005a. In situ hatching of invertebrate diapausing eggs from ships' ballast sediment. Diversity Distrib. 11: 453-460.

Bailey, S.A., Duggan, I.C., Jenkins, P.T., and MacIsaac, H.J. 2005b. Invertebrate resting stages in residual ballast sediment of transoceanic ships. Can. J. Fish. Aquat. Sci. 62: 1090-1103.

Bailey, S.A., Reid, D.F., Colautti, R.I., Therriault, T., and MacIsaac, H.J. (in press a). Management options for control of nonindigenous species in the Great Lakes. Tol. J. Great Lakes L., Sci. & Pol'y.

Bailey, S.A., Nandakumar, K., and MacIsaac, H.J. (in press b). Does saltwater flushing reduce viability of diapausing eggs in ship ballast sediment? Diversity Distrib. 11: 000-000.

Baker, R.F. 1989. An environmental assessment and biological investigation of the Nelson River Estuary. North/South Consultants Inc., Winnipeg, MB. 160 pp.

Baker, R.F. 1990. A fisheries survey of the Nelson River Estuary, August 1989. North/South Consultants Inc., Winnipeg, MB. 26 pp.

Baker, R.F. 1996. Abundance and species composition of zooplankton of the Nelson River Estuary in relation to depth, tide and location July 1995-Year I. North/South Consultants Inc., Winnipeg, MB. 61 pp.

Baker, R.F., Lawrence, M.J., and Schneider, F. 1993. Oceanography and mid-summer distribution and abundance of plankton and fish in the Nelson River Estuary, Hudson Bay. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 67 pp.

Baker, R.F., Lawrence, M.J., and Schneider-Vieira, F. 1994. Physical and chemical oceanography and aquatic biota of the Churchill River Estuary, August, 1993. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 81 pp.

Balcom, N.C. 1994. Aquatic Immigrants of the Northeast, No. 4: Asian Clam, *Corbicula fluminea*. Connecticut Sea Grant College Program.

Ball, I.R. 1969. *Dugesia lugubris* (Tricladida: Paludicola), a European immigrant into North American fresh waters. J. Fish. Res. Board Can. 26: 221-228.

Barton, D.R. and Griffiths, M. 1984. Benthic invertebrates of the nearshore zone of eastern Lake Huron, Georgian Bay and North Channel. J. Great Lakes Res. 10: 407-416.

Begin, C. and Scheibling, R. E. 2003. Growth and survival of the invasive green alga *Codium fragile* ssp. *tomentosoides* in tide pools on a rocky shore in Nova Scotia. Botanica Marina 46: 404-412.

Bekman, M.Y. and Bazikalova, A.Y. 1951. Biology and production capability of some Baikalian and Siberian amphipods. Proc. Them. Meet. 1: 61-67.

Benoit H.P., Johannsson O.E., Warner D.M., Sprules W.G., and Rudstam L.G. 2002. Assessing the impact of a recent predatory invader: the population dynamics, vertical distribution, and potential prey of *Cercopagis pengoi* in Lake Ontario. Limnol. Oceanogr. 47: 626-635.

Benthic Ecology Lab. 2001. *Codium fragile* ssp. *tomentosoides* (Dead Man`s Fingers). Dalhousie University: Marine Invasive Species in Nova Scotia. Summary: Available from: http://myweb.dal.ca/rescheib/codium.html

Berezina, N.A. and Panov, V.E. 2003. Establishment of new gammarid species in the eastern Gulf of Finland (Baltic Sea) and their effects on littoral communities. Proc. Estonian Acad. Sci. Biol. Ecol. 52: 284-304.

Berezina, N.A. and Panov, V.E. 2004. Distribution, population structure and salinity resistance of the invasive amphipod *Gmelinoides fasciatus* (Stebbing) in the Neva Estuary (Gulf of Finland, Baltic Sea). Hydrobiol. 514: 199-206.

Berezina, N.A., Khlebovich, V.V., Panov, V.E., and Zaporozhec, N.V. 2001. Salinity resistance of the amphipod *Gmelinoides fasciatus* (Stebb.), introduced into the Gulf of Finland (Baltic Sea) basin. Rep. Acad. Sci. 3

Berg, D.J. and Garton, D.W. 1988. Seasonal abundance of the exotic predatory cladoceran, *Bythotrephes cederstroemi*, in western Lake Erie. J. Great Lakes Res. 14: 479-488.

Berg, D.J., Garton, D.W., MacIsaac, H.J., Panov, V.E., and Telesh, I.V. 2002. Changes in genetic structure of North American *Bythotrephes* populations following invasion from Lake Ladoga, Russia. Fresh. Biol. 47: 275-282.

Bergman, E. 1987. Temperature-dependent differences in foraging ability of two percids, *Perca fluviatilis* and *Gymnocephalus cernuus*. Envir. Biol. Fish. 19: 45-53.

Bernhardt, W.J. 1995. Spring and fall fisheries investigations of five tributaries to the lower Churchill River, 1994. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 146 pp.

Bernhardt, W.J. and Holm, J. 2005. Lower Churchill River water level enhancement weir project post-project monitoring: Fish population responses to operation of the project Year IV, 2002. A report prepared for Manitoba Hydro by North/South Consultants Inc. 100 pp.

Bernhardt, W.J. and Neufeld, L.J. 2002. Lower Churchill River water level enhancement weir project post-project monitoring: an assessment of invertebrate responses to operation of the project, Year III, 2001. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 100 pp.

Bernhardt, W.J., Baker, R.F., and Graveline, P.G. 1992. A fisheries survey of the Nelson River mainstem near Angling River 1991. North/South Consultants Inc., Winnipeg, MB. 32 pp.

Bick, A. 2005. A new Spionidae (Polychaeta) from North Carolina, and a redescription of *Marenzelleria wireni* Augener, 1913, from Spitsbergen, with a key for all species of *Marenzelleria*. Helgoland Mar. Res. 59: 265-272.

Bij de Vaate, A., Jazdzewski, K., Ketelaars, H.A.M., Gollasch, S., and Van der Velde, G. 2002. Geographical patterns in range extension of Ponto-Caspian macroinvertebrate species in Europe. Can. J. Fish. Aquat. Sci. 59: 1159-1174.

Birshtein Y.A., Vinogradov L.G., Kondakov N.N., Astakhova M.S., and Romanova N.N. (eds.) 1968. Atlas of Invertebrates of the Caspian Sea. Pishchevaya Promyshlennost, Moscow: 413 pp.

Boalch, G.T. 1987. Changes in the phytoplankton of the western English Channel in recent years. Brit. Phycol. J. 22: 225-235.

Boalch, G.T. and Harbour, D.S. 1977. Unusual diatom off the coast of south-west England and its effect on fishing. Nature 269: 687-688.

Boer, G.J., McFarlane, N.A., and Lazare, M. 1992. Greenhouse gas-induced climate change simulated with the CCC second-generation general circulation model. J. Climate 5: 1045-1077.

Branstrator, D.K. 1995. Ecological interactions between *Bythotrephes cederstroemi* and *Leptodora kindtii* and the implications for species replacement in Lake Michigan. J. Great Lakes Res. 21: 670-679.

Bretecher, R.L. and MacDonell, D.S. 1998. A fisheries investigation of the Lower Nelson River 1997. North/South Consultants Inc., Winnipeg, MB. 11 pp.

Bruijs, M.C.M., Kelleher, B., Van der Velde, G., and Bij de Vaate, A. 2001. Oxygen consumption, temperature and salinity tolerance of the invasive amphipod *Dikerogammarus villosus*: indicators of further dispersal via ballast water transport. Arch. Hydrobiol. 152: 633-646.

Brylinski, J.M. 1981. Reports on the presence of *Acartia tonsa* Dana (Copepoda) in the area of Dunkirk and its geographical distribution in Europe. J. Plank. Res. 3: 255-261.

Bur, M.T., Klarer, D.M., and Krieger, K.A. 1986. First records of a European cladoceran, *Bythotrephes cederstroemi*, in Lakes Erie and Huron. J. Great Lakes Res. 12: 144-146.

Buschbaum, C. and Gutow, L. 2005. Mass occurrence of an introduced crustacean (*Caprella* cf. *mutica*) in the south-eastern North Sea. Helgoland Mar. Res. 59: 252-253.

Cáceres, C.E. 1997. Dormancy in invertebrates. Invertebr. Biol. 116: 371-383.

Carlton, J.T. and Geller, J.B. 1993. Ecological roulette: the global transport of nonindigenous marine organisms. Science 261: 78-82.

Caskey, R.R. and Remnant, R.A. 2002. Lower Churchill River water level enhancement weir project post-project monitoring: fish use of the Goose Creek Enhancement Reach, Year III, 2001. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 41 pp.

Clarke, A.H. 1981. The freshwater molluscs of Canada. National Museums of Canada, Ottawa. 446 pp.

Claxton, W.T. and Mackie, G.L. 1998. Seasonal and depth variations in gametogenesis and spawning of *Dreissena polymorpha* and *Dreissena bugensis* in eastern Lake Erie. Can. J. Zool. 76: 2010-2019.

Cohen, A.N. and Carlton, J.T. 1995. Nonindigenous aquatic species in a United States estuary: a case study of the biological invasions of the San Francisco Bay and delta. A Report for the United States Fish and Wildlife Service, Washington, DC and The National Sea Grant College Program Connecticut Sea Grant Program, 272 pp.

Cohen, A.N. and Carlton, J.T. 1998. Accelerating invasion rate in a highly invaded estuary. Science 279: 555-558.

Colautti, R.I. and MacIsaac, H.J. 2004. A neutral terminology to define ‘invasive’ species. Diversity Distrib. 10: 135-141.

Colautti, R.I., Niimi, A.J., van Overdijk, C.D.A., Mills, E.L., Holeck, K., and MacIsaac, H.J. 2003. Spatial and temporal analysis of transoceanic shipping vectors to the Great Lakes. *In*: Ruiz, G. and Carlton, J.T. (eds.). Invasive species: vectors and management strategies. Island Press. pp. 227-246.

Colautti, R.I., Bailey, S.A., van Overdijk, C.D.A., Amundsen, K., and MacIsaac, H.J. 2006. Characterised and projected costs of nonindigenous species in Canada. Biol. Invasions 8: 45-59.

Cone, D., Eurell T., and Beasley, V. 1994. A report of *Dactylogyrus amphibothrium* (Monogenea) on the gills of European ruffe in western Lake Superior. J. Parasitol. 80: 476-478.

Conover, R.J. 1957. Notes on the seasonal distribution of zooplankton in Southampton Water with special reference to the genus *Acartia*. Ann. Mag. Nat. Hist. 12th Ser. 10: 63-67.

Cordell, J.R., Morgan, C.A., and Simenstad, C.A. 1992. Occurrence of the Asian calanoid copepod *Pseudodiaptomus inopinus* in the zooplankton of the Columbia River estuary. J. Crustacean Biol. 12: 260-269.

Coutant, C.C. 1981. Foreseeable effects of CO2 –induced climatic change: freshwater concerns. Env. Conser. 8: 285-297.

Cudmore-Vokey, B. and Crossman, E.J. 2000. Checklists of the fish fauna of the Laurentian Great Lakes and their connecting channels. Can. MS Rep. Fish. Aquat. Sci. No. 2550.

Czaika, S.C. 1978. Crustacean zooplankton of southwestern Lake Ontario in spring 1973 and at the Niagara and Genesee River mouth areas in 1972 and spring 1973. J. Great Lakes Res. 4: 1-9.

Dechtiar, A.O. 1965. Preliminary observations on *Glugea hertwigi*, Weissenberg, 1911 (Microsporidia; Glugeidae) in American smelt, *Osmerus mordax* (Mitchill), from Lake Erie. Can. Fish. Cult. 34: 35-38.

Deevey, E.S., Jr. and Deevey, G.B. 1971. The American species of *Eubosmina* Seligo (Crustacea, Cladocera). Limnol. Oceanogr. 16: 201-218.

De Melo, R. and Hebert, P.D.N. 1994. A taxonomic reevaluation of North American Bosminidae. Can. J. Zool. 72: 1808-1825.

Dick, J.T.A. and Platvoet, D. 2000. Invading predatory crustacean *Dikerogammarus villosus* eliminates both native and exotic species. Proc. R. Soc. Lond. Biol. Sci. 267: 977-983.

Dick, J.T.A. and Platvoet, D. 2001. Predicting future aquatic invaders; the case of *Dikerogammarus villosus*. Aquat. Nuisance Species Dig. 4: 25-27.

Duggan. I.C., van Overdijk, C.D.A., Bailey, S.A., Jenkins, P.T., Limen, H., and MacIsaac, H.J. 2005. Invertebrates associated with residual ballast water and sediments of cargo-carrying ships entering the Great Lakes. Can. J. Fish. Aquat. Sci. 62: 2463-2474.

Edlund, M.B., Taylor, S.M., Schelske, C.L., and Stoermer, E.F. 2000. *Thalassiosira baltica* (Grunow) Ostenfeld (Bacillariophyta), a new exotic species in the Great Lakes. Can. J. Fish. Aquat. Sci. 57: 610-615.

Essink, K. and Kleef, H.L. 1993. Distribution and life cycle of the North American spionid polychaete *Marenzelleria viridis* in the Ems estuary. Netherl. J. Aquat. Ecol. 27: 237-246.

Evans, M.S. 1988. *Bythotrephes cederstroemi*: its new appearance in Lake Michigan. J. Great Lakes Res. 14: 234-240.

Fago, D. 1993. Skipjack herring, *Alosa chrysochloris*, expanding its range into the Great Lakes. Can. Field-Nat. 107: 352-353.

Farara, D.G. and Erseus, C. 1991. *Phallodrilus aquaedulcis* Hrabe, 1960, a meiobenthic freshwater oligochaete (Tubificidae) previously known only from Europe, recorded from the Niagara River, North America. Can. J. Zool. 69: 291-294.

Fazakas, C.R. and Remnant, R.A. 1997. Fish utilization of the lower Churchill River mainstem, Year II, 1996. A report prepared for Manitoba Hydro by North/South Consultants Inc. 93 pp.

Fazakas, C.R., Schneider-Vieira, F., and Bretecher, R.L. 1997. Invertebrates of the lower Churchill River and Goose Creek, Year II, 1996. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 63 pp.

Ferguson, M.M. 1990. The genetic impact of introduced fishes on native species. Can. J. Zool. 68: 1053-1057.

Folino, N.C. 1999. The freshwater expansion and classification of the colonial hydroid *Cordylophora* (Phylum Cnidaria, Class Hydrozoa). Mar. Bioinvasions. Proc. First Nat. Conf. p. 139-144.

Franzin, W.G., Barton, B.A., Remnant, R.A., Wain, D.B., and Pagel, S.J. 1994. Range extension, present and potential distribution, and possible effects of rainbow smelt in Hudson Bay drainage waters of northwestern Ontario, Manitoba, and Minnesota. N. Amer. J. Fish. Manag. 14: 65-76.

Fuller, P.L., Nico, L.G., and Williams, J.D. 1999. Nonindigenous fishes introduced into inland waters of the United States. Am. Fish. Soc., Spec. Publ. No. 27, Bethesda, Md.

Gaboury, M.N. 1980. A report on the 1979 study of brook trout (*Salvelinus fontinalis*) populations in the lower Nelson River system. Man. Dep. Nat. Res., Winnipeg, MB. MS report 80-23: 52 pp.

Galarowicz, T. and Cochran, P.A. 1991. Response by the parasitic crustacean *Argulus japonicus* to host chemical cues. J. Freshwat. Ecol. 6: 455-456.

Garton, D.W. and Haag, W.R. 1991. Heterozygosity, shell length and metabolism in the European mussel, *Dreissena polymorpha*, from a recently established population in Lake Erie. Comp. Biochem. Physiol. A Comp. Physiol. 99: 45-48.

Geitler, O., Homma, S., and Kinzelbach, R. 2002. Bestandsaufnahme und Bewertung von Neozoen in Deutschland. Umweltbundesamt, Berlin, UBA Texte 25/02. 290 pp.

Gollasch, S. 1999. Current status on the increasing abundance of the Chinese mitten crab *Eriocheir sinensis* H. Milne Edwards, 1854 in German rivers. Proc. First Ann. Meeting Chinese mitten crab in California. 23 March, Sacramento, CA.

Gorokhova, E., Aladin, N., and Dumont, H. 2000. Further expansion of the genus *Cercopagis* (Crustacea, Branchiopoda, Onychopoda) in the Baltic Sea, with notes on the taxa present and their ecology. Hydrobiol. 429: 207-218.

Gozlan, R.E., St-Hilaire, S., Feist, S.W., Martin, P., and Kent, M.L. 2005. Disease threat to European fish. Nature 435: 1046.

Grigorovich, I.A. and Shevtsova, L.V. 1995. Effect of *Dreissena* mussels on the distribution of zooplankton as exemplified by the main Kakhovka Canal. Proc. Fifth Inter. Zebra Mussel and Other Aquat. Nuisance Organisms Conf., Toronto, Canada, February 1995.

Grigorovich, I.A. and MacIsaac, H.J. 1999. First record of *Corophium mucronatum* Sars (Crustacea: Amphipoda) in the Great Lakes. J. Great Lakes Res. 25: 401-405.

Grigorovich, I.A., Pashkova, O.V., Gromova, Y.F., and van Overdijk, C.D.A. 1998. *Bythotrephes longimanus* in the Commonwealth of Independent States: variability, distribution and ecology. Hydrobiol. 379: 183-198.

Grigorovich, I.A., Dovgal, I.V., MacIsaac, H.J., and Monchenko, V.I. 2001. *Acineta nitocrae*: a new suctorian epizooic on non-indigenous harpacticoid copepods, *Nitocra hibernica* and *N. incerta*, in the Laurentian Great Lakes. Arch. Hydrobiol. 152: 161-176.

Grigorovich, I.A., Korniushin, A.V., Gray, D.K., Duggan, I.C., Colautti, R.I., and MacIsaac, H.J. 2003a. Lake Superior: an invasion cold spot? Hydrobiol. 499: 191-210.

Grigorovich, I.A., Therriault, T.W., and MacIsaac, H.J. 2003b. History of aquatic invertebrate invasions in the Caspian Sea. Biol. Invasions 5: 103-115.

Grigorovich, I.A., Colautti, R.I., Mills, E.L., Holeck, K., Ballert, A.G., and MacIsaac, H.J. 2003c. Ballast-mediated animal introductions in the Laurentian Great Lakes: retrospective and prospective analyses. Can. J. Fish. Aquat. Sci. 60: 740-756.

Groves, R.H. and Burdon, J.J. (eds). 1986. Ecology of biological invasions. Cambridge University Press, New York.

Gunderson, J.L., Klepinger, M.R., Bronte, C.R., and Marsden, J.E. 1998. Overview of the International Symposium on Eurasian ruffe (*Gymnocephalus cernuus*) biology, impacts, and control. J. Great Lakes Res. 24: 165-169.

Haag, W.R., Berg, D.J., Garton, D.W., and Farris, J.L. 1993. Reduced survival and fitness in native bivalves in response to fouling by the introduced zebra mussel (*Dreissena polymorpha*) in western Lake Erie. Can. J. Fish. Aquat. Sci. 50: 13-19.

Hairston, N.G. Jr., Perry, L.J., Bohonak, A.J., Fellows, M.Q., Kearns, C.M., and Engstrom, D.R. 1999. Population biology of a failed invasion: paleolimnology of *Daphnia exilis* in upstate New York. Limnol. Oceanogr. 44: 447-486.

Hajdu, S., Edler, L., Olenina, I., and Witek, B. 2000. Spreading and establishment of the potentially toxic dinoflagellate *Prorocentrum minimum* in the Baltic Sea. Internat. Rev. Hydrobiol. 85: 561-575.

Harvey, M., Therriault, J-C., and Simard, N. 2001. Hydrodynamic control of late summer species composition and abundance of zooplankton in Hudson Bay and Hudson Strait (Canada). J. Plankton Res. 23: 481-496.

Hebert, P.D.N., Muncaster, B.W., and Mackie, G.L. 1989. Ecological and genetic studies on *Dreissena polymorpha* (Pallas): a new mollusc in the Great Lakes. Can. J. Fish. Aquat. Sci. 46: 1587-1591.

Hoffman, G.L. and G. Schubert. 1984. Some parasites of exotic fishes. *In*: W.R. Courtenenay, Jr. and J.R. Stauffer, Jr. (eds.), Distribution, biology, and management of exotic fishes. John Hopkins University Press, Baltimore, MD. p. 233-261.

Holeck, K.T., Mills, E.L., MacIsaac, H.J., Dochoda, M.R., Colautti, R.I., and Ricciardi, A. 2004. Bridging troubled waters: biological invasions, transoceanic shipping, and the Laurentian Great Lakes. Bioscience 54: 919-929.

Holm, E. and Coker, G.A. 1981. First records of the ghost shiner (*Notropis buchanani*) and the orangespotted sunfish (*Lepomis humilis*). Can. Field-Nat. 95: 210-211.

Holm, E. and Hamilton, J.G. 1988. Range extension for the fourspine stickleback, *Apeltes quadracus*, to Thunder Bay, Lake Superior. Can. Field-Nat. 102: 653-656.

Horne, B. 1997. Abundance and species composition of zooplankton in the Nelson River Estuary: baseline monitoring program 1996 - Year I. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 68 pp.

Horne, B. and Bretecher, R.L. 1998. Abundance and species composition of zooplankton in the Nelson River Estuary: baseline monitoring program 1997 - Year II. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 67 pp.

Horvath, T.G., Whitman, R.L., and Last, L. 2001. Establishment of two invasive crustaceans (Copepoda: Harpacticoida) in the nearshore sands of Lake Michigan. Can. J. Fish. Aquat. Sci. 58: 1261-1264.

Hrabik, T.R., Magnuson, J.J., and McLain, A.S. 1998. Predicting the effects of rainbow smelt on native fishes in small lakes: evidence from long-term research on two lakes. Can. J. Fish. Aquat. Sci. 55: 1364-1371.

Hudson, P.L. and Bowen II, C.A. 2002. First record of *Neoergasilus japonicus* (Poecilostomatoida: Ergasilidae), a parasitic copepod new to the Laurentian Great Lakes. J. Parasitol. 88: 657-663.

Hudson, P.L., Reid, J.W., Lesko, L.T., and Selgeby, J.H. 1998. Cyclopoid and harpactacoid copepods of the Laurentian Great Lakes. Bulletin of the Ohio Biological Survey (New Ser.), 12: 1-50.

Internationale Kommission Zum Schutz Des Rheins (IKSR). 2002. Das Makrozoobenthos des Rheins 2000. Bericht Nr. 128-d.doc. 46 pp.

Jackson, D.A. and Mandrak, N.E. 2002. Changing fish biodiversity: predicting the loss of cyprinid biodiversity due to global climate change. *In*: N.A. McGinn (ed). Fisheries in a Changing Climate. American Fisheries Society Symposium 32. American Fisheries Society, Bethesda, MD. pp. 89-98

Janech, M.G. and Hunter, R.D. 1995. *Corbicula fluminea* in a Michigan River: implications for low temperature tolerance. Malacol. Rev. 28: 119-124.

Jansson, K. 1994. Alien species in the marine environment. Introductions to the Baltic Sea and the Swedish west coast. Solna, Swed. Envir. Prot. Agency, 68 pp.

Jarnagin, S.T., Swan, B.K., and Kerfoot, W.C. 2000. Fish as vectors in the dispersal of *Bythotrephes cederstroemi*: diapausing eggs survive passage through the gut. Fresh. Biol. 43: 579-589.

Jazdzewski, K. 1980. Range extension of some gammaridean species in European inland waters caused by human activity. Crustaceana Suppl. 6: 84-107.

Jazdzewski, K., Konopacka, A., and Grabowski, M. 2004. Recent drastic changes in the gammarid fauna (Crustacea, Amphipoda) of the Vistula River deltaic system in Poland caused by alien invaders. Diversity Distrib. 10: 81-87.

Johnston, T.A., Leggett, W.C., Bodaly, R.A., and Swanson, H.K. 2003. Temporal changes in mercury bioaccumulation by predatory fishes of boreal lakes following the invasion of an exotic forage fish. Environ. Tox. Chem. 22: 2057-2062.

Josefsson, M. and Andersson, B. 2001. The environmental consequences of alien species in the Swedish lakes Malären, Hjälmaren, Värnern and Vättern. Ambio 30: 514-521.

Jude, D.J., Janssen, J., and Crawford, G. 1992. Ecology, distribution, and impact of the newly introduced round (and) tubenose gobies on the biota of the St. Clair and Detroit rivers. *In:* Munawar, M., Edsall, T., and Leach, J. (eds.), The Lake Huron ecosystem: ecology, fisheries and management. SPB Publishing, Amsterdam. pp. 447-460.

Kerr, S.J., Brousseau, C.S., and Muschett, M. 2005. Invasive aquatic species in Ontario: a review and anlaysis of potential pathways for introduction. Fisheries 30: 21-30.

Ketelaars, H.A.M. and van Breemen, W.C.A. 1993. The invasion of the predatory cladoceran *Bythotrephes longimanus* Leydig and its influence on the plankton communities in the Biesbosch reservoirs. Verh. Internat. Verein. Limnol. 25: 1168-1175.

Koste, W. and Sheil, R.J. 1989. Rotifera from the Australian inland waters, 3. Euchlanidae, Mytilinidae, and Trichotriidae (Rotifera: Monogononta). Trans. R. Soc. S. Aust. 113: 85-114.

Kotta, J., Orav-Kotta, H., and Kotta, I. 2003. Effects of the introduced polychaete (*Marenzelleria viridis*) on the simple ecosystem of the northern Baltic Sea. Proc. Third Int. Conf. Mar. Bioinv., La Jolla, California, March 16-19, 2003, p. 74.

Kowarik, I. 2003. Biologische Invasionen: Neophyten und Neozoen in Mitteleuropa. Stuttgart, Germany, Ulmer. 380 pp.

Kroeker, K. 1992. Brook trout stream utilization. Lower Nelson River Tributaries Study. North/South Consultants Inc., Winnipeg, MB. 46 pp.

Kurashova, E.K. and Tinenkova, D.H. 1988. Abundance, biomass and distribution of the colonizer *Acartia clausi* Giesbrecht (Calanoida, Acartiidae) in the Northern and Middle Caspian. Hydrobiol J. 24: 23-27.

Lange, C. and Cap, R. 1986. *Bythotrephes cederstroemi* (Schödler), (Cercopagidae: Cladocera): a new record for Lake Ontario. J. Great Lakes Res. 12: 142-143.

Lappalainen, J. and Kjellman, J. 1998. Ecological and life history characteristics of ruffe (*Gymnocephalus cernuus*) in relation to other freshwater fish species J. Great Lakes Res. 24: 228-234.

Lasee, B.A., Sutherland, D.R., and Moubry, M.E. 1988. Host-parasite relationships between burbot (*Lota lota*) and adult *Salmincola lotae* (Copepoda). Can. J. Zool. 66: 2459-2463.

Lawrence, M.J. and Baker, R.F. 1995. Biological survey of the Churchill River Estuary, July, 1994. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 30 pp.

Leppäkoski E. 1999. *Balanus improvisus* (Darwin 1854), Balanidae, Cirripedia. *In*: Gollasch, S., Minchin, D., Rosenthal, H., and Voigt, M. (eds) Exotics across the ocean. Case histories on introduced species: their general biology, distribution, range expansion and impact. University of Kiel, Germany, p. 49-54.

Leppäkoski, E. and Olenin, S. 2000. Non-native species and rates of spread: lessons from the brackish Baltic Sea. Biol. Invasions 2: 151-163.

Leppäkoski, E., Gollasch, S., and Olenin, S. 2002. The Baltic Sea - a field laboratory for invasion biology. *In*: Leppakoski, E., Gollasch, S. and Olenin, S. (eds) Invasive Aquatic species of Europe - distribution impacts and management. Kluwer Academic Publishers, Dordrecht, Boston, London. p. 253-259.

Locke, A., Reid, D.M., van Leeuwen, H.C., Sprules, W.G., and Carlton, J.T. 1993. Ballast water exchange as a means of controlling dispersal of freshwater organisms by ships. Can. J. Fish. Aquat. Sci. 50: 2086-2093.

Lodge, D.M. 1993. Biological invasions: lessons for ecology. Trends Ecol. Evol. 8: 133-137.

Lozon, J.D. and MacIsaac, H.J. 1997. Biological invasions: are they dependent on disturbance? Environ. Rev. 5: 131-144.

Maarouf, A.R. 1985. Carbon dioxide effects on climate with emphasis on climate model results for Canada. Canadian Climate Centre, Canadian Atmospheric Environment Service, Downsview, Ontario, Canada.

MacDonald, J.E. and Remnant, R.A. 2003. Lower Churchill River water level enhancement weir project post-project monitoring: fish use of the Goose Creek Enhancement Reach, Year IV, 2002. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 46 pp.

MacDonell, D.S. 1991. Enumeration and biological description of migrating fish in Moondance Creek, Manitoba, 1990. North/South Consultants Inc., Winnipeg, MB. 49 pp.

MacIsaac, H.J. 1999. Biological invasions in Lake Erie: past, present, and future. *In*: Munawar, M. and Edsall, T. (eds.), State of Lake Erie (SOLE) - past, present, and future. Ecovision World Monograph Series, Backhuys, Leiden, The Netherlands. p. 305-322.

MacIsaac, H.J., Grigorovich, I.A., Hoyle, J.A., Yan, N.D., and Panov, V.E. 1999. Invasion of Lake Ontario by the Ponto-Caspian predatory cladoceran *Cercopagis pengoi*. Can. J. Fish. Aquat. Sci. 56: 1-5.

MacIsaac, H.J., Ketelaars, H.A.M., Grigorovich, I.A., Ramcharan, C.W., and Yan, N.D. 2000. Modeling *Bythotrephes longimanus* invasions in the Great Lakes basin based on its European distribution. Arch. Hydrobiol. 149: 1-21.

MacIsaac, H.J., Robbins, T.C., and Lewis, M.A. 2002. Modeling ships' ballast water as invasion threats to the Great Lakes. Can. J. Fish. Aquat. Sci. 59: 1245-1256.

Mack, R.N. 1996. Predicting the identity and fate of plant invaders: emergent and emerging approaches. Biol. Conserv. 78: 107-121.

Mackie, G.L. 1999. Ballast water introductions of Mollusca. *In*: Claudi, R. and Leach, J.H. (eds.) Nonindigenous freshwater organisms: vectors, biology, and impacts. CRC Press LLC, Boca Raton, Florida. p. 219-254.

Magnuson, J.J., Webster, K.E., Assel, R.A., Bowser, C.J., Dillon, P.J., Eaton, J.G., Evans, H.E., Fee, E.J., Hall, R.I., Mortsch, L.R., Schindler, D.W., and Quinn, F.H. 1997. Potential effects of climate changes on aquatic systems: Laurentian Great Lakes and Precambrian Shield region. Hydrol. Processes 11: 825-871.

Manabe, S. and Wetherald, R. 1980. On the distribution of climactic change resulting from an increase in CO2 content in the atmosphere. J. Atmos. Sci. 37: 99-118.

Mandrak, N.E. 1989. Potential invasion of the Great Lakes by fish species associated with climate warming. J. Great Lakes. Res. 15: 306-316.

Manitoba Hydro and the Town of Churchill. 1997a. Lower Churchill River water level enhancement weir project: environmental impact statement.

Manitoba Hydro and the Town of Churchill. 1997b. Lower Churchill River water level enhancement weir project: environmental impact statement - Appendices.

May, B. and Marsden, J.E. 1992. Genetic identification and implications of another invasive species of Dreissenid mussel in the Great Lakes. Can. J. Fish. Aquat. Sci. 49: 1501-1506.

Maximov, A.A. and Panov, V.E. 2002. Expansion of *Marenzellaria viridis* (Polychaeta: Spionidae) in the eastern Gulf of Finland. Gulf of Finland Symp. p. 27.

McLusky, D.S., Hull, S.C., and Elliott, M. 1993. Variations in the intertidal and subtidal macrofauna and sediments along a salinity gradient in the upper Forth estuary. Netherl. J. Aquat. Ecol. 27: 101-109.

McMahon, R.F. 1999. Invasive characteristics of the freshwater bivalve clam *Corbicula fluminea*. *In*: R. Claudi and J.H. Leach (eds.), Nonindigenous freshwater organisms in North America: their biology and impact. Lewis Publishers, Boca Raton, FL. p. 315-343.

Meisner, J.D., Goodier, J.L., Regier, H.A., Shuter, B.J., and Christie, W.J. 1987. As assessment of the effects of climate warming on Great Lakes basin fishes. J. Great Lakes Res. 13: 340-352.

Merritt, R.W. and Cummins, K.W. 1996. An introduction to the aquatic insects of North America: third edition. Kendall/Hunt Publishing Company, Iowa, USA. 862 pp.

Mills, E.L., Leach, J.H., Carlton, J.T., and Secor, C.L. 1993a. Exotic species in the Great lakes: a history of biotic crises and anthropogenic introductions. J. Great Lakes Res. 19: 1-54.

Mills, E.L., Leach, J.H., Secor, C.L., and Carlton, J.T. 1993b. What's next? The prediction and management of exotic species in the Great Lakes. Report to the Great Lakes Fishery Commission, Ann Arbor, MI.

Mills, E.L., Scheuerell, M.D., Strayer, D.L., and Carlton, J.T. 1996a. Exotic species in the Hudson River basin: a history of invasions and introductions. Estuaries 19: 814-823.

Mills, E.L., Rosenberg, G., Spidle, A.P., Ludyanskiy, M., Pligin, Y., and May, B. 1996b. A review of the biology and ecology of the quagga mussel (*Dreissena bugensis*), a second species of freshwater dreissenid introduced to North America. Amer. Zool. 36: 271-286.

Minns, C.K. and Moore, J.E. 1995. Factors limiting the distributions of Ontario's freshwater fishes: the role of climate and other variables, and the potential impacts of climate change. *In*: Beamish R.J. (ed.) Climate Change and Northern Fish Populations. Can. Spec. Publ. Fish. Aquat. Sci. 121.

Mordukhai-Boltovskoi, F.D. 1964. Caspian fauna beyond the Caspian Sea. Int. Rev. Gestamen Hydrobiol. 53: 357-408.

Morton, B. 1979. Freshwater fouling bivalves. *In*: Britton, J.C. (ed.). Proceedings of the First International Corbicula Symposium (1977). Texas Christian University, Fort Worth, TX. p. 1-14.

Morton, B. 1997. The aquatic nuisance species problem: a global perspective and review. *In:* D'Itri, F. (ed.). Zebra mussels and aquatic nuisance species. Ann Arbor Press, Chelsea, MI. p. 1-53.

Muzinic, C.J. 2000. First record of *Daphnia lumholtzi* Sars in the Great Lakes. J. Great Lakes Res. 26: 352-354.

Nehring, S. 2000. Neozoen im Makrozoobenthos der deutschen Ostseeküste. Lauterbornia 39: 117-126.

Nehring, S. 2001. After the TBT era: Alternative anti-fouling paints and their ecological risks. Senckenbergiana marit. 31: 341-351.

Nehring, S. 2002. Biological invasions into German waters: an evaluation of the importance of different human-mediated vectors for nonindigenous macrozoobenthic species. *In*: Leppäkoski, E., Gollasch, S., and Olenin, S. (eds.), Invasive Aquatic Species of Europe - Distribution, Impacts and Management. Kluwer Academic Publishers, Netherlands. p. 373-383.

Nehring, S. and Leuchs, H. 2000. Neozoen im Makrozoobenthos der Brackgewässer an der deutschen Nordseeküste. Lauterbornia 39: 73-116.

Neufeld, L.J. and Bernhardt, W.J. 2000. Lower Churchill River water level enhancement weir project post-project monitoring: an assessment of invertebrate responses to operation of the project, Year I, 1999. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 66 pp.

Neufeld, L.J., Juliano, K.M., Bortoluzzi, T., and Bernhardt, W. 2004. Lower Churchill River water level enhancement weir project post-project monitoring: an assessment of invertebrate responses to operation of the project, Year V, 2003. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 119 pp.

Ogle, D.H., Selgeby, J.H., Newman, R.M., and Henry, M.G. 1995. Diet and feeding periodicity of ruffe in the St. Louis River Estuary, Lake Superior. Trans. Am. Fish. Soc. 124: 356-369.

Ojaveer, H., Leppäkoski, E., Olenin, S., and Ricciardi, A. 2002. Ecological impact of Ponto-Caspian invaders in the Baltic Sea, European inland waters and the Great Lakes: an inter-ecosystem comparison. *In:* Leppäkoski, E., Gollasch, S., and Olenin, S. (eds.), Invasive Aquatic Species of Europe - Distribution, Impacts and Management. Kluwer Academic Publishers, Netherlands. p. 373-383. p. 412-425.

Ojaveer, H., Simm, M., and Lankov, A. 2004. Population dynamics and ecological impact of the non-indigenous *Cercopagis pengoi* in the Gulf of Riga (Baltic Sea). Hydrobiol. 522: 261-269.

Olenin, S. and Leppäkoski, E. 1999. Non-native animals in the Baltic Sea: alteration of benthic habitats in coastal inlets and lagoons. Hydrobiol. 393: 233-243.

Olenin, S., Leppäkoski, E., and Daunys, D. (eds.). 2004. Alien species directory. Baltic Sea Alien Species Database, www.ku.lt/nemo/mainnemo.html.

Olenina, I. 2004. Abiotic factors controlling abundance of the invasive dinoflagellate *Prorocentrum minimum* (Pavillard) Schiller in the coastal waters of Lithuania, Baltic Sea. Baltic - the sea of aliens, Gdynia, Poland 25-27.08.2004, Book of Abstracts: 39-40.

Pacific Northwest National Laboratory. 2003. The Asiatic clam, *Corbicula fluminea*. Richland, Washington: PNNL Ecology Group.

Panov, V.E. 2006. First record of the Chinese mitten crab, *Eriocheir sinensis*, H. Milne Edwards, 1853 (Crustacea: Brachyura: Varunidae) from Lake Ladoga, Russia.

Panov, V.E., Krylov, P.I., and Telesh, I.V. 1999. The St. Petersburg harbour profile. *In:* Gollasch S. & Leppäkoski E. (eds.). Initial risk assessment of alien species in Nordic coastal waters. Nordic Council of Ministers, Copenhagen. p. 225-244.

Panov, V.E. and Berezina, N.A. 2001. *Gmelinoides fasciatus* (Stebbing). http://www.zin.ru/projects/invasions/gaas/gmefas.htm

Patalas, K. 1969. Composition and horizontal distribution of crustacean plankton in Lake Ontario. J. Fish. Res. Board Can. 26: 2135-2164.

Pekcan-Hekim, Z., Rahkonen, R., and Horppila, J. 2005. Occurrence of the parasite *Glugea hertwigi* in young-of-the-year smelt in Lake Tuusulanjärvi. J. Fish Biol. 66: 583-588.

Pimental, D., Lach, L., Zuniga, R., and Morrison, D. 2000. Environmental and economic costs of nonindigenous species in the United States. Bioscience 50: 53-65.

Platvoet, D., de Bruyne, R.H., and Gmelig Meyling, A.W. 1995. Description of a new *Caprella* species from the Netherlands: *Caprella macho* nov. spec. (Crustacea, Amphipoda, Caprellidae). Bull. Zool. Mus., Univ. Amsterdam 15: 1-4.

Popova, L.B. and Davydov, V.G. 1988. Studies on localization of *Amphilina foliacea* (Amphilinidae Dubinina, 1974) in definitive hosts. Helminthol. 25: 129-138.

Pronin, N.M., Fleischer, G.W., Baldanova, D.R., and Pronina, S.V. 1997a. Parasites of the recently established round goby (*Neogobius melanostomus*) and tubenose goby (*Proterorhinus marmoratus*) (Cottidae) from the St. Clair River and Lake St. Clair, Michigan, U.S.A. Folia Parasitol. 44: 1-6.

Pronin, N.M., Selgeby, J.H., Pronina, S.V., and Darlen, T. 1997b. Effect of parasites on resistance to oxygen starvation in the ruffe (*Gymnocephalus cernuus*). Russ. J. Ecol. 28: 278-280.

Pronin, N.M., Selgeby, J.H., Litvinov, A.G., and Pronina, S.V. 1998. Comparative ecology and parasitic fauna of exotic invaders in the great lakes of the world: the rotan (*Perccottus glenni*) in Lake Baikal and the ruffe (*Gymnocephalus cernuus*) in Lake Superior. Sibirskii Ekol. Zhurn. 5: 397-406. [in Russian]

Provan, J., Murphy, S., and Maggs, C.A. 2005. Tracking the invasive history of the green alga *Codium fragile* ssp. *tomentosoides*. Molec. Ecol. 14: 189-194.

Rasmussen, J.B., Rowan, D.J., Lean, D.R.S., and Carey, J.H. 1990. Food chain structure in Ontario lakes determines PCB levels in lake trout (*Salvelinus namaycush*) and other pelagic fish. Can. J. Fish Aquat. Sci. 47: 2030-2038.

Reed, E.B. and McIntyre, N.E. 1995. *Cyclops strenuus* (Fischer, 1851) sensu lato in Alaska and Canada, with new records of occurrence. Can. J. Zool. 73: 1699-1711.

Regier, H.A., Lin, P., Ing, K.K., and Wichert, G.A. 1996. Likely responses to climate change of fish associations in the Laurentian Great Lakes Basin: concepts, methods and findings. Boreal Env. Res. 1: 1-15.

Reise, K., Gollasch, S., and Wolff, W.J. 2002. Introduced marine species of the North Sea coasts. *In*: Leppäkoski, E., Gollasch, S., and Olenin, S. (eds.), Invasive Aquatic Species of Europe - Distribution, Impacts and Management. Kluwer, Dordrecht. p. 260-266.

Reise, K., Dankers, N., and Essink, K. (in press). Introduced species. Quality Status Report of the Wadden Sea, update 2004.

Rejmanek, M. 1996. A theory of seed plant invasiveness: the first sketch. Biol. Conserv. 78: 171-181.

Remnant, R.A. 1995. A fisheries survey of the lower Churchill River mainstem, 1994. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 70 pp.

Remnant, R.A. and Bernhardt, W.J. 1994. An assessment of fish utilization of Goose Creek, near Churchill, Manitoba, 1993. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 248 pp.

Remnant, R.A. and Kitch, I.H. 1996. An assessment of fish utilization of Goose Creek, near Churchill, Manitoba, Year II, 1995. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 233 pp.

Ricciardi, A. 1998. Global range expansion of the Asian mussel *Limnoperna fortunei* (Mytilidae): another fouling threat to freshwater systems. Biofouling 13: 97-106.

Ricciardi, A. 2001. Facilitative interactions among aquatic invaders: is an "invasional meltdown" occurring in the Great Lakes? Can. J. Fish. Aquat. Sci. 58: 2513-2525.

Ricciardi, A. 2003. Predicting the impacts of an introduced species from its invasion history: an empirical approach applied to zebra mussel invasions. Fresh. Biol. 48: 972-981.

Ricciardi, A. and Rasmussen, J.B. 1998. Predicting the identity and impact of future biological invaders: a priority for aquatic resource management. Can. J. Fish. Aquat. Sci. 55: 1759-1765.

Ricciardi, A. and Reiswig, H.M. 1994. Taxonomy, distribution, and ecology of the freshwater bryozoans (Ectoprocta) of eastern Canada. Can. J. Zool. 72: 339-359.

Rincé, Y. and Paulmier, G. 1986. Donnée novelles sur la distribution de la diatomée marine *Coscinodiscus wailesii* Gran & Angst (Bacillariophyceae). Phycol. 25: 73-79.

Rixon, C.A.M., Duggan, I.C., Bergeron, N.M.N., Ricciardi, A., and MacIsaac, H.J. 2005. Invasion risks posed by the aquarium trade and live fish markets on the Laurentian Great Lakes. Biodiv. Conserv. 14: 1365-1381.

Robertson, A. and Gannon, J.E. 1981. Annotated checklist of the free-living copepods of the Great Lakes. J. Great Lakes Res. 7: 382-393.

Roy, J., Navas, M.L., and Sonie, L. 1991. Invasion by annual brome grasses: a case study challenging the homocline approach to invasions. *In:* Groves, R.H. and Di Castri, F. (eds) Biogeography of Mediterranean invasions. Cambridge University Press, Cambridge, U.K. p. 207-224.

Rudnick, D. and Resh, V. 2002. A survey to examine the effects of the Chinese mitten crab on commercial fisheries in Northern California. Interagency Ecol. Progr. News. 15: 19-21.

Ruiz, G.M. and Hines, A.H. 1997. The risk of nonindigenous species invasion in Prince William Sound associated with oil tanker traffic and ballast water management: pilot study. Prepared for the Regional Citizens' Advisory Council of Prince William Sound.

Salemma, H. 1998. Mysid shrimps. *In*: Heliovaara, K. (ed.) Nature of Finland – Invertebrate Animals. Weilin and Goos, Helsinki. p. 46-47.

Salemma, H. and Hietalahti, V. 1993. *Hemimysis anomala*, G.O. Sars (Crustacea: Mysidacea) – immigration of a Pontocaspian mysid into the Baltic Sea. Ann. Zool. Fenn. 30: 271-276.

Sarda, R., Valiela, I., and Foreman, K. 1995. Life cycle, demography, and production of *Marenzelleria viridis* in a salt marsh of southern New England. J. Mar. Biol. Assoc. U.K. 75: 725-739.

Schindler, D.W. 1997. Widespread effects of climatic warming on freshwater ecosystems in North America. Hydrol. Processes. 11: 1043-1067.

Scholesser, D.W. and Masteller, E.C. 1999. Mortality of unionid bivalves (Mollusca) associated with dreissenid mussels. Northeast. Nat. 6: 341.

Schloesser, D.W., Kovalak, W.P., Longton, G.D., and Ohnesorg, K.L. 1998. Impact of zebra and quagga mussels (*Dreissena* spp.) on freshwater unionids (Bivalvia: Unionidae) in the Detroit River of the Great Lakes. Am. Midl. Nat. 140: 299-313.

Schneider, F. and Remnant, R.A. 1993. Habitat utilization by brook trout and other fish species in two Lower Nelson River tributaries. North/South Consultants Inc., Winnipeg, MB. 79 pp.

Schneider-Vieira, F., Zrum, L., and Remnant, R.A. 1996. Invertebrates of the lower Churchill River and two tributaries, Year I, 1995. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 47 pp.

Schrimpf, A. and Steinberg, C. 1982. Further recordings of the newly observed cladoceran *Daphnia parvula*, new record in southern Germany. Arch. Hydrobiol. 94: 373-381.

Selgeby, J.H. 1975. Life histories and abundance of crustacean zooplankton in the outlet of Lake Superior, 1971-1972. J. Fish. Res. Board Can. 32: 461-470.

Siferd, T.D., Welch, H.E., Bergmann, M.A., and Curtis, M.F. 1997. Seasonal distribution of sympagic amphipods near Chesterfield Inlet, N.W.T., Canada. Polar Biol. 18: 16-22.

Simberloff, D. and Von Holle, B. 1999. Positive interactions of nonindigenous species: invasion meltdown? Biol. Invasions 1: 21-32.

Simon, K.S. and Townsend, C.R. 2003. Impacts of freshwater invaders at different levels of ecological organisation, with emphasis on salmonids and ecosystem consequences. Fresh. Biol. 48: 982-994.

Simon, T.P. and Vondruska, J.T. 1991. Larval identification of the ruffe, *Gymnocephalus cernuus* (Linnaeus) (Percidae: Percini), in the St. Louis River Estuary, Lake Superior drainage basin, Minnesota. Can. J. Zool. 69: 436-442.

Smith, D.G., Werle, S.F., and Klekowski, E. 2002. The rapid colonization and emerging biology of *Cordylophora caspia* (Pallas, 1771) (Cnidaria: Clavidae) in the Connecticut River. J. Fresh. Ecol. 17: 423-430.

Spencer, C.N., McClelland, B.R., and Stanford, J.A. 1991. Shrimp stocking, salmon collapse, and eagle displacement. Bioscience 41: 14-21.

Steidinger, K. A. and Tangen, K. 1996. Dinoflagellates. *In*: Tomas, C. R. (ed.) Identifying marine diatoms and dinoflagellates. Academic Press, Inc., San Diego. p. 387-584.

Stepien, C.A., Brown, J.E., Neilson, M.E., and Tumeo, M.A. 2005. Genetic diversity of invasive species in the Great Lakes versus their Eurasian source populations: insights for risk analysis. Risk Anal. 25: 1043-1060.

Stern, G. (ed.). 2005. ArcticNet Leg 2 cruise report September 15th – October 26th, 2005, CCGS Amundsen. 95 pp.

Stewart, D.B. and Lockhart, W.L. 2005. An overview of the Hudson Bay marine ecosystem. Can. Tech. Rep. Fish. Aquat. Sci. 2586: vi + 487 p.

Stewart, K.W. and Watkinson, D.A. 2004. The freshwater fishes of Manitoba. University of Manitoba Press, Winnipeg, Manitoba. 276 pp.

Therriault, T.W., Grigorovich, I.A., Kane, D.D., Haas, E.M., Culver, D.A., and MacIsaac, H.J. 2002. Range expansion of the exotic zooplankter *Cercopagis pengoi* (Ostroumov) into western Lake Erie and Muskegon Lake. J. Great Lakes Res. 28: 698-701.

Tittizer, T., F. Scholl, M. Banning, A. Haybach, and M. Schleuter. 2000. Aquatische Neozoen im Makrozoobenthos der Binnenwasserstraßen Deutschlands. Lauterbornia 39: 1-72.

Trowbridge, C.D. 1999. An assessment of the potential spread and options for control of the introduced green macroalga *Codium fragile* spp. *tomentosoides* on Australian shores. Center for Research on Introduced Marine Pests and CSIRO Marine Research.

Uitto, A., Gorokhova, E., and Välipakka, P. 1999. Distribution of the non-indigenous *Cercopagis pengoi* in the coastal waters of the eastern Gulf of Finland. Ices J. Mar. Sci. 56: 49-57.

United States Department of the Interior. 1993. Ruffe parasites: hitchhikers on invaders? Research Information Bulletin No. 97, National Biological Survey, Ashland, Wisconsin.

Van den Brink, F.W.B., Van der Velde, G., and Bij de Vaate, A. 1991. Amphipod invasion on the Rhine. Nature 352: 576.

Van den Brink, F.W.B., Van der Velde, G., and Bij de Vaate, A. 1993. Ecological aspects, explosive range extension and impact of a mass invader, *Corophium curvispinum* Sars, 1895 (Crustacea: Amphipoda), in the Lower Rhine (The Netherlands). Oecol. 93: 224-232.

Vanderploeg, H.A., Liebig, J.R., and Omair, M. 1993. *Bythotrephes* predation on Great Lakes zooplankton Measured by an in situ method: implications for zooplankton community structure. Arch. Hydrobiol. 127: 1-8.

Vanderploeg, H.A., Nalepa, T.F., Jude, D.J., Mills, E.L., Holeck, K.T., Liebig, J.R., Grigorovich, I.A., and Ojaveer, H. 2002. Dispersal and emerging ecological impacts of Ponto-Caspian species in the Laurentian Great Lakes. Can. J. Fish. Aquat. Sci. 59: 1209-1228.

Van der Velde, G., Paffen, B.G.P., Van den Brink, F.W.B., Bij de Vaate, A., and Jenner, H.A. 1994. Decline of the zebra mussel populations in the Rhine: competition between two mass invaders (*Dreissena polymorpha* and *Corophium curvispinum*). Naturwissen. 81: 32-34.

Van der Velde, G., Rajagopal, S., Kelleher, B., Muskó, I. B., and Bij de Vaate, A. 2000. Ecological impact of crustacean invaders: general considerations and examples from the Rhine River. Crustac. Iss. 12: 3-33.

van Overdijk, C.D.A., Grigorovich, I.A., Mabee, T., Ray, W.J., Ciborowski, J.J.H., and MacIsaac, H.J. 2003. Microhabitat selection by the invasive amphipod *Echinogammarus ischnus* and native *Gammarus fasciatus* in laboratory experiments and in Lake Erie. Freshwat. Biol. 48: 567-578.

Veldhuizen, T.C. 2001. Life history, distribution, and impacts of the Chinese mitten crab, *Eriocheir sinensis*. Aquat. Invaders 12: 1-9.

Verbitsky, V.B. and Berezina, N.A. 2003. Effect of salinity-temperature combinations on tolerance in Baikalian amphipod *Gmelinoides fasciatus* (Stebb.) *In*: Invasions of alien species in Holarctic. Proceedings of U.S. –Russia Invasive Species Workshop, 27-31 August, 2001, Borok, Russia. Borok, p. 416-421.

Viitasalo, S. and Viitasalo, M. 2004. Predation by the mysid shrimps *Mysis mixta* and *M. relicta* on benthic eggs of *Bosmina longispina maritime* (Cladocera) in the northern Baltic Sea. Mar. Ecol. Prog. Ser. 281: 155-163.

Wallentinus, I. (in press). Status of introductions of non-indigenous marine species to north Atlantic waters: introductions and transfers of plants. ICES Co-op Res. Rep.

Weidema, I.R. 2000. Introduced species in the Nordic countries. Nord 2000 13: 242 pp.

Welcomme, R.L. 1984. International transfers of inland fish species. *In*: Courtnay, W.R. Jr. and Stauffer, J.R. Jr. (eds.) Distribution, biology, and management of exotic fishes. Johns Hopkins University Press, Baltimore, MD. p. 22-40.

Wells, L. 1970. Effects of alewife predation on zooplankton populations in Lake Michigan. Limnol. Oceanogr. 13: 556-565.

Werner, R.G. 1972. Bluespotted sunfish, *Enneacanthus gloriosus*, in the Lake Ontario drainage. Copeia 1972(4): 878-879.

Williamson, M. and Fitter, A. 1996. The varying success of invaders. Ecol. 77: 1655-1661.

Willis, K.J., Cook, E.J., Lozano-Fernandez, M., and Takeuchi, I. 2004. First record of the alien caprellid amphipod, *Caprella mutica*, for the UK. J. Mar. Biol. Ass. U.K. 84: 1027-1028.

Witt, J.D.S., Hebert, P.D.N., and Morton, W.B. 1997. *Echinogammarus ischnus*: another crustacean invader in the Laurentian Great Lakes basin. Can. J. Fish. Aquat. Sci. 54: 264-268.

Wonham, M.J., Bailey, S.A., MacIsaac, H.J., and Lewis, M.A. 2005. Modelling the invasion risk of diapausing organisms transported in ballast sediments. Can. J. Fish. Aquat. Sci. 62: 2386-2398.

Yan, N.D., Dunlop, W.I., Pawson, T.W., and MacKay, L.E. 1992. *Bythotrephes cederstroemi* (Schoedler) in Muskoka lakes: first records of the European invader in inland lakes in Canada. Can. J. Fish. Aquat. Sci. 49: 422-426.

Zadoenko, I.N., Leis, O.A., and Grigorjev, V.F. 1985. Results and perspectives of acclimatization of the Baikalian amphipods in water bodies of the USSR. Proc. Gos. 232: 30-34.

Zaiko, A. 2005. *Balanus improvisus*. *In:* Olenin, S., Leppäkoski, E., and Daunys, D. (eds.). Baltic Sea Alien Species Database. http://www.ku.lt/nemo/mainnemo.html

Zaranko, D.T., Farara, D.G., and Thompson, F.G. 1997. Another exotic mollusc in the Laurentian Great Lakes: the New Zealand native *Potamopyrgus antipodarum* (Gray 1843) (Gastropoda, Hydrobiidae). Can. J. Fish. Aquat. Sci. 54: 809-814.

Zrum, L. 1999. Abundance and species composition of zooplankton in the Nelson River Estuary: baseline monitoring program 1998 - Year III. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 68 pp.

Zrum, L. 2000. Abundance and species composition of zooplankton in the Nelson River Estuary: baseline monitoring program 1999 - Year IV. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 74 pp.

APPENDIX 1.

LIST OF AQUATIC SPECIES INDIGENOUS TO OR ALREADY PRESENT IN HUDSON BAY AND THE LOWER REACHES OF THE CHURCHILL AND NELSON RIVERS.

Table A-1.1. List of zooplankton, macroinvertebrate, fish, and macrophyte taxa recorded from freshwater sections of the Nelson (~100 km) and Churchill (~15 km) rivers, and some of their major tributaries immediately upstream of the Hudson Bay estuaries (i.e. south of Gillam Island and Mosquito Point, respectively) from 1988-2005.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
ZOOPLANKTON								
ARTHROPODA								
Cladocera								
Acroperus harpae	--	Churchill	--	1995	July	--	77	Schneider-Vieira et al. 1996
		Churchill		1996	July	--	240	Fazakas et al. 1997
		Churchill		2001	August	--	7922	Bernhardt and Neufeld 2002
		Churchill		2003	August	--	990	Neufeld et al. 2004
Alona guttata	--	Churchill	fresh	2001	August	--	566	Bernhardt and Neufeld 2002
		Churchill		2003	August	--	406	Neufeld et al. 2004
Alona sp.	--	Churchill	--	1995	July	--	177	Schneider-Vieira et al. 1996
		Churchill		1996	July	--	190	Fazakas et al. 1997
Bosmina longirostris	--	Churchill	fresh	1995	July	--	155	Schneider-Vieira et al. 1996
		Churchill		1996	July	--	400	Fazakas et al. 1997
		Churchill		2003	July	--	579	Neufeld et al. 2004
Ceriodaphnia quadrangula	--	Churchill	--	2001	August	--	5942	Bernhardt and Neufeld 2002
		Churchill		2003	August	--	3856	Neufeld et al. 2004
Chydorus sphaericus	--	Churchill	--	1995	July	--	1730	Schneider-Vieira et al. 1996
		Churchill		1996	July	--	690	Fazakas et al. 1997
		Churchill		2001	August	--	106	Bernhardt and Neufeld 2002
		Churchill		2003	August	--	566	Neufeld et al. 2004

Table A-1.1. Continued.

Taxon / Species	**Common name**	**Location**	**Habitat[1]**	**Year**	**Month**	**Abundance[2]**	**Density[3]**	**Reference**
Daphnia pulex	--	Churchill	--	2003	August	--	116	Neufeld et al. 2004
Daphnia retrocurva	--	Churchill	fresh	2001	August	--	35	Bernhardt and Neufeld 2002
Daphnia schoedleri	--	Churchill	--	2003	August	--	1157	Neufeld et al. 2004
Daphnia sp.	--	Nelson	fresh	1988	Jun/Jul	40	--	Baker 1989
Eurycercus lamellatus	--	Churchill	--	1995	July	--	1766	Schneider-Vieira et al. 1996
		Churchill		1996	July	--	340	Fazakas et al. 1997
		Churchill		2003	August	--	1132	Neufeld et al. 2004
Eurycercus sp.	--	Nelson	--	1988	Sept/Oct	40	--	Baker 1989
Holopedium gibberum	--	Churchill	--	1995	July	--	77	Schneider-Vieira et al. 1996
Ilyocryptus acutifrons	--	Churchill	--	1995	July	--	65	Schneider-Vieira et al. 1996
Leydigia quadrangularis	--	Churchill	--	2001	August	--	1415	Bernhardt and Neufeld 2002
Macrothrix spp.	--	Churchill	--	1996	July	--	220	Fazakas et al. 1997
Picripleuroxus denticulatus (syn. *Pleuroxus denticulatus*)	--	Churchill	--	1995	July	--	883	Schneider-Vieira et al. 1996
		Churchill		1996	July	--	20	Fazakas et al. 1997
Polyphemus pediculus	--	Churchill	--	2003	August	--	992	Neufeld et al. 2004
Sida crystallina	--	Churchill	fresh	1995	July	--	618	Schneider-Vieira et al. 1996
		Churchill		1996	July	--	280	Fazakas et al. 1997
		Churchill		2001	August	--	39046	Bernhardt and Neufeld 2002
		Churchill		2003	August	--	37837	Neufeld et al. 2004
Scapholeberis kingi	--	Churchill	--	1996	July	--	170	Fazakas et al. 1997
Simocephalus spp.	--	Churchill	--	1995	July	--	177	Schneider-Vieira et al. 1996
		Churchill		1996	July	--	410	Fazakas et al. 1997

Table A-1.1. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Copepoda								
Acanthocyclops vernalis	--	Churchill	--	1995	July	--	7769	Schneider-Vieira et al. 1996
		Churchill		1996	July	--	390	Fazakas et al. 1997
		Churchill		2001	August	--	42	Bernhardt and Neufeld 2002
		Churchill		2003	August	--	101	Neufeld et al. 2004
Acartia bifilosa	--	Nelson	brackish	1988	August	4	--	Baker 1989
Cyclops edax	--	Churchill	--	2003	August	--	141	Neufeld et al. 2004
Cyclops sp.	--	Nelson	--	1988	Jun/Jul	60	--	Baker 1989
		Churchill		1995	July	--	82	Schneider-Vieira et al. 1996
Cyclops varicans rubellus	--	Churchill	--	1995	July	--	95	Schneider-Vieira et al. 1996
		Churchill		1996	July	--	240	Fazakas et al. 1997
Cyclops vernalis	--	Nelson	fresh	1988	Jun/Jul	80	--	Baker 1989
Diacyclops bicuspidatus thomasi	--	Churchill	--	2001	August	--	35	Bernhardt and Neufeld 2002
		Churchill		2003	August	--	424	Neufeld et al. 2004
Diaptomus minutus	--	Churchill	--	1995	July	--	353	Schneider-Vieira et al. 1996
		Churchill		1996	July	--	180	Fazakas et al. 1997
Diaptomus sicilis	--	Nelson	fresh	1988	Jun/Jul	65	--	Baker 1989
Diaptomus sp.	--	Nelson	fresh	1988	Jun/Jul	1	--	Baker 1989
Epischura lacustris	--	Nelson		1988	Jun/Jul	5	--	Baker 1989
Epischura nevadensis	--	Nelson	fresh	1988	Jun/Jul	1	--	Baker 1989

Table A-1.1. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Eucyclops agilis	--	Churchill	--	1995	July	--	412	Schneider-Vieira et al. 1996
		Churchill		1996	July	--	140	Fazakas et al. 1997
		Churchill		2001	August	--	1698	Bernhardt and Neufeld 2002
		Churchill		2003	August	--	830	Neufeld et al. 2004
Eurytemora affinis	--	Nelson	brackish	1988	Jun/Jul	7	--	Baker 1989
Eurytemora raboti	--	Nelson	brackish	1988	Jun/Jul	4	--	Baker 1989
Leptodiaptomus ashlandi (syn. *Diaptomus ashlandi*)	--	Nelson	fresh	1988	August	8	--	Baker 1989
Limnocalanus macrurus	--	Nelson	fresh	1988	Jun/Jul	20	--	Baker 1989
Macrocyclops albidus	--	Churchill	fresh	1995	July	--	989	Schneider-Vieira et al. 1996
		Churchill		2003	August	--	99	Neufeld et al. 2004
Paracyclops poppei	--	Churchill	--	1995	July	--	530	Schneider-Vieira et al. 1996
		Churchill		1996	July	--	340	Fazakas et al. 1997
Pseudocalanus minutus	--	Nelson	marine	1988	Jun/Jul	1	--	Baker 1989
Skistodiaptomus oregonensis (syn. *Diaptomus oregonensis*)	--	Churchill	fresh	2003	August	--	255	Neufeld et al. 2004
Tropocyclops prasinus mexicanus	--	Churchill	--	1995	July	--	5816	Schneider-Vieira et al. 1996

Table A-1.1. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
			MACROINVERTEBRATES					
ANNELIDA								
Oligochaeta								
Bratislavia unidentata	--	Nelson	--	1988	Jun/Jul	1	--	Baker 1989
Chaetogaster diaphanus	--	Nelson	--	1988	Sept/Oct	2	--	Baker 1989
Limnodrilus hoffmeisteri	--	Nelson	--	1988	Sept/Oct	1110	--	Baker 1989
Limnodrilus udekemianus	--	Nelson	--	1988	Sept/Oct	140	--	Baker 1989
Nais behningi	--	Nelson	--	1988	Sept/Oct	1	--	Baker 1989
Nais communis	--	Nelson	--	1988	Sept/Oct	1	--	Baker 1989
Nais sp.	--	Nelson	--	1988	August	8	--	Baker 1989
Nais variabilis	--	Nelson	--	1988	Jun/Jul	3	--	Baker 1989
Pristina aequiseta	--	Nelson	--	1988	Jun/Jul	4	--	Baker 1989
Slavina appendiculata	--	Nelson	--	1988	Jun/Jul	2	--	Baker 1989
Specaria josinae	--	Nelson	--	1988	Jun/Jul	1	--	Baker 1989
Tubifex tubifex	--	Nelson	--	1988	Sept/Oct	1590	--	Baker 1989
Unicinais uncinata	--	Nelson	--	1988	Jun/Jul	3	--	Baker 1989
Vejdovskyella intermedia	--	Nelson	--	1988	Jun/Jul	1	--	Baker 1989

Table A-1.1. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
ARTHROPODA								
Amphipoda								
Gammarus lacustris	--	Churchill	--	1995	July	--	77	Schneider-Vieira et al. 1996
		Churchill		1996	July	--	30	Fazakas et al. 1997
Hyalella azteca	--	Churchill	fresh	2001	August	--	71	Bernhardt and Neufeld 2002
		Churchill		2003	August	--	177	Neufeld et al. 2004
Arachnida								
Spechon sp.	--	Nelson	--	1988	August	10	--	Baker 1989
Ephemeroptera								
Baetis pygmaeus	small minnow mayfly	Churchill	fresh	2001	August	--	212	Bernhardt and Neufeld 2002
Leptophlebia sp.	prongill mayfly	Churchill	fresh	2001	August	--	35	Bernhardt and Neufeld 2002
Megaloptera								
Sialis sp.	alderfly	Churchill	fresh	2003	August	--	2	Neufeld et al. 2004
Mysidacea								
Mysis litoralis	--	Nelson	marine	1988	Jun/Jul	5	--	Baker 1989
Trichoptera								
Phryganea sp.	giant case maker	Churchill	fresh	2001	August	--	35	Bernhardt and Neufeld 2002

Table A-1.1. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
BRYOZOA								
Cristatella mucedo	--	Nelson	--	1988	August	3	--	Baker 1989
Eucratea loricata	--	Nelson	--	1988	Aug-Oct	present	--	Baker 1989
CNIDARIA								
Hydrozoa								
Hartlaubella gelatinosa	--	Nelson	--	1988	Sept/Oct	present	--	Baker 1989
Hartlaubella sp.	--	Nelson	--	1988	Aug-Oct	present	--	Baker 1989
Hydra sp.	--	Nelson	fresh	1988	Jun/Jul	10	--	Baker 1989
		Churchill		2001	August	--	531	Bernhardt and Neufeld 2002
		Churchill		2003	August	--	179	Neufeld et al. 2004
Sertularia tenera	--	Nelson	--	1988	Sept/Oct	present	--	Baker 1989
MOLLUSCA								
Bivalvia								
Macoma balthica	Baltic macoma	Nelson	--	1988	Sept/Oct	15	--	Baker 1989
Sphaerium rhomboideum	rhomboid fingernail clam	Nelson	--	1988	August	2	--	Baker 1989
Sphaerium sp.	--	Churchill	--	2001	August	--	35	Bernhardt and Neufeld 2002
Gastropoda								
Ferrissia rivularis	creeping ancylid	Nelson	--	1988	Sept/Oct	4	--	Baker 1989

Table A-1.1. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Gyraulus parvus	ash gyro	Nelson	--	1988	Sept/Oct	10	--	Baker 1989
Lymnaea [*Fossaria*] *parva*	pygmy fossaria	Nelson	--	1988	Sept/Oct	1	--	Baker 1989
Physa jennessi	obtuse physa	Churchill	--	2001	August	--	71	Bernhardt and Neufeld 2002
Physa sp.	--	Nelson	--	1988	August	2	--	Baker 1989
Planorbella trivolvis (syn. *Helisoma trivolvis*)	marsh rams-horn	Churchill	--	2001	August	--	35	Bernhardt and Neufeld 2002
Stobilops labyrinthica	--	Nelson	--	1988	Sept/Oct	1	--	Baker 1989
Vallonia gracilicosta	multiribbed vallonia	Nelson	--	1988	Sept/Oct	8	--	Baker 1989
Valvata sincera	mossy valvata	Churchill	--	2001	August	--	141	Bernhardt and Neufeld 2002
Valvata tricarinata	three-ridge valvata	Nelson	--	1988	Sept/Oct	2	--	Baker 1989
			FISHES					
ACIPENSERIDAE								
Acipenser fulvescens	lake sturgeon	Nelson	S	1988	Jun-Oct	1	--	Baker 1989
		Nelson		1991	June	25	--	Bernhardt et al. 1992
		Nelson		1997	Sept/Oct	10	--	Bretecher and MacDonell 1998
		Nelson		--	--	--	--	Baker et al. 1993
		Churchill		1994	Sept	1	--	Remnant 1995
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		n/a		--	--	--	--	Stewart and Lockhart 2005

Table A-1.1. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
CATOSTOMIDAE								
Catostomus catostomus	longnose sucker	Nelson	S	1988	Jun-Aug	1045	--	Baker 1989
		Nelson	(T)	1990	Jun-Oct	1390	--	MacDonell 1991
		Nelson		1991	June	260	--	Bernhardt et al. 1992
		Nelson		1997	Sept/Oct	425	--	Bretecher and MacDonell 1998
		Nelson		--	--	--	--	Baker et al. 1993
		Nelson		--	--	--	--	Stewart and Lockhart 2005
		Churchill		1994	Jun/Au/Se	272	--	Remnant 1995
		Churchill	(T)	1994	Jun/Sept	840	--	Bernhardt 1995
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
Catostomus commersoni	white sucker	Nelson	S	1988	Sept/Oct	3	--	Baker 1989
		Nelson	(T)	1990	May-Oct	275	--	MacDonell 1991
		Nelson		1991	Sept/Oct	60	--	Bernhardt et al. 1992
		Nelson		1997	Sept/Oct	425	--	Bretecher and MacDonell 1998
		Nelson		--	--	--	--	Baker et al. 1993
		Churchill		1994	Jun/Au/Se	206	--	Remnant 1995
		Churchill	(T)	1994	Jun/Sept	1135	--	Bernhardt 1995
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		n/a		--	--	--	--	Stewart and Lockhart 2005
Moxostoma macrolepidotum	shorthead redhorse	Nelson	S	1997	Sept/Oct	1	--	Bretecher and MacDonell 1998

Table A-1.1. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
		Nelson		--	--	--	--	Baker et al. 1993
		n/a		--	--	--	--	Stewart and Lockhart 2005
COTTIDAE								
Cottus bairdi	mottled sculpin	Churchill	FW (T)	2002	Jun/Jul	1	--	MacDonald and Remnant 2003
Cottus cognatus	slimy sculpin	Nelson	S	1988	Sept/Oct	4	--	Baker 1989
		Nelson		1991	Sept/Oct	1	--	Bernhardt et al. 1992
		Nelson	(T)	1992	Jun-Oct	1190	--	Schneider and Remnant 1993
		Nelson		--	--	--	--	Baker et al. 1993
		Churchill	(T)	1994	Jun/Sept	53	--	Bernhardt 1995
		Churchill	(T)	2002	Jun/Jul	11	--	MacDonald and Remnant 2003
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		n/a		--	--	--	--	Stewart and Lockhart 2005
Cottus ricei	spoonhead sculpin	Nelson	S	1988	Jun-Aug	4	--	Baker 1989
		Nelson		--	--		--	Baker et al. 1993
		n/a		--	--		--	Stewart and Lockhart 2005
Myoxocephalus quadricornis	fourhorn sculpin	Nelson	E	1988	Jun-Oct	1	--	Baker 1989
		n/a		--	--	--	--	Stewart and Lockhart 2005
CYPRINIDAE								
Couesius plumbeus	lake chub	Nelson	S	1988	Jun-Aug	4	--	Baker 1989
		Nelson		--	--	--	--	Baker et al. 1993
		Churchill	(T)	2001	Jun/Jul	19	--	Caskey and Remnant 2002

Table A-1.1. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
		n/a		--	--	--	--	Stewart and Lockhart 2005
Margariscus margarita	pearl dace	Churchill	S (T)	1994	Jun/Sept	40	--	Bernhardt 1995
		Churchill	(T)	1995	Jun/Jul	14	--	Remnant and Kitch 1996
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
Notropis atherinoides	emerald shiner	Nelson	S	--	--	--	--	Baker et al. 1993
		Nelson		--	--	--	--	Stewart and Lockhart 2005
Rhinichthys obtusus (ex. *Rhinichthys atratulus*)	blacknose dace	Churchill	FW (T)	2002	Jun/Jul	1	--	MacDonald and Remnant 2003
Rhinichthys cataractae	longnose dace	Churchill	S (T)	1994	Jun/Sept	29	--	Bernhardt 1995
		Churchill	(T)	2002	Jun/Jul	67	--	MacDonald and Remnant 2003
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
ESOCIDAE								
Esox lucius	northern pike	Churchill	S	1994	Jun/Au/Sep	211	--	Remnant 1995
		Churchill	(T)	1994	Jun/Sept	441	--	Bernhardt 1995
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		n/a		--	--	--	--	Stewart and Lockhart 2005

Table A-1.1. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
GADIDAE								
Lota lota	burbot	Churchill	S	1994	Jun/Au/Se	13	--	Remnant 1995
		Churchill	(T)	1994	Jun/Sept	10	--	Bernhardt 1995
		Churchill	(T)	2003-04	May-Jul	9	--	Bernhardt and Holm 2005
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		n/a		--	--	--	--	Stewart and Lockhart 2005
GASTEROSTEIDAE								
Culaea inconstans	brook stickleback	Churchill	S (T)	2002	Jun/Jul	1	--	MacDonald and Remnant 2003
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		n/a		--	--	--	--	Stewart and Lockhart 2005
Pungitius pungitius	ninespine stickleback	Churchill		2002	Jun/Jul	30	--	MacDonald and Remnant 2003
OSMERIDAE								
Osmerus mordax	rainbow smelt	Nelson	S	1998	July	1	--	Zrum 1999
		Nelson, Churchill		--	--	--	--	Stewart and Lockhart 2005
PERCIDAE								
Perca flavescens	yellow perch	Churchill	S (T)	2003-04	May-Jul	2	--	Bernhardt and Holm 2003
Sander vitreus	walleye	Churchill	S	1994	Sept	1	--	Remnant 1995

Table A-1.1. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
		Churchill	(T)	2003-04	May-Jul	18	--	Bernhardt and Holm 2005
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		n/a		--	--	--	--	Stewart and Lockhart 2005
PERCOPSIDAE								
Percopsis omiscomaycus	trout-perch	Churchill	S (T)	1994	Jun/Sept	17	--	Bernhardt 1995
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		n/a		--	--	--	--	Stewart and Lockhart 2005
SALMONIDAE								
Coregonus artedi	cisco	Nelson	A	1988	Jun-Aug	20	--	Baker 1989
		Nelson		1991	Sept/Oct	30	--	Bernhardt et al. 1992
		Nelson		1997	Sept/Oct	20	--	Bretecher and MacDonell 1998
		Churchill		1994	Jun/Au/Se	8	--	Remnant 1995
		Churchill		1994	Jun/Sept	2	--	Bernhardt 1995
		Churchill		2003-04	May-Jul	17	--	Bernhardt and Holm 2005
		n/a		--	--	--	--	Stewart and Lockhart 2005
Coregonus clupeaformis	lake whitefish	Nelson	A	1988	Jun-Oct	47	--	Baker 1989
		Nelson		1991	June	30	--	Bernhardt et al. 1992
		Nelson		1997	Sept/Oct	100	--	Bretecher and MacDonell 1998
		Churchill		1994	Jun/Au/Se	172	--	Remnant 1995
		Churchill		1994	Jun/Sept	37	--	Bernhardt 1995
		Churchill		2003-04	May-Jul	11	--	Bernhardt and Holm 2003

Table A-1.1. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		n/a		--	--	--	--	Stewart and Lockhart 2005
Prosopium cylindraceum	round whitefish	Churchill	A	1994	Jun/Au/Sep	22	--	Remnant 1995
		Churchill		1994	Jun/Sept	13	--	Bernhardt 1995
Salvelinus alpinus	Arctic char	Churchill	A	1994	Sept	1	--	Remnant 1995
		Churchill		1994	Jun/Sept	1	--	Bernhardt 1995
		Churchill		1996	Sept/Oct	3	--	Fazakas and Remnant 1997
Salvelinus fontinalis	brook trout	Nelson	A (T)	1990	May-Oct	16	--	MacDonell 1991
		Nelson	(T)	1991	Aug	60	--	Kroeker 1992
		Nelson	(T)	1992	Jun-Oct	135	--	Schneider and Remnant 1993
		Churchill		1994	Sept	1	--	Remnant 1995
		Churchill	(T)	1994	Jun/Sept	6	--	Bernhardt 1995
Thymallus arcticus	Arctic grayling	Churchill	FW (T)	1993	May/Sept	212	--	Remnant and Bernhardt 1994
		Churchill	(T)	1994	Jun/Sept	64	--	Bernhardt 1995
		Churchill	(T)	1995	May/Jun	1272	--	Remnant and Kitch 1996
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		n/a		--	--	--	--	Stewart and Lockhart 2005

Table A-1.1. Continued.

Taxon / Species	**Common name**	**Location**	**Habitat[1]**	**Year**	**Month**	**Abundance[2]**	**Density[3]**	**Reference**
				PHYTOPLANKTON, ALGAE, AND MACROPHYTES				
Charophyta (horn worts)								
Chara sp.	stonewort	Churchill	--	1995	July	--	--	Schneider-Vieira et al. 1996
		Churchill	--	1996	July	--	--	Fazakas et al. 1997
		Churchill	--	1999	August	--	--	Neufeld and Bernhardt 2000
		Churchill	--	2001	August	--	--	Bernhardt and Neufeld 2002
Magnoliophyta (flowering plants)								
Carex aquatilis	water sedge	Churchill	--	--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
Eleocharis palustris	common spikerush	Churchill	--	--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
Eleocharis spp.	spikerush	Churchill	--	2001	August	--	--	Bernhardt and Neufeld 2002
Hippuris vulgaris	common mare's tail	Churchill	--	1995	July	--	--	Schneider-Vieira et al. 1996
		Churchill	--	1996	July	--	--	Fazakas et al. 1997
		Churchill	--	2001	August	--	--	Bernhardt and Neufeld 2002
Myriophyllum sibiricum (syn. *Myriophyllum exalbescens*)	water milfoil	Churchill	--	1995	July	--	--	Schneider-Vieira et al. 1996
		Churchill	--	1996	July	--	--	Fazakas et al. 1997
		Churchill	--	1999	August	--	--	Neufeld and Bernhardt 2000
		Churchill	--	2001	August	--	--	Bernhardt and Neufeld 2002
		Churchill	--	2003	August	--	--	Neufeld et al. 2004

Table A-1.1. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Potamogeton alpinus	alpine pondweed	Churchill	--	1995	July	--	--	Schneider-Vieira et al. 1996
		Churchill	--	1996	July	--	--	Fazakas et al. 1997
		Churchill	--	1999	August	--	--	Neufeld and Bernhardt 2000
		Churchill	--	2001	August	--	--	Bernhardt and Neufeld 2002
Potamogeton filiformis	slenderleaf pondweed	Churchill	--	2001	August	--	--	Bernhardt and Neufeld 2002
Potamogeton friesii	Fries' pondweed	Churchill	--	2001	August	--	--	Bernhardt and Neufeld 2002
Potamogeton pusillus	small pondweed	Churchill	--	1999	August	--	--	Neufeld and Bernhardt 2000
		Churchill	--	2001	August	--	--	Bernhardt and Neufeld 2002
Potamogeton richardsonii	claspingleaf pondweed	Churchill	--	1995	July	--	--	Schneider-Vieira et al. 1996
		Churchill	--	1996	July	--	--	Fazakas et al. 1997
		Churchill	--	1999	August	--	--	Neufeld and Bernhardt 2000
		Churchill	--	2001	August	--	--	Bernhardt and Neufeld 2002
Potamogeton strictifolius	narrowleaf pondweed	Churchill	--	1995	July	--	--	Schneider-Vieira et al. 1996
		Churchill	--	1996	July	--	--	Fazakas et al. 1997
		Churchill	--	1999	August	--	--	Neufeld and Bernhardt 2000
Stuckenia vaginatus (syn. *Potamogeton vaginatus*)	sheathed pondweed	Churchill	--	2003	August	--	--	Neufeld et al. 2004

1 - Invertebrate and fish species occurrences in fresh, brackish, and marine habitats as reported by Baker et al. (1993), Merritt and Cummins (1996), Horne (1997), Manitoba Hydro and the Town of Churchill (1997a), Horne and Bretecher (1998), Zrum (1999, 2000), Stewart and Watkinson (2004), and Stewart and Lockhart (2005).
Fish species occurrence (letter codings identify habitat use by each species [Stewart and Lockhart 2005]): M – marine species that do not frequent brackish estuaries or enter fresh water, B – marine species that use brackish estuaries on a seasonal basis, often for nursery grounds, E – estuarine species that can live in brackish water throughtout their lives, A – anadromous species that spawn and winter in fresh water but enter coastal marine waters in summer to feed, S – Semi-anadromous species that are primarily freshwater but enter coastal marine waters to feed, FW – freshwater species that do not frequent brackish or marine water, (T) indicates fish were captured from downstream portions of major tributaries.

2 - Zooplankton and macroinvertebrate estimates of abundance in the Nelson and Churchill rivers are summed over all sites and rounded up to 5 or 10.

3 - Densities shown represent the highest estimates obtained for any site or season (measured in #/m^3).

Table A-1.2. List of zooplankton, macroinvertebrate, fish, and macrophyte taxa recorded from the Nelson and Churchill River estuaries, Hudson Bay, and Hudson Strait from 1988-2005.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
ZOOPLANKTON								
ARTHROPODA								
Cladocera								
Alona guttata	--	Nelson	fresh	1999	Jul/Aug	--	<1	Zrum 2000
Bosmina longirostris	--	Nelson	fresh	1996	July	--	40	Horne 1997
		Nelson	--	1998	July	--	162	Zrum 1999
		Nelson	--	1999	Jul/Aug	--	642	Zrum 2000
Bosmina sp.	--	Nelson	--	1992	August	240	--	Baker et al. 1993
Camptocercus rectirostris	--	Nelson	fresh	1999	Jul/Aug	--	24	Zrum 2000
Ceriodsphnia reticulata	--	Nelson	fresh	1999	Jul/Aug	--	<1	Zrum 2000
Ceriodsphnia sp.	--	Nelson	fresh	1996	July	--	<1	Horne 1997
Chydorus sp.	--	Nelson	fresh	1996	July	--	<1	Horne 1997
Daphnia middendorffiana	--	Nelson	fresh	1999	Jul/Aug	--	7	Zrum 2000
Daphnia retrocurva	--	Nelson	fresh	1999	Jul/Aug	--	81	Zrum 2000
Daphnia sp.	--	Nelson	fresh	1992	August	10	--	Baker et al. 1993
Eurycercus sp.	--	Nelson	--	1988	Sept/Oct	3	--	Baker 1989
Holopedium gibberum	--	Nelson	--	1995	July	--	<1	Baker 1996
Leptodora kindtii	--	Nelson	--	1995	July	--	<1	Baker 1996

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Sida crystallina	--	Nelson	fresh	1999	Jul/Aug	--	7	Zrum 2000
Copepoda								
Acartia bifilosa	--	Nelson	brackish	1988	August	3620	--	Baker 1989
		Nelson		1996	July	--	78616	Horne 1997
Acartia clausi	--	Nelson	brackish	1992	August	4,411,550	--	Baker et al. 1993
		Nelson		1995	July	--	4	Baker 1996
		Churchill		1993	Aug/Sept	1	--	Baker et al. 1994
Acartia clausi complex	--	Nelson	--	1998	July	--	6677	Zrum 1999
		Nelson		1999	Jul/Aug	--	7766	Zrum 2000
Acartia longiremis	--	Nelson	brackish	1997	July	--	22	Horne and Bretecher 1998
		Nelson		1998	August	--	6	Zrum 1999
		Churchill		1994	July	8045	--	Lawrence and Baker 1995
		Hudson Bay and Strait		1993	September	--	--	Harvey et al. 2001
Acartia longispina	--	Nelson	--	1995	July	--	<1	Baker 1996
Acartia sp.	--	Nelson	--	1992	August	22,000	--	Baker et al. 1993
		Nelson		1996	July	--	50510	Horne 1997
		Nelson		1997	July	--	40839	Horne and Bretecher 1998
Ameira longipes	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
Calanus finmarchicus	--	Churchill	--	1993	Aug/Sept	80	--	Baker et al. 1994
		Hudson Bay and Strait		1993	September	--	--	Harvey et al. 2001

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Calanus glacialis	--	Nelson	marine	1992	August	570	--	Baker et al. 1993
		Nelson		1996	July	--	4	Horne 1997
		Nelson		1998	July	--	14	Zrum 1999
		Churchill		1994	July	1055	--	Lawrence and Baker 1995
		Hudson Bay and Strait		1993	September	--	--	Harvey et al. 2001
Calanus hyperboreus	--	Churchill	--	1994	July	9	--	Lawrence and Baker 1995
		Hudson Bay and Strait		1993	September	--	--	Harvey et al. 2001
Calanus sp.	--	Nelson	marine	1995	July	--	2	Baker 1996
		Nelson		1999	Jul/Aug	--	2	Zrum 2000
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Canthocamptus rectinervis	--	Nelson	fresh	1998	July	--	1	Zrum 1999
Canthocamptus sp.	--	Nelson	fresh	1996	July	--	1653	Horne 1997
Centropages hamatus	--	Nelson	marine	1999	Jul/Aug	--	9	Zrum 2000
		Churchill		1993	Aug/Sept	105	--	Baker et al. 1994
		Churchill		1994	July	190	--	Lawrence and Baker 1995
		Hudson Bay and Strait		1993	September	--	--	Harvey et al. 2001
Cyclops bicuspidatus thomasi	--	Nelson	fresh	1997	July	--	83	Horne and Bretecher 1998
		Nelson		1998	July	--	44	Zrum 1999
		Nelson		1999	Jul/Aug	--	274	Zrum 2000
Cyclops scutifer	--	Nelson	--	1995	July	--	<1	Baker 1996

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Cyclops sp.	--	Nelson	--	1995	July	--	<1	Baker 1996
Cyclops vernalis	--	Nelson	fresh	1988	Jun/Jul	90	--	Baker 1989
		Nelson		1997	July	--	1050	Horne and Bretecher 1998
		Nelson		1998	July	--	796	Zrum 1999
		Nelson		1999	Jul/Aug	--	3196	Zrum 2000
		Nelson		1998	July	--	78	Zrum 1999
		Nelson		1999	Jul/Aug	--	137	Zrum 2000
Diaptomus pribilofensis	--	Nelson	fresh	1996	July	--	3	Horne 1997
Diaptomus sicilis	--	Nelson	fresh	1996	July	--	306	Horne 1997
		Nelson		1998	July	--	<1	Zrum 1999
Diaptomus sp.	--	Nelson	fresh	1992	August	40	--	Baker et al. 1993
				1996	July	--	306	Horne 1997
Epischura affinis complex	--	Nelson	--	1999	Jul/Aug	--	7501	Zrum 2000
Epischura lacustris	--	Nelson	--	1992	August	65	--	Baker et al. 1993
		Nelson		1995	July	--	<1	Baker 1996
Epischura nevadensis	--	Nelson	fresh	1992	August	2	--	Baker et al. 1993
		Nelson		1999	Jul/Aug	--	<1	Zrum 2000
Epischura sp.	--	Nelson	--	1995	July	--	<1	Baker 1996
Eucyclops agilis	--	Nelson	fresh	1996	July	--	7	Horne 1997
Eurytemora affinis	--	Nelson	brackish	1988	Jun/Jul	5870	--	Baker 1989
					August	2000	--	Baker 1989
					Sept/Oct	3780	--	Baker 1989

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Eurytemora affinis group	--	Nelson	--	1998	July	--	2784	Zrum 1999
Eurytemora americana	--	Nelson	--	1992	August	2550	--	Baker et al. 1993
Eurytemora herdmani	--	Nelson	brackish	1992	August	5250	--	Baker et al. 1993
		Nelson		1998	July	--	294	Zrum 1999
		Nelson		1999	Jul/Aug	--	35	Zrum 2000
		Churchill		1993	Aug/Sept	2	--	Baker et al. 1994
		Churchill		1994	July	140	--	Lawrence and Baker 1995
Eurytemora raboti	--	Nelson	brackish	1992	August	2000	--	Baker et al. 1993
		Nelson		1996	July	--	5460	Horne 1997
		Churchill		1993	Aug/Sept	1	--	Baker et al. 1994
Eurytemora sp.	--	Nelson	--	1992	August	700	--	Baker et al. 1993
		Nelson		1996	July	--	826	Horne 1997
		Nelson		1997	July	--	16,000	Horne and Bretecher 1998
Harpacticus uniremis	--	Nelson	--	1992	August	7	--	Baker et al. 1993
		Nelson		1995	July	--	<1	Baker 1996
		Churchill		1993	Aug/Sept	6	--	Baker et al. 1994
		Churchill		1994	July	50	--	Lawrence and Baker 1995
Jaschnovia tolli (syn. *Derjujinia tolli*)	--	Nelson	brackish	1996	July	--	11	Horne 1997
		Churchill		1993	Aug/Sept	1	--	Baker et al. 1994
Leptodiaptomus ashlandi (syn. *Diaptomus ashlandi*)	--	Nelson	fresh	1997	July	--	2583	Horne and Bretecher 1998

Table A-1.2. Continued.

Taxon / Species	**Common name**	**Location**	**Habitat[1]**	**Year**	**Month**	**Abundance[2]**	**Density[3]**	**Reference**
Limnocalanus macrurus	--	Nelson	fresh	1988	Aug-Oct	2	--	Baker 1989
		Nelson		1999	Jul/Aug	--	13	Zrum 2000
Macrochiron sp.	--	Churchill	--	1994	July	120	--	Lawrence and Baker 1995
Macrocyclops albidus	--	Nelson	fresh	1996	July	--	22	Horne 1997
Metridia longa		Hudson Bay and Strait	--	1993	September	--	--	Harvey et al. 2001
Microcalanus pygmaeus	--	Nelson	--	1988	August	8	--	Baker 1989
Oithona similis	--	Churchill	--	1994	July	6140	--	Lawrence and Baker 1995
Pseudocalanus minutus	--	Nelson	marine	1992	August	17,200	--	Baker et al. 1993
		Nelson		1999	Jul/Aug	--	18	Zrum 2000
		Churchill		1994	July	10,000	--	Lawrence and Baker 1995
Pseudocalanus sp.	--	Nelson	marine	1996	July	--	306	Horne 1997
		Nelson		1998	July	--	7	Zrum 1999
Pseudocalanus spp.		Hudson Bay and Strait	--	1993	September	--	--	Harvey et al. 2001
Skistodiaptomus oregonensis (syn. *Diaptomus oregonensis*)	--	Nelson	fresh	1997	July	--	<1	Horne and Bretecher 1998
Tisbe furcata	--	Nelson	--	1992	August	940	--	Baker et al. 1993
		Churchill		1994	July	20	--	Lawrence and Baker 1995
Tonicella lineata (syn. *T. blaneyi*)	--	Churchill	--	1993	Aug/Sept	2	--	Baker et al. 1994
Tortanus discaudatus	--	Nelson	brackish	1995	July	--	<1	Baker 1996
		Nelson		1996	July	--	1	Horne 1997

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
		Nelson		1998	July	--	1	Zrum 1999
		Churchill		1993	Aug/Sept	6	--	Baker et al. 1994
CHAETOGNATHA								
Parasagitta elegans (syn. *Sagitta elegans*)	--	Nelson	marine	1998	July	--	1	Zrum 1999
		Churchill		1993	Aug/Sept	12	--	Baker et al. 1994
		Churchill		1994	July	18,372	--	Lawrence and Baker 1995
		Hudson Bay and Strait		1993	September	--	--	Harvey et al. 2001
CHORDATA: UROCHORDATA								
Larvacea								
Fritillaria borealis	--	Nelson	--	1992	August	1		Baker et al. 1993
		Churchill		1994	July	70,292	--	Lawrence and Baker 1995
Oikopleura sp.	--	Nelson	--	1992	August	1		Baker et al. 1993
Oikopleura spp.	--	Hudson Bay and Strait	--	1993	September	--	--	Harvey et al. 2001
Oikopleura vanhoeffeni	--	Churchill	--	1994	July	661	--	Lawrence and Baker 1995
CNIDARIA								
Scyphozoa								
Cyanea capillata	lion's mane	Nelson	marine	1996	July	--	<1	Horne 1997
		Churchill		1993	Aug/Sept	1	--	Baker et al. 1994
		Churchill		1994	July	90	--	Lawrence and Baker 1995

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
CTENOPHORA								
Beroe cucumis	--	Churchill	--	1994	July	4	--	Lawrence and Baker 1995
Mertensia ovum	--	Churchill	--	1993	Aug/Sept	269	--	Baker et al. 1994
		Churchill		1994	July	558	--	Lawrence and Baker 1995
Pleurobrachia pileus	--	Nelson	--	1995	July	--	<1	Baker 1996
		Churchill		1993	Aug/Sept	2	--	Baker et al. 1994
EUPHAUSIACEA								
Thysanoessa raschii	--	Hudson Bay and Strait	--	1993	September	--	--	Harvey et al. 2001
PROTOZOA								
Globigerina sp.	--	Nelson	all	1996	July	--	67	Horne 1997
Gorisella sp.	--	Churchill	--	1994	July	--	--	Lawrence and Baker 1995
ROTIFERA								
Asplanchna sp.	--	Nelson	--	1996	July	--	204	Horne 1997
MACROINVERTEBRATES								
ANNELIDA								
Oligochaeta								
Amphichaeta leydigi	--	Nelson	--	1988	Sept/Oct	95	--	Baker 1989
Chaetogaster diaphanus	--	Nelson	--	1988	Sept/Oct	10	--	Baker 1989

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Limnodrilus hoffmeisteri	--	Nelson	--	1988	Sept/Oct	4920	--	Baker 1989
Limnodrilus profundicola	--	Nelson	--	1988	Sept/Oct	35	--	Baker 1989
Limnodrilus sp.	--	Nelson	--	1988	August	1545	--	Baker 1989
Limnodrilus udekemianus	--	Nelson	--	1988	Sept/Oct	5	--	Baker 1989
Nais communis	--	Nelson	--	1988	Sept/Oct	5	--	Baker 1989
Nais pseudobtusa	--	Nelson	--	1988	Sept/Oct	5	--	Baker 1989
Nais simplex	--	Nelson	--	1988	Sept/Oct	5	--	Baker 1989
Nais sp.	--	Nelson	--	1988	August	15	--	Baker 1989
Nais variabilis	--	Nelson	--	1988	Sept/Oct	45	--	Baker 1989
Paranais litoralis	--	Nelson	--	1988	Sept/Oct	135	--	Baker 1989
Tasserkidrilus kessleri	--	Nelson	--	1988	Jun/Jul	1	--	Baker 1989
Tubifex sp.	--	Nelson	--	1988	August	175	--	Baker 1989
Tubifex tubifex	--	Nelson	--	1988	Sept/Oct	4790	--	Baker 1989
Unicinais uncinata	--	Nelson	--	1988	Sept/Oct	5	--	Baker 1989
Vejdovskyella intermedia	--	Nelson	--	1988	Sept/Oct	5	--	Baker 1989
Polychaeta								
Ampharete acutifrons	--	Churchill	--	1994	July	--	--	Lawrence and Baker 1995
Amphitrite johnstoni	--	Churchill	--	1993	Aug/Sept	2	--	Baker et al. 1994
Anaitides groenlandica (syn. *Phyllodoce groenlandica*)	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Anobothrus gracilis	--	Churchill	--	1993	Aug/Sept	54	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Artacama proboscidea	--	Churchill	--	1993	Aug/Sept	3	--	Baker et al. 1994
Asabellides sp.	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Autolytus alexandri	--	Nelson	--	1992	August	10	--	Baker et al. 1993
Autolytus sp.	--	Nelson	--	1995	July	5	--	Baker 1996
Capitella capitata	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Cirratulus cirratus	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
Eteone sp.	--	Nelson	--	1988	Sept/Oct	5	--	Baker 1989
		Churchill		1993	Aug/Sept	17	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Eulalia sp.	--	Churchill	--	1993	Aug/Sept	5	--	Baker et al. 1994
Hypaniola sp.?	--	Churchill	--	1993	Aug/Sept	5	--	Baker et al. 1994
Laonice cirrata	--	Churchill	--	1993	Aug/Sept	9	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Lepidasthenia commensalis (syn. *Lepidametria commensalis*)	--	Churchill	--	1993	Aug/Sept	2	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Lepidonotus sp.	--	Churchill	--	1993	Aug/Sept	106	--	Baker et al. 1994
Lumbrineris brevipes	--	Churchill	--	1994	July	--	--	Lawrence and Baker 1995
Manayunkia aestuarina	--	Nelson	--	1988	Aug-Oct	7240	--	Baker 1989
Nephtys (*bucera* or *longosetosa*)	--	Churchill	--	1993	Aug/Sept	12	--	Baker et al. 1994
Nephtys caeca	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Nephtys ciliata	--	Churchill	--	1994	July	--	--	Lawrence and Baker 1995
Nephtys sp.	--	Churchill	--	1993	Aug/Sept	383	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Nereis zonata	--	Churchill	--	1993	Aug/Sept	23	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Ophelina aulogaster (syn. *Ammotrypane aulogaster*)	--	Churchill	--	1993	Aug/Sept	5	--	Baker et al. 1994
Ophelia limacina	--	Churchill	--	1993	Aug/Sept	75	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Pectinaria moorei	--	Churchill	--	1994	July	--	--	Lawrence and Baker 1995
Pectinaria sp.	--	Churchill	--	1993	Aug/Sept	672	--	Baker et al. 1994
Pherusa plumosa	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995

Table A-1.2. Continued.

Taxon / Species	**Common name**	**Location**	**Habitat[1]**	**Year**	**Month**	**Abundance[2]**	**Density[3]**	**Reference**
Pholoe minuta	--	Churchill	--	1993	Aug/Sept	70	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Proceraea spp.	--	Nelson	marine	1999	Jul/Aug	--	<1	Zrum 2000
Scoloplos acutus	--	Churchill	--	1993	Aug/Sept	13	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Spio sp.	--	Nelson	marine	1996	July	--	<1	Horne 1997
Travisia sp.	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Terebellides stroemi	--	Churchill	--	1993	Aug/Sept	19	--	Baker et al. 1994
ARTHROPODA								
Amphipoda								
Ampelisca eschrichti	--	Churchill	--	1993	Aug/Sept	62	--	Baker et al. 1994
Andaniexis abyssi	--	Churchill	--	1994	July	6	--	Lawrence and Baker 1995
Apherusa glacialis	--	Churchill	--	1994	July	5	--	Lawrence and Baker 1995
Apherusa megalops	--	Hudson Bay	--	1988	Feb-Jun	present	--	Siferd et al. 1997
Byblis serrata	--	Churchill	--	1994	July	--	--	Lawrence and Baker 1995
Calliopius laeviusculus	--	Hudson Bay	--	1988	Feb-Jun	present	--	Siferd et al. 1997
Caprella sp.	--	Churchill	--	1993	Aug/Sept	2	--	Baker et al. 1994
Diporeia brevicornis	--	Nelson	fresh	1997	July	--	14	Horne and Bretecher 1998
Dyopedos porrectus (syn. *Dulichia porrecta*)	--	Churchill	--	1994	July	--	--	Lawrence and Baker 1995

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Gammaracanthus loricatus	--	Nelson	fresh/brack	1988	Aug-Oct	2	--	Baker 1989
		Nelson		1999	Jul/Aug	--	<1	Zrum 2000
		Churchill		1993	Aug/Sept	20	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995
		Hudson Bay		1988	Feb-Jun	present	--	Siferd et al. 1997
Gammarellus homari	--	Hudson Bay	--	1988	Feb-Jun	present	--	Siferd et al. 1997
Gammarus homari	--	Nelson	--	1995	July	--	1	Baker 1996
Gammarus oceanicus	--	Nelson	marine	1988	August	2	--	Baker 1989
		Nelson		1999	Jul/Aug	--	<1	Zrum 2000
		Hudson Bay		1988	Feb-Jun	present	--	Siferd et al. 1997
Gammarus setosus	--	Nelson	fresh	1992	August	4	--	Baker et al. 1993
		Nelson		1996	July	--	<1	Horne 1997
		Churchill		1994	July	--	--	Lawrence and Baker 1995
		Hudson Bay		1988	Feb-Jun	present	--	Siferd et al. 1997
Gammarus wilkitzkii	--	Nelson	marine	1999	Jul/Aug	--	<1	Zrum 2000
		Churchill		1993	Aug/Sept	106	--	Baker et al. 1994
Halirages sp.	--	Churchill	--	1994	July	--	--	Lawrence and Baker 1995
Hyperia galba	--	Nelson	--	1995	July	--	<1	Baker 1996
		Churchill		1993	Aug/Sept	582	--	Baker et al. 1994
		Churchill		1994	July	7	--	Lawrence and Baker 1995
		Hudson Bay and Strait		1993	September	--	--	Harvey et al. 2001

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Hyalella azteca	--	Nelson	fresh	1997	July	--	<1	Horne and Bretecher 1998
Hyperoche medusarum	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
Ischyrocerus anguipes	--	Hudson Bay	--	1988	Feb-Jun	present	--	Siferd et al. 1997
Lysianopsis sp.	--	Churchill	--	1994	July	--	--	Lawrence and Baker 1995
Metopa sp.	--	Churchill	--	1993	Aug/Sept	69	--	Baker et al. 1994
Metopa spp.	--	Hudson Bay	--	1988	Feb-Jun	present	--	Siferd et al. 1997
Metopella angusta	--	Churchill	--	1994	July	--	--	Lawrence and Baker 1995
Monoculodes borealis	--	Nelson	marine	1988	Sept/Oct	80	--	Baker 1989
		Nelson		1999	Jul/Aug	--	1	Zrum 2000
		Churchill		1993	Aug/Sept	86	--	Baker et al. 1994
Monoculodes sp.	--	Nelson	--	1988	August	8	--	Baker 1989
		Churchill		1994	July	--		Lawrence and Baker 1995
Onisimus glacialis	--	Nelson	--	1999	Jul/Aug	--	<1	Zrum 2000
		Churchill		1993	Aug/Sept	4	--	Baker et al. 1994
Onisimus litoralis	--	Nelson	brack/mar	1988	Aug-Oct	61	--	Baker 1989
		Nelson		1997	July	--	<1	Horne and Bretecher 1998
		Churchill		1994	July	16	--	Lawrence and Baker 1995
Onisimus nanseni	--	Churchill	--	1993	Aug/Sept	29	--	Baker et al. 1994
Onisimus sp.	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
Onisimus spp.	--	Hudson Bay	--	1988	Feb-Jun	present	--	Siferd et al. 1997
Orchomene sp.	--	Churchill	--	1994	July	--	--	Lawrence and Baker 1995

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Pontoporeia affinis	--	Nelson	--	1992	August	1	--	Baker et al. 1993
Pontoporeia femorata	--	Churchill	--	1993	Aug/Sept	13	--	Baker et al. 1994
Pontoporeia sp.	--	Nelson	--	1995	July	--	<1	Baker 1996
Pontogeneia inermis	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
		Hudson Bay		1988	Feb-Jun	present	--	Siferd et al. 1997
Themisto abyssorum (syn. *Parathemisto abyssorum*)	--	Nelson	--	1995	July	--	<1	Baker 1996
		Churchill		1993	Aug/Sept	1	--	Baker et al. 1994
		Hudson Bay and Strait		1993	September	--	--	Harvey et al. 2001
Themisto compressa (syn. *Parethemisto compressa*)	--	Churchill	--	1994	July	--	--	Lawrence and Baker 1995
Themisto libellula (syn. *Parathemisto libellula*)	--	Nelson	--	1995	July	--	<1	Baker 1996
		Churchill		1993	Aug/Sept	1	--	Baker et al. 1994
		Churchill		1994	July	3301	--	Lawrence and Baker 1995
		Hudson Bay and Strait		1993	September	--	--	Harvey et al. 2001
Themisto spp.	--	Hudson Bay	--	1988	Feb-Jun	present	--	Siferd et al. 1997
Weyprechtia pinguis	--	Hudson Bay	--	1988	Feb-Jun	present	--	Siferd et al. 1997
Arachnida								
Hydrachna sp.	--	Nelson	--	1996	July	--	5	Horne and Bretecher 1998
Pontoporeia affinis	--	Nelson	--	1992	August	1	--	Baker et al. 1993

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Spechon sp.	--	Nelson	--	1988	August	1	--	Baker 1989
Branchiopoda								
Lynceus brachyurus	common lynceus	Churchill	--	1994	July	--	--	Lawrence and Baker 1995
Cirripedia								
Balanus crenatus	--	Churchill	brack/mar	1994	July	--	--	Lawrence and Baker 1995
Balanus sp.	--	Churchill	marine	1993	Aug/Sept	10	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Semibalanus balanoides (syn. *Balanus balanoides*)	--	Churchill	marine	1993	Aug/Sept	4	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Cumacea								
Diastylis rathkei	--	Churchill	--	1993	Aug/Sept	35	--	Baker et al. 1994
Diastylis quadrispinosa	--	Churchill	--	1994	July	--		Lawrence and Baker 1995
Diastylis scorpioides	--	Nelson	marine	1999	Jul/Aug	--	<1	Zrum 2000
Diastylis sp.	--	Churchill	--	1994	July	103	--	Lawrence and Baker 1995
Lamprops quadriplicatus (syn. *Lamprops quadriplicata*)	--	Churchill	--	1994	July	--	--	Lawrence and Baker 1995
Decapoda								
Atelecyclus sp.	--	Nelson	marine	1998	July	--	<1	Zrum 1999
Brachyura (short-tailed crabs, true crabs)	--	Churchill	--	1994	July	--	--	Lawrence and Baker 1995

Table A-1.2. Continued.

Taxon / Species	**Common name**	**Location**	**Habitat[1]**	**Year**	**Month**	**Abundance[2]**	**Density[3]**	**Reference**
Eualus gaimardi	--	Churchill	--	1993	Aug/Sept	2	--	Baker et al. 1994
Eualus sp.	--	Churchill	--	1993	Aug/Sept	2	--	Baker et al. 1994
Hyas coarctatus	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
Hyas sp.	--	Nelson	marine	1988	August	3	--	Baker 1989
		Nelson		1996	July	--	<1	Horne 1997
		Churchill		1993	Aug/Sept	71	--	Baker et al. 1994
		Churchill		1994	July	9200	--	Lawrence and Baker 1995
Orconectes virilis	virile crayfish	Nelson	fresh	1998	July	--	<1	Zrum 1999
Spirontocaris sp.	--	Churchill	--	1993	Aug/Sept	12	--	Baker et al. 1994
Diptera								
Cyphomella sp.	midge	Churchill	fresh	1994	July	--	--	Lawrence and Baker 1995
Simulium sp.	black fly	Nelson	fresh	1999	Jul/Aug	--	2	Zrum 2000
Ephemeroptera								
Ameletus sp.	primitive minnow mayfly	Nelson	fresh	1996	July	--	1	Horne 1997
Baetis sp.	small minnow mayfly	Nelson	fresh	1998	July	--	4	Zrum 1999
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Caenis sp.	small squaregill mayfly	Nelson	fresh	1999	Jul/Aug	--	<1	Zrum 2000
Heptagenia sp.	flatheaded mayfly	Nelson	fresh	1997	July	--	<1	Horne and Bretecher 1998
Hexagenia sp.	common burrower mayfly	Nelson	fresh	1998	July	--	<1	Zrum 1999

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Isopoda								
Saduria entomon (syn. *Mesidotea entomon*)	--	Nelson	marine	1999	Jul/Aug	--	<1	Zrum 2000
Mysidacea								
Mysis litoralis	--	Nelson	marine	1988	Jun/Jul	1205	--	Baker 1989
		Nelson		1988	August	6780	--	Baker 1989
		Nelson		1988	Sept/Oct	5030	--	Baker 1989
		Nelson		1992	August	1,146,250	--	Baker et al. 1993
		Nelson		1997	July	--	8	Horne and Bretecher 1998
		Nelson		1998	July	--	82	Zrum 1999
		Churchill		1993	Aug/Sept	1609	--	Baker et al. 1994
		Churchill		1994	July	16	--	Lawrence and Baker 1995
Mysis ocultus	--	Nelson	marine	1999	Jul/Aug	--	<1	Zrum 2000
Mysis sp.	--	Churchill	--	1994	July	70	--	Lawrence and Baker 1995
Plecoptera								
Haploperla brevis	least sallfly	Nelson	fresh	1997	July	--	<1	Horne and Bretecher 1998
Isoperla sp.	perlodid stonefly	Nelson	fresh	1999	Jul/Aug	--	<1	Zrum 2000
Perlesta placida	freckled stone	Nelson	fresh	1997	July	--	<1	Horne and Bretecher 1998
Pycnogonida								
Nymphon hirtipes	--	Churchill	--	1994	July	--	--	Lawrence and Baker 1995

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Trichoptera								
Brachycentrus sp.	humpless case maker	Nelson	fresh	1997	July	--	<1	Horne and Bretecher 1998
Cheumatopsyche sp.	common netspinner	Nelson	fresh	1997	July	--	8	Horne and Bretecher 1998
Hydropsyche sp.	common netspinner	Nelson	fresh	1998	July	--	1	Zrum 1999
Hydroptila sp.	micro caddisfly	Nelson	fresh	1997	July	--	<1	Horne and Bretecher 1998
Lepidostoma sp.	lepidostomatid case maker	Nelson	fresh	1998	July	--	<1	Zrum 1999
Oecetis sp.	longhorned case maker	Nelson	fresh	1997	July	--	<1	Horne and Bretecher 1998
	--	Nelson	fresh	1999	Jul/Aug	--	<1	Zrum 2000
Polycentropus sp.	trumpetnet and tubemaker	Nelson	fresh	1998	July	--	1	Zrum 1999
Potamyia sp.	common netspinner	Nelson	fresh	1997	July	--	<1	Horne and Bretecher 1998
Protoptila sp.	saddlecase maker	Nelson	fresh	1997	July	--	10	Horne and Bretecher 1998
Psychomyia sp.	nettube caddisfly	Nelson	fresh	1997	July	--	<1	Horne and Bretecher 1998
Stactobiella sp.	micro caddisfly	Nelson	fresh	1998	July	--	<1	Zrum 1999
Triaenodes sp.	longhorned case maker	Nelson	fresh	1999	Jul/Aug	--	<1	Zrum 2000
BRACHIOPODA								
Cyzicus setosa (syn. *Caenestheriella setosa*)	--	Nelson	--	1995	July	--	<1	Baker 1996
Hemithiris psittacea	--	Churchill	--	1993	Aug/Sept	12	--	Baker et al. 1994

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
BRYOZOA								
Alcyonidium sp.	--	Churchill	--	1994	July	--	--	Lawrence and Baker 1995
Callopora sp.	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
Cristatella mucedo	--	Nelson	--	1988	Jun-Oct	38	--	Baker 1989
Eucratea loricata	--	Nelson	--	1988	Aug-Oct	present	--	Baker 1989
Hippothoa sp.	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
Lichenopora sp.	--	Churchill	--	1993	Aug/Sept	2	--	Baker et al. 1994
Tricellaria peachii	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Tubulipora sp.	--	Churchill	--	1993	Aug/Sept	2	--	Baker et al. 1994
CHORDATA								
Ascidiacea								
Boltenia echinata	--	Churchill	--	1993	Aug/Sept	5	--	Baker et al. 1994
Boltenia ovifera	--	Churchill	--	1993	Aug/Sept	9	--	Baker et al. 1994
Bostrichobranchus pilularis	--	Churchill	--	1993	Aug/Sept	7	--	Baker et al. 1994
Distaplia clavata	--	Churchill	--	1993	Aug/Sept	2	--	Baker et al. 1994
Molgula citrina	--	Churchill	--	1993	Aug/Sept	4	--	Baker et al. 1994
Molgula griffithsii	--	Churchill	--	1993	Aug/Sept	4	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
CNIDARIA								
Anthozoa								
Aulactinia stella (syn. *Bunodactis stella*)	--	Churchill	--	1993	Aug/Sept	17	--	Baker et al. 1994
Stomphia coccinea	--	Churchill	--	1993	Aug/Sept	2	--	Baker et al. 1994
		Churchill		1994	July	--		Lawrence and Baker 1995
Hydrozoa								
Aeginopsis laurentii	--	Nelson	--	1995	July	--	<1	Baker 1996
		Churchill		1993	Aug/Sept	2346	--	Baker et al. 1994
		Churchill		1994	July	341	--	Lawrence and Baker 1995
Aglantha digitalis	--	Nelson	--	1992	August	1	--	Baker et al. 1993
		Nelson		1995	July	--	<1	Baker 1996
		Churchill		1993	Aug/Sept	229	--	Baker et al. 1994
		Churchill		1994	July	360	--	Lawrence and Baker 1995
Bougainvillia principis	--	Nelson	marine	1996	July	--	<1	Horne 1997
		Churchill		1993	Aug/Sept	100	--	Baker et al. 1994
		Churchill		1994	July	275	--	Lawrence and Baker 1995
Bougainvillia superciliaris	--	Nelson	--	1999	Jul/Aug	--	<1	Zrum 2000
Campanularia sp.	--	Churchill	--	1993	Aug/Sept	5	--	Baker et al. 1994
Diphasia pulchra	--	Nelson	--	1988	August	present	--	Baker 1989

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Halitholus cirratus	--	Churchill	--	1993	Aug/Sept	22	--	Baker et al. 1994
	--	Churchill		1994	July	11	--	Lawrence and Baker 1995
Hartlaubella gelatinosa	--	Nelson	--	1988	Aug-Oct	present	--	Baker 1989
Hartlaubella sp.	--	Nelson	--	1988	Jun-Oct	present	--	Baker 1989
Hippopodius hippopus	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
Hydra sp.	--	Nelson	fresh	1992	August	1280	--	Baker et al. 1993
		Nelson		1999	Jul/Aug	--	53	Zrum 2000
Leuckartiara nobilis	--	Churchill	--	1994	July	1	--	Lawrence and Baker 1995
Obelia sp.	--	Churchill	--	1993	Aug/Sept	10	--	Baker et al. 1994
		Churchill		1994	July	25	--	Lawrence and Baker 1995
Phialidium languidum	--	Churchill	--	1993	Aug/Sept	4	--	Baker et al. 1994
		Churchill		1994	July	35	--	Lawrence and Baker 1995
Sarsia princeps	--	Nelson	marine	1992	August	8	--	Baker et al. 1993
		Nelson		1999	Jul/Aug	--	1	Zrum 2000
		Churchill		1993	Aug/Sept	458	--	Baker et al. 1994
		Churchill		1994	July	340	--	Lawrence and Baker 1995
Sertularia schmidti	--	Nelson	--	1988	Aug-Oct	present	--	Baker 1989
Sertularia sp.	--	Nelson	--	1988	August	present	--	Baker 1989
Sertularia tenera	--	Nelson	--	1988	Aug-Oct	present	--	Baker 1989
Tima formosa	--	Churchill	--	1993	Aug/Sept	6	--	Baker et al. 1994

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
ECHINODERMATA								
Asteroidea								
Asterias rubens	--	Churchill	marine	1993	Aug/Sept	5	--	Baker et al. 1994
Holothuroidea								
Psolus fabricii	--	Churchill	marine	1993	Aug/Sept	19	--	Baker et al. 1994
Ophiurida								
Ophiomusium lymani	--	Churchill	marine	1993	Aug/Sept	1	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995
MOLLUSCA								
Bivalvia								
Congeria conradi	--	Churchill	--	1993	Aug/Sept	70	--	Baker et al. 1994
Crenella glandula	glandular crenella	Churchill	--	1993	Aug/Sept	64	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Cyrtodaria kurriana	Kurr propeller clam	Nelson	--	1988	Sept/Oct	5	--	Baker 1989
Ennucula tenuis (syn. *Nucula tenuis*)	smooth nutclam	Churchill	--	1993	Aug/Sept	8	--	Baker et al. 1994
Hiatella arctica	Arctic hiatella	Churchill	--	1993	Aug/Sept	2	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Macoma baltica	baltic macoma	Nelson	--	1988	Sept/Oct	1820	--	Baker 1989
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Macoma sp.	--	Nelson	brack/mar	1996	July	--	1	Horne 1997
		Churchill		1993	Aug/Sept	95	--	Baker et al. 1994
Musculus discors	discordant mussel	Churchill	--	1993	Aug/Sept	24	--	Baker et al. 1994
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Mya arenaria	softshell clam	Churchill	--	1994	July	--	--	Lawrence and Baker 1995
Mytilus edulis	blue mussel	Nelson	--	1988	August	700	--	Baker 1989
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Thyasira flexuosa	flexuose cleft clam	Churchill	--	1993	Aug/Sept	102	--	Baker et al. 1994
Tonicella lineata (syn. *Tonicella blaneyi*)	--	Churchill	--	1993	Aug/Sept	4	--	Baker et al. 1994
Gastropoda								
Acanthodoris pilosa	hairy spiny doris	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
Tectura testudinalis (syn. *Acmaea testudinalis*)	plant limpet	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
Acteocina sp.	--	Churchill	--	1993	Aug/Sept	2	--	Baker et al. 1994
Alderia modesta (syn. *Alderia harvardiensis*)	modest alderia	Churchill	--	1993	Aug/Sept	4	--	Baker et al. 1994
Clione limacina	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
		Churchill		1994	July	77	--	Lawrence and Baker 1995

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
		Hudson Bay and Strait		1993	September	--	--	Harvey et al. 2001
Gyraulus parvus	ash gyro	Nelson	--	1988	Sept/Oct	5	--	Baker 1989
		Churchill		1994	July	--	--	Lawrence and Baker 1995
Limacina helicina	helicid pteropod	Churchill	--	1994	July	159	--	Lawrence and Baker 1995
		Hudson Bay and Strait		1993	September	--	--	Harvey et al. 2001
Limacina sp.	--	Hudson Bay and Strait	--	1993	September	--	--	Harvey et al. 2001
Lymnaea sp.	--	Nelson	--	1988	August	5	--	Baker 1989
Margarites helicinus	spiral margarite	Churchill	--	1993	Aug/Sept	11	--	Baker et al. 1994
Margarites olivaceus	olive margarite	Nelson	--	1988	August	5	--	Baker 1989
Mohnia sp.	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
Omalogyra sp.	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
Physa jennessi	obtuse physa	Nelson	--	1988	August	5	--	Baker 1989
Probythinella lacustris	delta hydrobe	Nelson	--	1988	Sept/Oct	5	--	Baker 1989
Propebela turricula	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
Solariella obscura	obscure solarelle	Churchill	--	1993	Aug/Sept	3	--	Baker et al. 1994
Trophonopsis sp.	--	Churchill	--	1993	Aug/Sept	1	--	Baker et al. 1994
Valvata sincera	mossy valvata	Nelson	--	1988	August	5	--	Baker 1989
NEMERTEA								
Tubulanus sp.	--	Churchill	--	1993	Aug/Sept	22	--	Baker et al. 1994

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
		Churchill		1994	July	--	--	Lawrence and Baker 1995
PORIFERA								
Hymeniacidon heliophila	--	Churchill	--	1993	Aug/Sept	2	--	Baker et al. 1994
SIPUNCULA								
Themiste alutacea	--	Churchill	--	1994	July	--	--	Lawrence and Baker 1995
			FISHES					
AGONIDAE								
Aspidophoroides monopterygius	alligatorfish	Hudson Strait	M	--	--	--	--	Stewart and Lockhart 2005
Leptagonus decagonus	alligator poacher	Hudson Bay and Strait	M	--	--	--	--	Stewart and Lockhart 2005
Ulcina olriki	Atlantic alligatorfish	Churchill	M	1994	July	1	--	Lawrence and Baker 1995
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
AMMODYTIDAE								
Ammodytes americanus	American sand lance	Nelson	B	1992	August	630	--	Baker et al. 1993
		Nelson		1998	July	--	600	Zrum 1999
		Churchill		1993	Aug/Sept	65	--	Baker et al. 1994
		Churchill		1994	July	70	--	Lawrence and Baker 1995

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
Ammodytes dubius	northern sand lance	Hudson Bay and Strait	B	--	--	--	--	Stewart and Lockhart 2005
Ammodytes hexapterus	stout sand lance	Nelson	B	1992	August	1325	--	Baker et al. 1993
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
ANARHICHADIDAE								
Anarhichas lupus	Atlantic wolffish	Hudson Strait	M	--	--	--	--	Stewart and Lockhart 2005
Anarhichas minor	spotted wolffish	Hudson Strait	M	--	--	--	--	Stewart and Lockhart 2005
CATOSTOMIDAE								
Catostomus catostomus	longnose sucker	Nelson	S	1988	Jun-Oct	90	--	Baker 1989
		Nelson		1989	August	194	--	Baker 1990
		Nelson, Hudson Bay and Strait		--	--	--		Stewart and Lockhart 2005
CLUPEIDAE								
Clupea harengus	Atlantic herring	Hudson Bay and Strait	M	--	--	--	--	Stewart and Lockhart 2005

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
COTTIDAE								
Artediellus scaber	rough hookear	Hudson Strait	M	--	--	--	--	Stewart and Lockhart 2005
Artediellus uncinatus	Arctic hookear sculpin	Hudson Strait	M	--	--	--	--	Stewart and Lockhart 2005
Cottus cognatus	slimy sculpin	Nelson	S	1988	Sept/Oct	10	--	Baker 1989
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
Cottus ricei	spoonhead sculpin	Nelson	S	1988	Jun-Oct	25	--	Baker 1989
		Nelson		1999	Jul/Aug	--	<1	Zrum 2000
		Hudson Bay		--	--	--	--	Stewart and Lockhart 2005
Gymnocanthus tricuspis	Arctic staghorn sculpin	Churchill	B	1994	July			Lawrence and Baker 1995
		Churchill		--		--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
Icelus bicornis	twohorn sculpin	Hudson Bay and Strait	M	--	--	--	--	Stewart and Lockhart 2005
Icelus spatula	spatulate sculpin	Hudson Bay and Strait	M	--	--	--	--	Stewart and Lockhart 2005
Myoxocephalus aenaeus	grubby	Hudson Strait	B	--	--	--	--	Stewart and Lockhart 2005
Myoxocephalus octodecemspinusus	longhorn sculpin	Hudson Strait	M	--	--	--	--	

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Myoxocephalus quadricornis	fourhorn sculpin	Nelson	E	1988	Sept/Oct	15	--	Baker 1989
		Nelson		1992	August	30	--	Baker et al. 1993
		Nelson		1998	July	--	<1	Zrum 1999
		Churchill		1993	Aug/Sept	1	--	Baker et al. 1994
		Churchill		1994	July	5	--	Lawrence and Baker 1995
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
Myoxocephalus scorpioides	Arctic sculpin	Churchill	B	1994	July	--	--	Lawrence and Baker 1995
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
Myoxocephalus scorpius	shorthorn sculpin	Nelson	B	1998	July	--	<1	Zrum 1999
		Churchill		1994	July	--	--	Lawrence and Baker 1995
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
Triglops murrayi	moustache sculpin	Hudson Bay and Strait	M	--	--	--	--	Stewart and Lockhart 2005
Triglops nybelini	bigeye sculpin	Hudson Bay and Strait	M	--	--	--	--	Stewart and Lockhart 2005

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Triglops pingeli	ribbed sculpin	Churchill	M	1994	July	1	--	Lawrence and Baker 1995
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
CYCLOPTERIDAE								
Cyclopterus lumpus	lumpfish	Churchill	M	--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
Eumicrotremus derjugini	leatherfin lumpsucker	Hudson Bay and Strait	M	--	--	--	--	Stewart and Lockhart 2005
Eumicrotremus spinosus	spiny lumpsucker	Churchill	M	--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
CYPRINIDAE								
Margariscus margarita	pearl dace	Nelson	FW	1988	Sept/Oct	5	--	Baker 1989
Notropis atherinoides	emerald shiner	Nelson	S	1988	Jun-Oct	790	--	Baker 1989
		Nelson, Hudson Bay		--	--	--	--	Stewart and Lockhart 2005
Notropis hudsonius	spottail shiner	Nelson	S	1988	Sept/Oct	5	--	Baker 1989
Phoxinus neogaeus	finescale dace	Nelson	S	1988	Sept/Oct	5	--	Baker 1989
Rhinichthys cataractae	longnose dace	Nelson	S	1988	Jun-Aug	15	--	Baker 1989

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
ESOCIDAE								
Esox lucius	northern pike	Nelson	S	1989	August	1	--	Baker 1990
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
GADIDAE								
Arctogadus glacialis	polar cod	Hudson Bay and Strait	M	--	--	--	--	Stewart and Lockhart 2005
Boreogadus saida	Arctic cod	Nelson	M	1995	July	--	<1	Baker 1996
		Churchill		1993	Aug/Sept	1	--	Baker et al. 1994
		Churchill		1994	July	2	--	Lawrence and Baker 1995
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
Gadus morhua	Atlantic cod	Hudson Strait	M	--	--	--	--	Stewart and Lockhart 2005
Gadus ogac	Greenland cod	Churchill	B	--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
Lota lota	burbot	Nelson	S	1988	Jun-Oct	5	--	Baker 1989
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
GASTEROSTEIDAE								
Gasterosteus aculeatus	threespine stickleback	Nelson	A	1988	Aug-Oct	65	--	Baker 1989
		Nelson		1999	Jul/Aug	--	<1	Zrum 2000
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
Pungitius pungitius	ninespine stickleback	Nelson	A	1988	Jun-Oct	70	--	Baker 1989
		Nelson		1992	August	70	--	Baker et al. 1993
		Nelson		1999	Jul/Aug	--	<1	Zrum 2000
		Churchill		1993	Aug/Sept	2	--	Baker et al. 1994
		Churchill		1994	July	1	--	Lawrence and Baker 1995
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
LIPARIDAE								
Liparis atlanticus	Atlantic snailfish	Hudson Strait	M	--	--	--	--	Stewart and Lockhart 2005
Liparis fabricii	gelatinous snailfish	Churchill	M	1994	July	2	--	Lawrence and Baker 1995
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Liparis gibbus	dusky snailfish	Hudson Bay and Strait	M	--	--	--	--	Stewart and Lockhart 2005
Liparis tunicatus	kelp snailfish	Hudson Bay and Strait	M	--	--	--	--	Stewart and Lockhart 2005
OSMERIDAE								
Mallotus villosus	capelin	Nelson	B	1988	Aug-Oct	70	--	Baker 1989
		Nelson		1999	Jul/Aug	--	173	Zrum 2000
		Churchill		1993	Aug/Sept	1235	--	Baker et al. 1994
		Churchill		1994	July	1849	--	Lawrence and Baker 1995
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		Nelson, Churchill, Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
Osmerus mordax	rainbow smelt	Nelson	A	1998	July	--	<1	Zrum 1999
		Nelson, Churchill, Hudson Bay		--	--	--	--	Stewart and Lockhart 2005
PERCIDAE								
Perca flavescens	yellow perch	Nelson	S	1988	Sept/Oct	10	--	Baker 1989
Percina caprodes	logperch	Nelson	FW	1996	July	--	<1	Horne 1997
Percina shumardi	river darter	Nelson	FW	1988	Jun-Aug	5	--	Baker 1989

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
PERCOPSIDAE								
Percopsis omiscomaycus	trout-perch	Nelson	S	1988	Sept/Oct	10	--	Baker 1989
		Nelson		1996	July	--	<1	Horne 1997
		Hudson Bay?		--	--	--	--	Stewart and Lockhart 2005
PHOLIDAE								
Pholis fasciata	banded gunnel	Churchill	M	--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
PLEURONECTIDAE								
Hippoglossoides platessoides	Canadian plaice	Hudson Bay?, Hudson Strait	B	--	--	--	--	Stewart and Lockhart 2005
Reinhardtius hippoglossoides	Greenland halibut	Hudson Bay?, Hudson Strait	M	--	--	--	--	Stewart and Lockhart 2005
SALMONIDAE								
Coregonus artedi	cisco	Nelson	A	1988	Jun-Oct	25	--	Baker 1989
		Nelson		1992	August	20	--	Baker et al. 1993
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
Coregonus clupeaformis	lake whitefish	Nelson	A	1988	Jun-Oct	25	--	Baker 1989
		Nelson		1989	August	154	--	Baker 1990
		Churchill		1995	May/Jun	218	--	Remnant and Kitch 1996
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
Prosopium cylindraceum	round whitefish	Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
Salvelinus alpinus	Arctic charr	Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
Salvelinus fontinalis	brook trout	Nelson	A	1989	August	1	--	Baker 1990
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
SCORPAENIDAE								
Sebastes mentella	deepwater redfish	Hudson Strait	M	--	--	--	--	Stewart and Lockhart 2005
Sebastes norvegicus	golden redfish	Hudson Strait	M	--	--	--	--	Stewart and Lockhart 2005

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
STICHAEIDAE								
Anisarchus medius	stout eelblenny	Hudson Bay and Strait	M	--	--	--	--	Stewart and Lockhart 2005
Eumesogrammus praecisus	fourline snakeblenny	Hudson Bay and Strait	M	--	--	--	--	Stewart and Lockhart 2005
Leptoclinus maculatus	daubed shanny	Hudson Bay?, Hudson Strait	M	--	--	--	--	Stewart and Lockhart 2005
Lumpenus fabricii	slender eelblenny	Nelson	B	1992	August	1	--	Baker et al. 1993
		Nelson		1998	July	--	<1	Zrum 1999
		Churchill		1993	Aug/Sept	1	--	Baker et al. 1994
		Churchill		1994	July	present	--	Lawrence and Baker 1995
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005
Lumpenus lampretaeformis	snake blenny	Hudson Strait	M	--	--	--	--	Stewart and Lockhart 2005
Stichaeus punctatus	Arctic shanny	Nelson	B	1988	Sept/Oct	5	--	Baker 1989
		Churchill		1994	July	2	--	Lawrence and Baker 1995
		Churchill		--	--	--	--	Manitoba Hydro and the Town of Churchill 1997*a*
		Hudson Bay and Strait		--	--	--	--	Stewart and Lockhart 2005

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
ZOARCIDAE								
Gymnelus barsukovi	Barsukov's pout	Hudson Bay and Strait	M	--	--	--	--	Stewart and Lockhart 2005
Gymnelus viridis	fish doctor	Hudson Bay and Strait?	M	--	--	--	--	Stewart and Lockhart 2005
Lycodes esmarkii	greater eelpout	Hudson Strait	M	--	--	--	--	Stewart and Lockhart 2005
Lycodes mucosus	saddled eelpout	Hudson Strait	M	--	--	--	--	Stewart and Lockhart 2005
Lycodes pallidus	pale eelpout	Hudson Bay? and Strait	M	--	--	--	--	Stewart and Lockhart 2005
Lycodes polaris	polar eelpout	Hudson Strait	M	--	--	--	--	Stewart and Lockhart 2005
Lycodes reticulatus	Arctic eelpout	Hudson Bay and Strait	M	--	--	--	--	Stewart and Lockhart 2005
Lycodes vahlii	checher eelpout	Hudson Strait	M	--	--	--	--	Stewart and Lockhart 2005

Table A-1.2. Continued.

Taxon / Species	Common name	Location	Habitat[1]	Year	Month	Abundance[2]	Density[3]	Reference
				PHYTOPLANKTON, ALGAE, AND MACROPHYTES				
Magnoliophyta (flowering plants)								
Calamagrostis deschampsioides	circumpolar reedgrass	Churchill	--	--	--	--	--	Manitoba Hydro and the Town of Churchill 1997b
Eleocharis acicularis	needle spikerush	Churchill	--	--	--	--	--	Manitoba Hydro and the Town of Churchill 1997a
Puccinellia phryganodes	creeping alkaligrass	Churchill	--	--	--	--	--	Manitoba Hydro and the Town of Churchill 1997a

1 - Invertebrate and fish species occurrences in fresh, brackish, and marine habitats as reported by Baker et al. (1993), Merritt and Cummins (1996), Horne (1997), Manitoba Hydro and the Town of Churchill (1997a), Horne and Bretecher (1998), Zrum (1999, 2000), Stewart and Watkinson (2004), and Stewart and Lockhart (2005).
Fish species occurrence (letter codings identify habitat use by each species [Stewart and Lockhart 2005]): M – marine species that do not frequent brackish estuaries or enter fresh water, B – marine species that use brackish estuaries on a seasonal basis, often for nursery grounds, E – estuarine species that can live in brackish water throughtout their lives, A – anadromous species that spawn and winter in fresh water but enter coastal marine waters in summer to feed, S – Semi-anadromous species that are primarily freshwater but enter coastal marine waters to feed, FW – freshwater species that do not frequent brackish or marine water

2 - Zooplankton and macroinvertebrate estimates of abundance in the Nelson and Churchill rivers are summed over all sites and rounded up to 5 or 10.

3 - Densities shown represent the highest estimates made from open-water (#/m^3) sampling.

APPENDIX 2.

LIST OF INVASIVE SPECIES IN THE LAURENTIAN GREAT LAKES AND THE NORTH AND BALTIC SEAS.

Table A-2.1. List of aquatic non-indigenous taxa reported from the Laurentian Great Lakes since the 1830s.

Taxon / Species	Common name	Origin	Date	Location	Mechanism / Vector	Source
			ZOOPLANKTON			
ARTHROPODA						
Cladocera						
Bythotrephes longimanus (syn. *Bythotrephes cederstroemi*)	spiny waterflea	Eurasia	1982[a] / 1984[b]	Lake Huron	Shipping (ballast water)	[a]Bur et al. 1986; [b]Mills et al. 1993a; [b]Holeck et al. 2004; Lange and Cap 1986; Yan et al. 1992
Cercopagis pengoi	fish-hook waterflea	Ponto-Caspian	1998	--	Shipping (ballast-mediated vector, fouling)	MacIsaac et al. 1999; Holeck et al. 2004
Daphnia lumholtzi	--	Africa / Asia	1999	Lake Erie	Release (fishing), natural	Muzinic 2000 (cited in Ricciardi 2001); Holeck et al. 2004
Eubosmina coregoni	--	Eurasia	1966	Lake Michigan	Shipping (ballast water)	Wells 1970; Deevey and Deevey 1971; Mills et al. 1993a; Holeck et al. 2004
Eubosmina maritima (syn. *Bosmina maritima*)	--	Eurasia	<1980s	--	Shipping (ballast water)	De Melo and Hebert 1994 (cited in Ricciardi 2001); Holeck et al. 2004
Copepoda						
Cyclops strenuus	--	Boreal Holarctic	1972	--	Release (fishing), natural?	Selgeby 1975; Reed and McIntyre 1995; Holeck et al. 2004
Heteropsyllus cf. *nunni*	--	Eurasia	1996	--	Shipping (ballast-mediated vector)	Horvath et al. 2001 (cited in Ricciardi 2001); Holeck et al. 2004

Table A-2.1. Continued.

Taxon / Species	Common name	Origin	Date	Location	Mechanism / Vector	Source
Nitokra hibernica (syn. *Nitocra hibernica*)	--	Eurasia	1973	--	Shipping (ballast water)	Czaika 1978; Hudson et al. 1998 (cited in Ricciardi 2001); Holeck et al. 2004
Nitokra incerta (syn. *Nitocra incerta*)	--	Ponto-Caspian	1998-99	--	Shipping (ballast-mediated vector)	Holeck et al. 2004; Grigorovich et al. 2001
Onychocamptus mohammed	--	Holarctic	1992	--	Shipping (ballast water)	Hudson et al. 1998; Holeck et al. 2004
Schizopera borutzkyi	--	Ponto-Caspian	1998	--	Shipping (ballast-mediated vector)	Horvath et al. 2001 (cited in Ricciardi 2001); Holeck et al. 2004
Skistodiaptomus pallidus	--	Mississippi basin	1967	Lake Ontario	Shipping (ballast water), release (fishing)	Patalas 1969; Robertson and Gannon 1981; Mills et al. 1993a; Holeck et al. 2004
			<u>MACROINVERTEBRATES</u>			
ANNELIDA						
Oligochaeta						
Branchiura sowerbyi	--	Asia	1951	Kalamazoo River (M)	Release (accidental)	Mills et al. 1993a
Gianius aquaedulcis	--	Europe	1983	--	Shipping (ballast water)	Farara and Ersues 1991; Holeck et al. 2004
Phallodrilus aquaedulcis	--	Eurasia	1980	North Channel (H)	Shipping (ballast water)	Mills et al. 1993a
Ripistes parasita	--	Eurasia	1980[a] / 1983[b]	Niagara River	Shipping (ballast water)	[a]Barton and Griffiths 1984; [a]Holeck et al. 2004; [b]Mills et al. 1993a

Table A-2.1. Continued.

Taxon / Species	Common name	Origin	Date	Location	Mechanism / Vector	Source
ARTHROPODA						
Amphipoda						
Chelicorophium mucronatum	--	Ponto-Caspian	1997	Lake St. Clair	Shipping (ballast water)	Grigorovich and MacIsaac 1999
Echinogammarus ischnus (syn. *Chaetogammarus ischnus*)	--	Ponto-Caspian[b]	1994-95	Detroit River	Shipping (ballast water)	Witt et al. 1997; van Overdijk et al. 2003; Ricciardi and Rasmussen 1998; Holeck et al. 2004
Gammarus fasciatus	--	Atlantic N.A.	<1940	Detroit River	Shipping (solid ballast, ballast water)	Mills et al. 1993a
Coleoptera						
Tanysphyrus lemnae	aquatic weevil	Eurasia	<1943	Unknown	Unknown	Mills et al. 1993a
Decapoda						
Eriocheir sinensis	Chinese mitten crab	--	1965	--	Shipping (ballast water)	Holeck et al. 2004
BRYOZOA						
Lophopodella carteri	--	Asia	1934	--	--	Ricciardi and Reiswig 1994
CNIDARIA						
Hydrozoa						
Cordylophora caspia	freshwater hydroid	Unknown	1956	Lake Erie	Release (accidental)	Mills et al. 1993a; Ricciardi and Rasmussen 1998
Craspedacusta sowerbyi	freshwater jellyfish	Asia	1933	Lake Erie (T)	Release (accidental)	Mills et al. 1993a

Table A-2.1. Continued.

Taxon / Species	Common name	Origin	Date	Location	Mechanism / Vector	Source
MOLLUSCA						
Bivalvia						
Corbicula fluminea	Asian clam	Asia	1980	Lake Erie	Shipping (ballast water), release (accidental, aquarium, fishing)	Clarke 1981; Mills et al. 1993a; McMahon 1999; Holeck et al. 2004
Dreissena bugensis	quagga mussel	Ponto-Caspian[a] / Eurasia[b]	1989[b] / 1991[a]	Lake Ontario	Shipping (ballast water, fouling)	[a]Mills et al. 1993a; [b]Ricciardi and Rasmussen 1998; [b]Holeck et al. 2004; May and Marsden 1992
Dreissena polymorpha	zebra mussel	Ponto-Caspian[a] / Eurasia[b]	1988	Lake St. Clair	Shipping (ballast water, fouling)	[a]Hebert et al. 1989; [a]Ricciardi and Rasmussen 1998; [b]Mills et al. 1993a; Holeck et al. 2004
Lasmigona subviridis	green floater	Atlantic N.A.	<1959	Erie Canal	Canals	Mills et al. 1993a
Pisidium amnicum	greater European pea clam	Eurasia	1897	Genesse County, NY (O)	Shipping (ballast water)	Mills et al. 1993a
Pisidium henslowanum	Henslow pea clam	Eurasia	<1916	--	--	MacIsaac 1999
Pisidium supinum	humpbacked pea clam	Europe	1959	--	Shipping (ballast water)	Mackie 1999; MacIsaac 1999; Holeck et al. 2004
Sphaerium corneum	European fingernail clam	Eurasia	1952	Rice Lake (H/O)	Unknown	Mills et al. 1993a
Gastropoda						
Bithynia tentaculata	faucet snail	Eurasia	1871	Lake Michigan	Shipping (solid ballast), release (deliberate)	Mills et al. 1993a
Cipangopaludina chinensis malleata	Chinese mystery snail	Asia	1931	Niagara River	Release (aquarium)	Mills et al. 1993a

Table A-2.1. Continued.

Taxon / Species	Common name	Origin	Date	Location	Mechanism / Vector	Source
Cipangopaludina japonica	Japanese mystery snail	Asia	1940s	Lake Erie	Release (deliberate)	Mills et al. 1993a
Gillia altilis	buffalo pebble snail	Atlantic N.A.	1918	Oneida Lake (O)	Canals	Mills et al. 1993a
Potamopyrgus antipodarum	New Zealand mud snail	New Zealand	1991	--	Shipping (ballast-mediated vector)	Zaranko et al. 1997; Ricciardi and Rasmussen 1998; Holeck et al. 2004
Radix auricularia	European ear snail	Eurasia	1901	Chicago (M)	Release (aquarium, accidental)	Mills et al. 1993a
Valvata piscinalis	European stream valvata	Eurasia	1897	Lake Ontario	Shipping (solid ballast)	Mills et al. 1993a
Viviparus georgianus	banded mystery snail	Mississippi basin	<1906	Lake Michigan (T)	Release (aquarium)	Mills et al. 1993a
			FISH			
ANGUILLIDAE						
Anguilla rostrata	American eel	Atlantic N.A.	--	--	Canals	Bailey and Smith 1981
CATOSTOMIDAE						
Ictiobus niger	black buffalo	Lake Michigan (T)	--	Lake Erie	Release (accidental and/or deliberate?)	Bailey and Smith 1981
CENTRARCHIDAE						
Enneacanthus gloriosus	bluespotted sunfish	Atlantic N.A.	1971	Jamesville Res. (O)	Release (aquarium, fishing)	Werner 1972; Bailey and Smith 1981; Mills et al. 1993a
Lepomis humilis	orangespotted sunfish	Mississippi basin	1929	Lake St. Mary's (E)	Canals	Mills et al. 1993a

Table A-2.1. Continued.

Taxon / Species	Common name	Origin	Date	Location	Mechanism / Vector	Source
Lepomis microlophus	redear sunfish	Southern U.S.	1928	Inland Indiana (M)	Release (deliberate)	Bailey and Smith 1981; Mills et al. 1993a
CLUPEIDAE						
Alosa aestivalis	blueback herring	Atlantic N.A.	1981[a] / 1995[b]	--	Natural	[a]Holeck et al. 2004; [b]MacNeill 1998 (cited in Ricciardi 2001)
Alosa chrysochloris[1]	skipjack herring	Mississippi & Hudson basins	1989	--	Canals	Fago 1993; Fuller et al. 1999; Holeck et al. 2004
Alosa pseudoharengus	alewife	Atlantic N.A.	1873	Lake Ontario	Canals, release (fishing)	Bailey and Smith 1981; Mills et al. 1993a
COBITIDAE						
Misgurnus anguillicaudatus	Oriental weatherfish	Asia	1939	Shiawassee River (O)	Release (accidental)	Bailey and Smith 1981; Mills et al. 1993a
CYPRINIDAE						
Carassius auratus	goldfish	Asia	<1878	Widespread	Release (deliberate, aquarium, fishing, accidental)	Bailey and Smith 1981; Mills et al. 1993a
Cyprinus carpio	common carp	Asia	1879	Widespread	Release (deliberate)	Bailey and Smith 1981; Mills et al. 1993a; Ricciardi & Rasmussen 1998
Notropis buchanani	ghost shiner	Mississippi basin	1979	Thames River (StC)	Release (deliberate, fishing)	Holm and Coker 1981; Mills et al. 1993a; Holeck et al. 2004
Notropis procne	swallowtail shiner	Atlantic N.A.	--	Lake Ontario (T)	Canals? release?	Bailey and Smith 1981
Phenacobius mirabilis	suckermouth minnow	Mississippi basin	1950	Ohio (E)	Canals, release (fishing)	Bailey and Smith 1981; Mills et al. 1993a

Table A-2.1. Continued.

Taxon / Species	Common name	Origin	Date	Location	Mechanism / Vector	Source
Pimephales vigilax perspicuus	southwestern bullhead minnow	Lake Michigan (T)	--	Lake Erie (T)	Canals? release?	Bailey and Smith 1981
Scardinius erythrophthalmus	Eurasian rudd	Eurasia	1989	Lake Ontario	Release (deliberate, fishing)	Mills et al. 1993a; Holeck et al. 2004
GASTEROSTEIDAE						
Apeltes quadracus	fourspine stickleback	Atlantic N.A.	1986	Thunder Bay (S)	Shipping (ballast water)	Holm and Hamilton 1988; Mills et al. 1993a; Holeck et al. 2004
GOBIIDAE						
Neogobius melanostomus	round goby	Ponto-Caspian[a] / Eurasia[b]	1990	St. Clair River	Shipping (ballast water)	[a]Jude et al. 1992; [a]Ricciardi and Rasmussen 1998; [b]Mills et al. 1993a; Holeck et at. 2004
Proterorhinus marmoratus	tubenose goby	Ponto-Caspian[a] / Eurasia[b]	1990	St. Clair River	Shipping (ballast water)	[a]Jude et al. 1992; [a]Ricciardi and Rasmussen 1998; [b]Mills et al. 1993a; Holeck et al. 2004
ICTALURIDAE						
Ameiurus catus (syn. *Ictalurus catus*)	white bullhead	--	--	Lake Erie	Release (accidental and/or deliberate?)	Bailey and Smith 1981
Noturus insignis	margined madtom	Atlantic N.A.	1928	Oswego River (O)	Canals, release (fishing)	Bailey and Smith 1981; Mills et al. 1993a
LEPISOSTEIDAE						
Lepisosteus platostomus	shortnose gar	Mississippi basin	1962	Lake Michigan (T)	Canals	Bailey and Smith 1981; Fuller et al. 1999; Cudmore-Vokey and Crossman 2000; Holeck et al. 2004

Table A-2.1. Continued.

Taxon / Species	Common name	Origin	Date	Location	Mechanism / Vector	Source
OSMERIDAE						
Osmerus mordax	rainbow smelt	Atlantic N.A.	1912	Crystal Lake (M)	Release (deliberate)	Bailey and Smith 1981; Mills et al. 1993a
MORONIDAE						
Morone americana	white perch	Atlantic N.A.	1950	Cross Lake (O)	Canals	Bailey and Smith 1981; Mills et al. 1993a
Morone mississippiensis	yellow bass	--	--	Lake Michigan (T)	Release (accidental and/or deliberate?)	Bailey and Smith 1981
PERCIDAE						
Gymnocephalus cernuus	Eurasian ruffe	Eurasia	1986	St. Louis River (S)	Shipping (ballast water)	Simon and Vondruska 1991; Mills et al. 1993a; Ricciardi and Rasmussen 1998; Holeck et al. 2004
PETROMYZONTIDAE						
Petromyzon marinus	sea lamprey	Atlantic N.A.	1830s	Lake Ontario	Canals, shipping (fouling)	Bailey and Smith 1981; Mills et al. 1993a
PLEURONECTIDAE						
Platichthys flesus[1]	European flounder	--	1974	--	Shipping (ballast water)	Holeck et al. 2004
POECILIIDAE						
Gambusia affinis	western mosquitofish	Mississippi basin	1923	Cooks County, IL	Release (deliberate)	Bailey and Smith 1981; Mills et al. 1993a

Table A-2.1. Continued.

Taxon / Species	Common name	Origin	Date	Location	Mechanism / Vector	Source
SALMONIDAE						
Oncorhynchus mykiss gairdnerii	Columbia River redband trout	--	--	All lakes	Release (deliberate)	Bailey and Smith 1981
Salmo salar	Atlantic salmon	Atlantic N.A.	--	Lakes Michigan and Huron	Release (accidental and/or deliberate?)	Bailey and Smith 1981
Salmo trutta	brown trout	Eurasia	1883	Lakes Ontario and Michigan (T)	Release (accidental, deliberate)	Bailey and Smith 1981; Mills et al. 1993a
Oncorhynchus tshawytscha	chinook salmon	Pacific	1873	All lakes but (S)	Release (deliberate)	Bailey and Smith 1981; Mills et al. 1993a
Oncorhynchus kisutch	coho salmon	Pacific	1933	Lake Erie	Release (deliberate)	Bailey and Smith 1981; Mills et al. 1993a
Oncorhynchus nerka	kokanee	Pacific	1950	Lake Ontario	Release (deliberate)	Bailey and Smith 1981; Mills et al. 1993a
Oncorhynchus gorbuscha	pink salmon	Pacific	1956	Current River (S)	Release (accidental)	Bailey and Smith 1981; Mills et al. 1993a
Oncorhynchus mykiss	rainbow trout	Pacific	1876	Lake Huron (T)	Release (deliberate)	Mills et al. 1993a
PARASITES, DISEASE VECTORS, AND COMMENSALS						
ARTHROPODA						
Copepoda						
Argulus japonicus †	Japanese fishlouse	Asia	1988	Lake Michigan	Release (aquarium, fishing)	Galarowicz and Cochran 1991; Mills et al. 1993a
Neoergasilus japonicus ƒ	--	Eastern Asia	1994	--	Release (aquaculture)	Hudson and Bowen 2002

Table A-2.1. Continued.

Taxon / Species	Common name	Origin	Date	Location	Mechanism / Vector	Source
Salmincola lotae Φ	--	Eurasia	1985	--	Unknown	Lasee et al. 1988
BACTERIA						
Aeromonas salmonicida	furunculosis	Unknown	<1902	Unknown	Release (fishing)	Mills et al. 1993a
MYXOZOA						
Glugea hertwigi Ω	microsporidian parasite	Eurasia	1960	Lake Erie	Release (fishing)	Dechtiar 1965; Mills et al. 1993a
Myxobolus cerebralis ††	salmonid whirling disease	Unknown	1968[a] / 1969[b]	Ohio (E)	Release (fishing)	[a]Hoffman and Schubert 1984; [b]Mills et al. 1993a; Anonymous 1988
Sphaeromyxa sevastopoli §ж	--	Black Sea basin	1994	--	Shipping (ballast-mediated vector)	Pronin et al. 1997a
PLATYHELMINTHES						
Cestoda						
Scolex pleuronectis §	--	Black Sea basin	1994	--	Shipping (ballast-mediated vector)	Pronin et al. 1997a
Trematoda						
Acanthostomum sp.	digenean fluke	Black Sea basin	1994	--	--	Pronin et al. 1997b
Dactylogyrus amphibothrium ξ	monogenean fluke	Eurasia	1980s[a] / 1992[b]	--	--	[a]Cone et al. 1994; [b]Pronin et al. 1998

Table A-2.1. Continued.

Taxon / Species	**Common name**	**Origin**	**Date**	**Location**	**Mechanism / Vector**	**Source**
Dactylogyrus hemiamphibothrium ξ	monogenean fluke	Eurasia	1980s[a] / 1992[b]	--	--	[a]United States Department of the Interior 1993 (cited in Ricciardi 2001); [b]Pronin et al. 1998 (cited in Grigorovich et al. 2003)
Ichthyocotylurus pileatus §	digenean fluke	Eurasia	1994	--	--	Pronin et al. 1997a (cited in Ricciardi 2001 and Grigorovich et al. 2003)
Neascus brevicaudatus ξ	digenean fluke	Eurasia	1980s[a] / 1992[b]	--	Shipping (ballast-mediated vector)	[a]United States Department of the Interior 1993 (cited in Ricciardi 2001); [b]Pronin et al. 1998 (cited in Grigorovich et al. 2003)
Turbellaria						
Dugesia polychroa	triclad flatworm	Eurasia	1968	Lake Ontario	Shipping (ballast water)	Ball 1969; Mills et al. 1993a; Holeck et al. 2004
PROTOZOA						
Acineta nitocrae ƒƒ	suctorian	Europe	1997	--	--	Grigorovich et al. 2001
Trypanosoma acerinae ξ	flagellate	Black Sea basin	1980s[a] / 1992[b]	--	--	[a]United States Department of the Interior 1993 (cited in Ricciardi 2001); [b]Pronin et al. 1998 (cited in Grigorovich et al. 2003)
PHYTOPLANKTON, ALGAE, AND MACROPHYTES						
BUTOMACEAE						
Butomus umbellatus	flowering rush	Eurasia	<1930	Detroit River (E)	Shipping (solid ballast)	Mills et al. 1993a

Table A-2.1. Continued.

Taxon / Species	Common name	Origin	Date	Location	Mechanism / Vector	Source
CABOMBACEAE						
Cabomba caroliniana	Carolina fanwort	Southern U.S.	1935	Kimble Lake (M)	Release (aquarium, accidental)	Mills et al. 1993a
CHARACEAE						
Nitellopsis obtusa	starry stonewort	Eurasia	1983	Lake St. Clair	Shipping (ballast water)	Mills et al. 1993a
CYPERACEAE						
Carex acutiformis	lesser pond sedge	Eurasia	1951	St. Joseph Lake (M)	Unknown	Mills et al. 1993a
Carex disticha	two-rank sedge	Eurasia	1866	Belleville, Ontario (O)	Shipping (solid ballast)	Mills et al. 1993a
Carex flacca	Heath sedge	Eurasia	1896	Detroit River	Unknown	Mills et al. 1993a
HALORAGACEAE						
Myriophyllum spicatum	Eurasian water milfoil	Eurasia	1952	Lake Erie	Release (aquarium, accidental)	Mills et al. 1993a
HYDROCHARITACEAE						
Hydrocharis morsusranae	European frogbit	Eurasia	1972	Lake Ontario	Release (aquarium, deliberate), shipping (fouling)	Mills et al. 1993a
JUNCACEAE						
Juncus compressus	roundfruit rush	Eurasia	<1895	Cayuga Lake (O)	Release (accidental)	Mills et al. 1993a

Table A-2.1. Continued.

Taxon / Species	Common name	Origin	Date	Location	Mechanism / Vector	Source
Juncus gerardii	black-grass rush	Atlantic N.A.	1862	Chicago	Shipping (solid ballast)	Mills et al. 1993a
Juncus inflexus	European meadow rush	Eurasia	1922	Central, NY	Unknown	Mills et al. 1993a
LAMIACEAE						
Lycopus asper	rough water-horehound	Mississippi basin	1892	Lake Erie	Release (accidental)	Mills et al. 1993a
Lycopus europaeus	gypsywort	Eurasia	1903	Lake Ontario	Shipping (solid ballast)	Mills et al. 1993a
LYTHRACEAE						
Lythrum salicaria	purple loosestrife	Eurasia	1869	Ithaca, NY (O)	Canals, shipping (solid ballast)	Mills et al. 1993a
MARSILEACEAE						
Marsilea quadrifolia	European water-clover	Eurasia	<1925	Cayuga Lake (O)	Release (deliberate)	Mills et al. 1993a
MENYANTHACEAE						
Nymphoides peltata	yellow floating heart	Eurasia	1930	Conneaut River (E)	Release (accidental)	Mills et al. 1993a
NAJADACEAE						
Najas marina	spiny naiad	Eurasia	1864	Onondaga Lake (O)	Shipping (solid ballast)	Mills et al. 1993a
Najas minor	brittle water nymph	Eurasia	1932	Lake Cardinal (E)	Release (deliberate)	Mills et al. 1993a

Table A-2.1. Continued.

Taxon / Species	Common name	Origin	Date	Location	Mechanism / Vector	Source
ONAGRACEAE						
Epilobium hirsutum	great hairy willowherb	Eurasia	1874	Ithaca, NY (O)	Release (accidental), shipping (solid ballast)	Mills et al. 1993a
Epilobium parviflorum	smallflower hairy willowherb	Eurasia	1966	Benzie County, MI (M)	Unknown	Mills et al. 1993a
POACEAE						
Glyceria maxima	reed sweet-grass	Eurasia	1940	Lake Ontario	Release (cultivation), shipping (solid ballast)	Mills et al. 1993a
Puccinellia distans	spreading alkali grass	Eurasia	1893	Montzuma, NY (O)	Shipping (solid ballast), railroads and highways	Mills et al. 1993a
POTAMOGETONACEAE						
Potamogeton crispus	curly-leaved pondweed	Eurasia	1879	Keuka Lake (O)	Release (deliberate, fishing)	Mills et al. 1993a
SPARGANIACEAE						
Sparganium glomeratum	northern bur-reed	Eurasia	1936	Lake Superior	Unknown	Mills et al. 1993a
TRAPACEAE						
Trapa natans	water chestnut	Eurasia	<1959	Lake Ontario (T)	Release (accidental, aquarium)	Mills et al. 1993a
TYPHACEAE						
Typha angustifolia	narrow-leaved cattail	Eurasia	1880s	Central, NY (O)	Canals, release (accidental)	Mills et al. 1993a

Table A-2.1. Continued.

Taxon / Species	Common name	Origin	Date	Location	Mechanism / Vector	Source
CHRYSOPHYTA						
Hymenomonas roseola	--	Eurasia	1975	Lake Huron	Shipping (ballast water)	Mills et al. 1993a
CHLOROPHYTA						
Enteromorpha intestinalis	--	Atlantic	1926	Wolf Creek (O)	Release (accidental)	Mills et al. 1993a
Enteromorpha prolifera	--	Atlantic	1979	Lake St. Clair	Unknown	Mills et al. 1993a
PHAEOPHYTA						
Sphacelaria fluviatilis	--	Asia	1975	Gull Lake (M)	Release (aquarium), shipping (fouling)	Mills et al. 1993a
Sphacelaria lacustris	--	Unknown	1975	Lake Michigan	Shipping (ballast water)	Mills et al. 1993a
RHODOPHYTA						
Bangia fusco-purpurea (syn. *Bangia atropurpurea*)	--	Widespread	1964	Lake Erie	Shipping (ballast water, fouling)	Mills et al. 1993a
Chroodactylon ramosum	--	Atlantic	1964	Lake Erie	Shipping (ballast water)	Mills et al. 1993a
BACILLARIOPHYCEAE						
Actinocyclus normanii fo. *subsalsa*	--	Eurasia	1938	Lake Ontario	Shipping (ballast water)	Mills et al. 1993a
Chaetoceros muelleri var. *subsalsum*	--	Widespread	1946	Lake Michigan	Shipping (ballast water)	Mills et al. 1993a
Cyclotella atomus	--	Eurasia	1946	Lake Michigan	Shipping (ballast water)	Mills et al. 1993a
Cyclotella cryptica	--	Unknown	1978	Lake Huron	Shipping (ballast water)	Mills et al. 1993a

Table A-2.1. Continued.

Taxon / Species	Common name	Origin	Date	Location	Mechanism / Vector	Source
Cyclotella pseudostelligera	--	Europe	1988	Unknown	Unknown	Mills et al. 1993a
Cyclotella woltereckii	--	Widespread	<1978	Lake Erie	Shipping (ballast water)	Mills et al. 1993a
Diatoma ehrenbergii	--	Widespread	1978	Lake Michigan	Shipping (ballast water)	Mills et al. 1993a
Pleurosira laevis	--	Eurasia	1938	Lake Ontario	Shipping (ballast water)	Mills et al. 1993a
Skeletonema potamos	--	Widespread	1962	Detroit River	Shipping (ballast water)	Mills et al. 1993a
Skeletonema subsalsum	--	Widespread	1963	Toledo, Ohio (E)	Shipping (ballast water)	Mills et al. 1993a
Stephanodiscus binderanus	--	Widespread	1964	Lake Michigan	Shipping (ballast water)	Mills et al. 1993a
Stephanodiscus subtilis	--	Widespread	1964	Lake Michigan	Shipping (ballast water)	Mills et al. 1993a
Thalassiosira baltica	--	Widespread	1930s	Lake Michigan	Shipping (ballast water)	Mills et al. 1993a; Edlund et al. 2000 (cited in Ricciardi 2001)
Thalassiosira guillardii	--	Widespread	1964	Lake Michigan	Shipping (ballast water)	Mills et al. 1993a
Thalassiosira lacustris	--	Eurasia	1973	Sandusky Bay(E)	Shipping (ballast water)	Mills et al. 1993a
Thalassiosira pseudonana	--	Widespread	1973	Sandusky Bay(E)	Shipping (ballast water)	Mills et al. 1993a
Thalassiosira weissflogii	--	Widespread	1973	Ohio (E)	Shipping (ballast water)	Mills et al. 1993a

Origin – known or probable area region or ecozone of origin; **Date** – year in which the organism was either first collected or literature was first published of its existence in the Great Lakes; **Location** – area within the Great Lakes Basin where the organism was first reported (the term "widespread" is used when the location reported is not more specific); **Mechanism / Vector** – known or probable mechanism/vector of introduction. **Note**: Parasite and epibiont hosts: † – *Carassius auratus*; ƒ – cyprinid, percid, and centrarchid spp.; Φ – *Lota lota*; Ω – *Osmerus mordax*; †† – *Tubifex tubifex* and salmonid spp.; § – *Neogobius melanostomus*; ж – *Proterorhinus marmoratus; ƒƒ – Nitokra* spp.; ξ – *Gymnocephalus cernuus*.
Great Lakes region abbreviations: O=Ontario; E=Erie, H=Huron; M=Michigan; S=Superior; StC=Lake St. Clair; T=tributary
1 - Reported in the Great Lakes, but not thought to have established a reproducing population.

Table A-2.2. List of aquatic invasive species in inland waters and on the North and Baltic Sea coasts recorded since 1800 (Modified from Nehring 2002).

Taxon / Species[1]	**Common name**	**Origin**	**Date**	**Distribution**			**Mechanism / Vector**	**Status**	**Source**
				Inland	**North Sea**	**Baltic Sea**			
				ZOOPLANKTON					
ARTHROPODA									
Copepoda									
Acartia tonsa	--	Pacific / West Atlantic	1925		+++	+++	Ocean shipping (ballast water)		Leppakoski and Olenin 2000; Nehring 2001; Olenin et al. 2004
Ameira divagans	--	West Atlantic	1970s			++	Ocean shipping (ballast water)		Leppakoski and Olenin 2000; Olenin et al. 2004
Cercopagis pengoi	fish-hook waterflea	Ponto-Caspian	1992[a] / 2002[b]			+	Shipping canal and inland vessels		[a]Leppakoski and Olenin 2000; [b]Olenin et al. 2004
				MACROINVERTEBRATES					
ANNELIDA									
Hirudinea									
Barbronia weberi	--	South Asia	1994	+			Release		Tittizer et al. 2000; IKSR 2002
Caspiobdella fadejewi	--	Ponto-Caspian	1990s	+			Shipping canal		Tittizer et al. 2000; IKSR 2002
Piscicola haranti	--	Ponto-Caspian	1990s	+			Shipping canal		Tittizer et al. 2000

Table A-2.2. Continued.

Taxon / Species[1]	**Common name**	**Origin**	**Date**	**Distribution**			**Mechanism / Vector**	**Status**	**Source**
				Inland	**North Sea**	**Baltic Sea**			
Paranais frici	--	Ponto-Caspian	1995			+	Shipping		Leppakoski and Olenin 2000
Potamothrix heuscheri	--	Ponto-Caspian	1990s			+	Shipping		Leppakoski and Olenin 2000
Potamothrix vejdovskyi	--	Ponto-Caspian	1990s			+	Shipping		Leppakoski and Olenin 2000
Polychaeta									
Boccardia redeki (syn. *Polydora redeki*)	--	North Sea	1960			+	Shipping		Leppakoski and Olenin 2000
Ficopomatus enigmaticus	--	South Pacific	1953[a] / 1975[b]		+	+	Ocean shipping (hull)		[a]Leppakoski and Olenin 2000; [b]Nehring and Leuchs 2000; [b]Nehring 2001
Hypania invalida	--	Ponto-Caspian	1995	++			Shipping canal and inland vessels		Tittizer et al. 2000; IKSR 2002
Marenzelleria cf. *viridis*	--	West Atlantic	1985		++	+++	Ocean shipping (ballast water)	X	Leppakoski and Olenin 2000; Nehring 2000; Nehring 2001
Marenzelleria cf. *wireni*	--	North Atlantic	1983		++		Ocean shipping (ballast water)	X	Nehring and Leuchs 2000; Nehring 2001
ARTHROPODA									
Amphipoda									
Caprella mutica	--	Pacific	2004		+		Ocean shipping (hull) ?		www.neozoa.de

Table A-2.2. Continued.

Taxon / Species[1]	**Common name**	**Origin**	**Date**	**Distribution**			**Mechanism / Vector**	**Status**	**Source**
				Inland	**North Sea**	**Baltic Sea**			
Chelicorophium curvispinum (syn. *Corophium curvispinum*)	--	Ponto-Caspian	1912	+++	+	+	Shipping canal and inland vessels	X	Nehring 2000; Tittizer et al. 2000; Leppakoski and Olenin 2000; Nehring 2001; IKSR 2002
Chelicorophium robustum	--	Ponto-Caspian	2000	+			Shipping canal and inland vessels		Nehring unpubl.
Chelicorophium sextonae	--	South Pacific	1997		+		Ocean shipping (hull)		Nehring 2001
Dikerogammarus haemobaphes	--	Ponto-Caspian	1993	++			Shipping canal and inland vessels		Tittizer et al. 2000; IKSR 2002
Dikerogammarus villosus	--	Ponto-Caspian	1995	++			Shipping canal and inland vessels	X	Tittizer et al. 2000; IKSR 2002
Echinogammarus berilloni	--	Mediterranean	1924	+			Shipping canal and inland vessels		Tittizer et al. 2000; IKSR 2002
Echinogammarus ischnus (syn. *Chaetogammarus ischnus*)	--	Ponto-Caspian	1962[a] / 1977[b]	++		+	Shipping canal and inland vessels, stocking		[a]Leppakoski and Olenin 2000; [b]Tittizer et al. 2000; [b]IKSR 2002
Echinogammarus trichiatus	--	Ponto-Caspian	2000	+			Shipping canal and inland vessels		Tittizer et al. 2000
Echinogammarus warpachowskyi (syn. *Chaetogammarus warpachowskyi*)	--	Ponto-Caspian	1962	++		+	Stocking		Leppakoski and Olenin 2000

Table A-2.2. Continued.

Taxon / Species[1]	Common name	Origin	Date	Distribution: Inland	Distribution: North Sea	Distribution: Baltic Sea	Mechanism / Vector	Status	Source
Gammarus tigrinus	--	West Atlantic	1957	+++	++	+	Release, shipping		Nehring 2000; Tittizer et al. 2000; Leppakoski and Olenin 2000; Nehring 2001; IKSR 2002
Gmelinoides fasciatus	--	Baikal Lake	1996			+	Stocking		Leppakoski and Olenin 2000
Obesogammarus crassus	--	Ponto-Caspian	1962[a] / 2004[b]	+		+	Shipping canal and inland vessels, stocking		[a]Leppakoski and Olenin 2000; [b]www.neozoa.de
Obesogammarus obesus	--	Ponto-Caspian	2004	+			Shipping canal and inland vessels		www.neozoa.de
Pontogammarus robustoides	--	Ponto-Caspian	1962[a] / 1994[b]	+		+	Shipping canal and inland vessels, stocking		[a]Leppakoski and Olenin 2000; [b]Nehring 2000; [b]Tittizer et al. 2000
Cirripedia									
Balanus improvisus	--	West Atlantic	1858		+++	+++	Ocean shipping (hull)	X	Nehring 2000; Nehring 2001
Elminius modestus	--	South Pacific	1953		+++		Ocean shipping (hull)		Nehring 2001; Reise et al. 2002
Decapoda									
Astacus leptodactylus	Galician crayfish	Ponto-Caspian	1910s	++			Release		Geitler et al. 2002
Atyaephyra desmaresti	--	Mediterranean	1932	++			Shipping canal		Tittizer et al. 2000; IKSR 2002

Table A-2.2. Continued.

Taxon / Species[1]	**Common name**	**Origin**	**Date**	**Distribution**			**Mechanism / Vector**	**Status**	**Source**
				Inland	**North Sea**	**Baltic Sea**			
Eriocheir sinensis	Chinese mitten crab	North Pacific	1912	+++	++	++	Ocean shipping (ballast water)	X	Leppakoski and Olenin 2000; Nehring 2000; Tittizer et al. 2000; Nehring 2001; IKSR 2002
Rhithropanopeus harrisii	estuarine mud crab	West Atlantic	1936		++	++	Ocean shipping (hull)		Leppakoski and Olenin 2000; Nehring 2000; Nehring 2001; IKSR 2002
Isopoda									
Jaera istri	--	Ponto-Caspian	1995	++			Shipping canal and inland vessels		Tittizer et al. 2000; IKSR 2002
Proasellus coxalis	--	Mediterranean	~1931	++	+		Shipping canal and inland vessels		Tittizer et al. 2000; Nehring 2001; IKSR 2002
Proasellus meridianus	--	West Europe	~1930	++			Shipping canal and inland vessels		Tittizer et al. 2000
Mysidacea									
Hemimysis anomala	--	Ponto-Caspian	1962[a] / 1997[b]	+		+	Shipping canal, stocking		[a]Leppakoski and Olenin 2000; [b]Tittizer et al. 2000; [b]IKSR 2002
Limnomysis benedeni	--	Ponto-Caspian	1962[a] / 1997[b]	+		+	Shipping canal, stocking		[a]Leppakoski and Olenin 2000; [b]Tittizer et al. 2000; [b]IKSR 2002
Paramysis lacustris	--	Ponto-Caspian	1962			+	Stocking		Leppakoski and Olenin 2000
Ostracoda									
Pomatocypris humilis	--	NW Africa	1948			+	Shipping?		Leppakoski and Olenin 2000

Table A-2.2. Continued.

Taxon / Species[1]	Common name	Origin	Date	Distribution			Mechanism / Vector	Status	Source
				Inland	North Sea	Baltic Sea			
BRYOZOA									
Victorella pavida	--	Indo-Pacific?	1951		+	+	Ocean shipping (hull)		Nehring and Leuchs 2000; Leppakoski and Olenin 2000; Nehring 2001
CHORDATA									
Ascidiacea									
Styela clava	--	North Pacific	1997		+		Ocean shipping (hull)		Nehring 2001
CNIDARIA									
Anthozoa									
Diadumene cincta	orange anemone	Pacific	1928		+		Aquaculture product		Nehring 2001
Hydrozoa									
Bimeria franciscana	--	Indo-Pacific?	1952		+		Ocean shipping (hull)		Nehring 2001
Clavopsella navis	--	South Africa?	1960			+	Shipping		Leppakoski and Olenin 2000
Cordylophora caspia	--	Ponto-Caspian	1858	+++	++	++	Shipping canal and inland vessels		Nehring 2000; Tittizer et al. 2000; Leppakoski and Olenin 2000; Nehring 2001; IKSR 2002
Craspedacusta sowerbyi	--	East Asia	1923	++			Release		Tittizer et al. 2000
Garveia franciscana	--	North America?	1950			+	Shipping		Leppakoski and Olenin 2000

Table A-2.2. Continued.

Taxon / Species[1]	**Common name**	**Origin**	**Date**	**Distribution**			**Mechanism / Vector**	**Status**	**Source**
				Inland	**North Sea**	**Baltic Sea**			
Gonionemus vertens	clinging jellyfish	North Pacific	1921			+	Shipping		Leppakoski and Olenin 2000
Maeotias inexpectata	--	Ponto-Caspian	1999			+	Shipping		Leppakoski and Olenin 2000
Nemopsis bachei	--	West Atlantic	1942		+		Ocean shipping (hull)		www.neozoa.de
MOLLUSCA									
Bivalvia									
Congeria leucophaeta	--	East Atlantic	1928	+	+	+	Ocean shipping (hull)		Tittizer et al. 2000; Nehring 2001; Olenin et al. 2004
Corbicula fluminalis	--	East Asia	1984	++	++		Ocean shipping (ballast water)	X	Tittizer et al. 2000; Nehring 2001
Corbicula fluminea	Asian clam	Asia	1987	++			Ocean shipping (ballast water)	X	Tittizer et al. 2000
Crassostrea gigas	Pacific giant oyster	Pacific	1980s[a] / 1991[b]		+++	+	Aquaculture product	X	[a]Leppakoski and Olenin 2000; [b]Nehring 2001; [b]Reise et al. (in press)
Dreissena polymorpha	zebra mussel	Ponto-Caspian	1828	+++	+	++	Shipping canal and inland vessels	X	Leppakoski and Olenin 2000; Nehring 2000; Tittizer et al. 2000; Nehring 2001; IKSR 2002
Ensis americanus	--	West Atlantic	1979		+++	++	Ocean shipping (ballast water)	X	Leppakoski and Olenin 2000; Nehring 2000; Nehring 2001; Reise et al. (in press)
Mya arenaria	softshell clam	West Atlantic	<1800		+++	+++	Release (?)		Leppakoski and Olenin 2000; Nehring 2000; Nehring 2001

Table A-2.2. Continued.

Taxon / Species[1]	**Common name**	**Origin**	**Date**	**Distribution**			**Mechanism / Vector**	**Status**	**Source**
				Inland	**North Sea**	**Baltic Sea**			
Mytilopsis leucophaeata	dark false mussel	NW Africa?	1930s			+	Shipping		Leppakoski and Olenin 2000
Petricola pholadiformis	false angelwing	West Atlantic	1896		+++	+	Aquaculture product		Leppakoski and Olenin 2000; Nehring 2000; Nehring 2001
Tapes philippinarum	Japanese littleneck	SE Asia	1983			+	Associated		Leppakoski and Olenin 2000
Teredo navalis	naval shipworm	Indo-Pacific	<1800		+	++	Ocean shipping (hull)	X	Leppakoski and Olenin 2000; Reise et al. 2002; Olenin et al. 2004
Unio mancus	--	South Europe	<1922	+			Shipping canal and inland vessels		Tittizer et al. 2000
Gastropoda									
Crepidula fornicata	Atlantic slippersnail	West Atlantic	1934		+++		Aquaculture product		Nehring 2001; Reise et al. 2002
Ferrissia wautieri	Wautier's Limpet	SE Europe	1952	++			Ocean shipping, birds		IKSR 2002
Lithoglyphus naticoides	gravel snail	Ponto-Caspian	1883	++		+	Shipping canal and inland vessels		Leppakoski and Olenin 2000; Tittizer et al. 2000; IKSR 2002
Physella acuta	European physa	SW Europe	1895	+++					Tittizer et al. 2000; IKSR 2002
Potamopyrgus antipodarum	New Zeal. mud snail	South Pacific	1900	+++	++	++	Ocean shipping (ballast water)		Leppakoski and Olenin 2000; Nehring 2000; Tittizer et al. 2000; Nehring 2001; IKSR 2002

Table A-2.2. Continued.

Taxon / Species[1]	Common name	Origin	Date	Distribution			Mechanism / Vector	Status	Source
				Inland	North Sea	Baltic Sea			
Viviparus viviparus	river snail	Eastern Europe	1987	++			Ocean shipping, birds		IKSR 2002;
TUNICATA									
Styela clava	--	Pacific	1994			+	Shipping		Leppakoski and Olenin 2000
FISH									
ACIPENSERIDAE									
Acipenser baeri	Siberian sturgeon	Siberia	1962			+	Stocking		Leppakoski and Olenin 2000
Acipenser gueldenstaedtii	Russian sturgeon	Ponto-Caspian	1962			+	Stocking		Leppakoski and Olenin 2000
Acipenser ruthenus	sterlet	Ponto-Caspian	1982			+	Stocking		Leppakoski and Olenin 2000
Acipenser stellatus	star sturgeon	Ponto-Caspian	1999			+	Stocking?		Leppakoski and Olenin 2000
Huso huso	European sturgeon	Ponto-Caspian	<1800			+	Stocking		Leppakoski and Olenin 2000
CYPRINIDAE									
Aristichthys nobilis	bighead carp	East Asia	1970s			+	Stocking		Leppakoski and Olenin 2000
Ctenopharyngodon idella	grass carp	Asia Amur	1970			+	Stocking		Leppakoski and Olenin 2000

Table A-2.2. Continued.

Taxon / Species[1]	Common name	Origin	Date	Distribution			Mechanism / Vector	Status	Source
				Inland	North Sea	Baltic Sea			
Hypophthalmichthys molitrix	silver carp	East Asia	1970s?			+	Stocking		Leppakoski and Olenin 2000
Pseudorasbora parva	stone moroko	East Asia	1984	+			Release		Kowarik 2003
GOBIIDAE									
Neogobius melanostomus	round goby	Ponto-Caspian	1990			+	Shipping		Leppakoski and Olenin 2000
MUGILIDAE									
Mugil labrosus	thicklip mullet	SE Asia?	1998			+	Unknown		Leppakoski and Olenin 2000
ODONTOBUTIDAE									
Perccottus glenii	Amur sleeper	Amur River	1916			+	Ornamental		Leppakoski and Olenin 2000
SALMONIDAE									
Coregonus peled	peled	Siberia	1965			+	Stocking		Leppakoski and Olenin 2000
PARASITES, DISEASE VECTORS, AND COMMENSALS									
NEMATA									
Anguillicola crassus	--	East Asia	1980[a] / 1982[b]	+++	+++	+++	Release	X	[a]Leppakoski and Olenin 2000; [b]Nehring 2001; Geitler et al. 2002; Olenin et al. 2004

Table A-2.2. Continued.

Taxon / Species[1]	**Common name**	**Origin**	**Date**	**Distribution**			**Mechanism / Vector**	**Status**	**Source**
				Inland	**North Sea**	**Baltic Sea**			
PLATYHELMINTHES									
Trematoda									
Pseudodactylogyrus anguillae	--	Pacific	1980s			+	Associated		Leppakoski and Olenin 2000
Pseudodactylogyrus bini	--	Pacific	1980s			+	Associated		Leppakoski and Olenin 2000
Turbellaria									
Dendrocoelum romanodanubiale	--	Ponto-Caspian	1992	+			Shipping canal and inland vessels		Tittizer et al. 2000; IKSR 2002
PORIFERA									
Eunapius carteri	--	Africa / Asia	1993	+			Release		Tittizer et al. 2000
<u>PHYTOPLANKTON, ALGAE, AND MACROPHYTES</u>									
CHARACEAE									
Chara connivens	convergent stonewort	West Europe	1858			+	Shipping		Leppakoski and Olenin 2000
CRASSULACEAE									
Crassula helmsii	swamp stonecrop	Australia	1990s	+			Release		Kowarik 2003

Table A-2.2. Continued.

Taxon / Species[1]	Common name	Origin	Date	Distribution			Mechanism / Vector	Status	Source
				Inland	North Sea	Baltic Sea			
POACEAE									
Spartina anglica	common cordgrass	West Atlantic	1920s		+++		Release	X	Nehring 2001; Reise et al. (in press)
CHLOROPHYTA									
Codium fragile ssp. *tomentosoides*	--	North Pacific	1930		+	+	Aquaculture product, associated		Leppakoski and Olenin 2000; Nehring 2001; Reise et al. 2002
PHAEOPHYTA									
Colpomenia peregrina	--	Pacific	1905		+	+	Aquaculture product, associated		Leppakoski and Olenin 2000; Nehring 2001
Fucus evanescens	--	North Pacific / North Atlantic	1924			+	Ocean shipping (hull)		Leppakoski and Olenin 2000; Olenin et al. 2004
Sargassum muticum	--	North Pacific	1988		++	+	Aquaculture product, associated	X	Leppakoski and Olenin 2000; Nehring 2001; Reise et al. 2002
RHODOPHYTA									
Bonnemaisonia hamifera	--	North Pacific	1959		+	+	Aquaculture product, shipping		Leppakoski and Olenin 2000; Nehring 2001; Reise et al. 2002
Dasya baillouviana	--	W / S Atlantic	1940s[a] / 1960s[b]		+	+	Aquaculture product, shipping		[a]Leppakoski and Olenin 2000; [b]Nehring 2001; [b]Reise et al. 2002
Polysiphonia harveyi	--	North Pacific	1960s		+	+	Aquaculture product		Leppakoski and Olenin 2000; Nehring 2001; Reise et al. 2002

Table A-2.2. Continued.

Taxon / Species[1]	Common name	Origin	Date	Distribution			Mechanism / Vector	Status	Source
				Inland	North Sea	Baltic Sea			
BACILLARIOPHYTA									
Coscinodiscus wailesii	--	Indo-Pacific	1977		+++	++	Aquaculture product; associated	X	Leppakoski and Olenin 2000; Nehring 2001; Reise et al. 2002
Odontella sinensis (syn. *Biddulphia sinensis*)	--	Indo-Pacific	1903		+++	++	Ocean shipping (ballast water)		Leppakoski and Olenin 2000; Nehring 2001; Reise et al. 2002
Pleurosira leavis f. *polymorpha*	--	Unknown	1900s			+	Aquaculture product, associated		Leppakoski and Olenin 2000
Thalassiosira punctigera	--	Indo-Pacific	1978		+++	++	Aquaculture product, associated?		Leppakoski and Olenin 2000; Nehring 2001; Reise et al. 2002
DINOPHYCEAE									
Alexandrium tamarense	--	Unknown	no data			+	Shipping		Leppakoski and Olenin 2000
Gymnodinium catenatum	--	Unknown	1993			+	Shipping		Leppakoski and Olenin 2000
Gymnodinium mikimotoi	--	Pacific	1966		+++	+	Ocean shipping (ballast water)		Leppakoski and Olenin 2000; Nehring 2001; Reise et al. 2002
Pleurosigma simonsenii	--	Indian Ocean?	1987			+	Shipping		Leppakoski and Olenin 2000
RAPHIDOPHYCEAE									
Chattonella antiqua	--	Pacific?	1991		++		Ocean shipping (ballast water)		Nehring 2001

Table A-2.2. Continued.

Taxon / Species[1]	**Common name**	**Origin**	**Date**	**Distribution**			**Mechanism / Vector**	**Status**	**Source**
				Inland	**North Sea**	**Baltic Sea**			
Chattonella marina	--	Pacific?	1991		++		Ocean shipping (ballast water)		Nehring 2001
Fibrocapsa japonica	--	Pacific?	1991		+++		Ocean shipping (ballast water)	X	Nehring 2001; Reise et al. 2002

Origin – known or probable area of origin; **Date** – year of the first record, or probable time of introduction to the region; **Distribution** – occurring at one or a few localities (+), in part of the area (++), throughout the area (+++); **Mechanism / Vector** – known or probable mechanism/vector of introduction; **Status** – a non-indigenous species which threatens ecosystems, habitats or species (X).

1 - Non-indigenous species from North America are not listed.