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**Research Article**

# Establishing a baseline for early detection of non-indigenous species in ports of the Canadian Arctic

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## Abstract

The combination of global warming, resource exploitation and the resulting increase in Arctic shipping activity are expected to increase the risk of exotic species introductions to Arctic waters in the near future. Here, we provide for the first time a benthic invertebrate survey for non-indigenous species (NIS) from the Canadian Arctic coasts, incorporating historical information to identify new records. The top three ports at highest risk for introduction of NIS of the Canadian Arctic were surveyed: Churchill (Manitoba), Deception Bay (Quebec) and Iqaluit (Nunavut). A total of 236 genera and species were identified. Based on cross referencing comparisons of contemporary and historical information on species composition and distributions, 14.4% of the taxa identified can be considered new records within the port regions surveyed and 7.2% within the more extended, adjacent surrounding regions. Increased survey effort is the most likely explanation for the majority of new occurrences, however, a small number of records (n=7) were new mentions for Canada and were categorized as cryptogenic since we could not confidently describe them as being either native or introduced. Further research is required to better understand the status of these new taxa. This study provides a benchmark for early detection for benthic invertebrates in the region. Significant costs and intensive labor are involved in monitoring and in early detection surveys, but they provide a great opportunity for identifying native and introduced biodiversity, crucial to analyzing the changes taking place along one of the longest coastlines in the world, the Canadian Arctic coast.

**Key words:** Arctic, biological invasions, benthos, spatial distribution, shipping activity, risk for introduction

## Introduction

Changes in climate, hydrography, and ecology related to global warming are presently, and are expected to continue to be, more strongly expressed in the Arctic Ocean relative to other regions of the world (IPCC 2001; Hoegh-Guldberg and Bruno 2010). These changes are hypothesized to have an important impact on the structure and functioning of Arctic benthic systems (Piepenburg 2005) but these systems are still understudied (Wassmann et al. 2011). The combination of these modifications can be expected to facilitate introductions of non-indigenous species (Strayer 2012). Coastal waters have been shown to be more susceptible to non-indigenous species (NIS) since intertidal and subtidal biota in many regions have undergone rapid and profound changes caused by the arrival of NIS (Carlton 1996a; Ruiz et al. 1997). Although most introductions have occurred in southerly latitudes where there is the greatest shipping activity, the combination of global warming, resource exploitation and the resulting increase in Arctic shipping activity are expected to increase the risk of exotic species introductions to Arctic waters in the near future (Niimi 2004; Arctic Council 2009; Smith and Stephenson 2013). Canada has the longest coastline in the world (its territorial sea covers 14.3% of the territorial sea of the world and its coastline is 16.2% of the world total), the majority of which is located in Arctic waters (Archambault et al. 2010). Given the extent of coastline in the Canadian Arctic, it can be considered a region that is, and will continue to be, at high risk for future introductions of NIS.

Over the last two decades, high-latitude areas have shown a disproportionate increase in temperature, and their coasts are highly susceptible to a combination of climate change impacts in addition to sea-level rise (IPCC 2007; Hoegh-Guldberg and Bruno

2010). In summer 2012, the decline in the Arctic sea-ice was the lowest ever recorded (National Snow and Ice Data Center 2012). It is projected that there could be a further 31% mean reduction of annually averaged sea ice area in the Arctic by 2080-2100 (IPCC 2007), and there are even more extreme projections like the complete disappearance of summer sea ice by 2037 (Hoegh-Guldberg and Bruno 2010). These projected changes will result in warmer, less saline, ocean conditions, which together with increased shipping activity (Arctic Council 2009; Smith and Stephenson 2013), are expected to favour the establishment of high risk ship-mediated invasive species. Canadian Arctic ports are connected to international and Canadian coastal domestic ports, resulting in potential for species transfers via hull fouling and/or ballast water discharge (Chan et al. 2012). Research on the climate-driven reductions in Arctic sea ice predicts that, by 2040 to 2059, new shipping routes will become passable across the Arctic (many through the Canadian Arctic), linking the Atlantic and Pacific oceans (Smith and Stephenson 2013). This will result in an increase in vessel traffic with implications for the ecosystems of this fragile area including an increased probability of introducing non-indigenous species due to greater propagule pressure. Increasing temperatures are also expected to result in shifts in aquatic communities with southern species expanding their ranges to more northern locations (Ruiz and Hewitt 2009; Chust et al. 2013; Valle et al. 2014).

New species reported in the Arctic may be native to this region but not previously described, such as the polycheate *Streptospinigera niuqtuut* Olivier, San Martin and Archambault, 2013 (Olivier et al. 2013). On the other hand, unrecognized introduced species could be assumed to be native to the region (Carlton and Geller 1993; Petersen 1999). Some species could be either native or non-native (classified as 'cryptogenic') due to the lack of baseline surveys and information on historical species ranges, as is the case for the Canadian Arctic coast (Carlton and Geller 1993; Carlton 1996b; Ruiz et al. 1997). Underestimation of NIS is probably always high in a given region (Ruiz et al. 1997; Bax et al. 2001) for the above described reasons, but also because of the taxonomical challenges of studying and identifying small organisms and poorly known taxa (Bax et al. 2001). The challenge becomes greater knowing that many species remain to be described. There are estimates that 91% of species in the ocean still await description (Mora et al. 2011), and that between one-third and two-thirds of marine species may be undescribed (Appeltans et al. 2012a). To date, there have been no reported ship-mediated NIS in Arctic Canadian waters; however, the Arctic Ocean is the least sampled of the world´s oceans (Arctic Council 2009), and few systematic surveys have been conducted in this region of the country (particularly for benthic invertebrates) making it problematic in determining if newly reported species are native or introduced. In particular, the systematics and biogeography of benthic coastal invertebrates in the region are poorly known and mostly underestimated (Archambault et al. 2010). Regionally speaking, for the whole Arctic and sub-Arctic, a review of the literature revealed one north-eastern Asiatic crustacean, *Caprella mutica* Schurin, 1935*,* to be successfully established in Alaskan waters (Ashton et al. 2008) and the Alaskan king crab, *Paralithodes camtschaticus* (Tilesius, 1815), which has established non-indigenous populations in the Russian and Norwegian Arctic (Orlov and Ivanov 1978; Jørgensen and Nilssen 2011), causing substantial impacts on the invaded environments (Oug et al. 2011). An additional 10 NIS have been found in waters of Alaska, but without specific invasion success information (Hines and Ruiz 2000; Ruiz and Hewitt 2009). Also, one introduced species of benthic alga, *Dumontia contorta* (S.G.Gmelin) Ruprecht, 1850, has been recorded in James Bay and Ellesmere-Baffin Island, Canada (Mathieson et al. 2010). This alga is thought to have originated from Europe and was first observed in the Western North Atlantic at the beginning of the 20$^{th}$ century; the means of introduction to North America is unknown (Mathieson et al. 2008). Another species of alga, *Spyridia filamentosa* (Wulfen) Harvey, 1833, also recently found in the James Bay area of Canada, is considered cryptogenic as it is unclear if it was introduced (e.g., by migrating bird species) or if it originated from relict populations that survived from the mid-hypsithermal period (ca. 7000 years ago) (Mathieson et al. 2010). In the latest Arctic Biodiversity Assessment, Lassuy and Lewis (2013) provide a review of all terrestrial and aquatic species that have invaded the Arctic realm.

We lack robust information on the early stages of most introductions, whether successful or not, even though they may provide essential information on the vectors transporting the species as well as the invasion process in itself (Chang et al. 2011). As explained previously, lack of baseline data or insufficient taxonomic information can result in

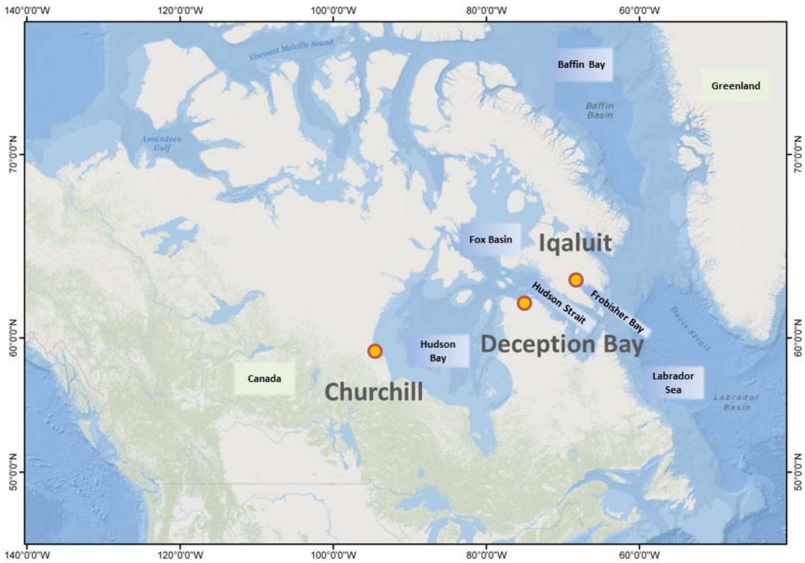


**Figure 1.** Map of the ports sampled: Churchill, Deception Bay and Iqaluit.

unnoticed changes related to aquatic community composition and existing populations of native species. There is a need for baseline research in order to determine if a species is new to an area and to detect changes within the probable introduction pathways (i.e., early detection) (NISC 2003). The shipping activity in a given region of study can result in the frequent release of propagules, and introduces the probability that at any given time some species are in the early stages of establishment, and may not be detected until several generations after they establish (Carlton 2009). Locke and Hanson (2009) propose a framework for rapid response to non-indigenous species which includes a detection phase during which they recommend the development of ecological inventories to establish baseline information on native and NIS populations. It is extremely important to know what was previously present to be able to identify new arrivals. The Canadian Arctic coasts can be considered a poorly studied area particularly with respect to benthic invertebrate biodiversity (Archambault et al. 2010; Piepenburg et al. 2011) thus emphasizing the importance of sampling and monitoring high-risk locations such as ports.

In this context, the objectives of this study were: 1) to compare species lists generated from a biodiversity survey performed in 2011 and 2012 in high risk port areas of the Canadian Arctic with historical survey information to identify new species and to evaluate if new records are best explained by increased survey effort, range expansions, ship mediated introduction, or other mechanisms and 2) to establish a baseline of biodiversity of coastal benthic invertebrates for further monitoring and early detection of aquatic non-indigenous species. This baseline will aid in identifying and managing new introductions of species in the Arctic, a region which is experiencing rapid change.

## Materials and methods

### *Characteristics of the ports sampled*

Three major Canadian Arctic ports: Churchill, Deception Bay and Iqaluit, Canada (Figure 1), were sampled because of their level of shipping activities. These ports are considered to be at highest risk for the introduction of NIS based on a recent assessment of the number of vessel arrivals and ballast discharge for all vessel categories between years 2005–2008 (Chan et al. 2012, 2013).

Churchill is located on the south western shores of Hudson Bay and is the major seaport in the region (Figure 1). Hudson Bay is connected to the Labrador Sea through Hudson Strait and is considered to be a large inland sea (surface area exceeds 1 million km$^2$) but is relatively shallow (an average depth of less than 150 m) and therefore warmer than many other regions of the Arctic

(Saucier et al. 2004; Séguin et al. 2005). The Hudson Bay complex is comprised of sub-regions such as Hudson Strait, Foxe Basin and Hudson Bay, among others (Figure 1). Churchill's main shipping activities are related to its unique location that provides opportunities for international traffic, dominated mainly by the export of grain, followed by manufactured, mining, and forest products, as well as the import of ores, minerals, steel, building materials, fertilizer, and petroleum products for distribution in the heartland of Canada and the United States. Churchill is currently the port at highest relative invasion risk for the Canadian Arctic since it receives the highest number of vessels and volume of ballast discharge, and is environmentally similar to a large number of connected source ports with established high risk NIS (as compared to other ports in the Arctic) (Chan et al. 2012). Mean values (± SE), between the years 2005–2008 of annual number of arrivals of international merchant vessels (17.75 ± 1.65) and the untreated annual volume of ballast water discharge (157,675 ± 19,409 $m^3$) in Churchill were the highest of all Canadian Arctic ports (Chan et al. 2012).

Deception Bay is located in northern Quebec, and is part of the Hudson complex since it is surrounded by the waters of Hudson Strait (Figure 1). Its main activity involves shipping from a single-base metal operation that exports nickel concentrate to Quebec (Arctic Council 2009). A new mining development is scheduled to start exporting ore to Finland in 2013, which is expected to increase the shipping traffic in Deception Bay port. It is predicted that by 2014, a total of 2.9 Mt will be shipped annually out of this port (Gavrilchuk and Lesage 2013). According to Chan et al. (2012), Deception Bay is in the top 3 ports receiving the greatest number of arrivals and releasing the greatest volumes of untreated ballast water for international and coastal domestic merchant vessels. Mean values (± SE), between the years 2005–2008 of the annual number of arrivals of international and coastal domestic merchant vessels in Deception Bay were 8.75±4.15 and 9.50±1.50, respectively (Chan et al. 2012). The values for the volumes of untreated ballast water were 8,069±4,020 $m^3$ for international merchant vessels and 60,144±11,852 $m^3$ for coastal domestic merchant vessels (Chan et al. 2012). This port was also found to have high environmental similarity with a large number of its source ports, thus increasing the probability of survival of NIS (Chan et al. 2012).

Iqaluit is located in the Eastern Arctic, at higher latitude than the other ports studied and it is situated in the southern portion of Baffin Island on Frobisher Bay (Figure 1). It is the capital of Nunavut, the largest community in that province (more than 7,250 habitants) and the gateway to the Arctic from Eastern Canada. Tidal amplitude may reach as much as 13 meters, and sea ice in Frobisher Bay area consists almost entirely of annual ice which does not break up until the middle of July (Ellis and Wilse 1961; Jacobs and Stenton 1985). The annual volumes of dry goods and petroleum products being shipped to Iqaluit have been increasing dramatically and other potential marine activities and tourism have also increased since 1980 (Aarluk Consulting Inc. et al. 2005). Iqaluit´s port is being used for different activities: dry cargo handling (government, commercial and private use), petroleum shipping, fisheries, tourist cruise ships, Canadian Coast Guard, military and research vessels, and small craft operators like hunters and fishermen (Aarluk Consulting Inc. et al. 2005). Iqaluit was found to have a high level of international and coastal domestic merchant vessel arrivals as well as international non-merchant vessel arrivals and is among the top ports in the Canadian Arctic for invasion risk via hull fouling (Chan et al. 2012). Mean values (± SE), between the years 2005–2008 of the annual number of arrivals of international merchant vessels in Iqaluit were 12.00 ± 1.08, of coastal domestic merchant vessels were 15.00±1.87, and of international non-merchant vessels were 9.25 ± 1.60 (Chan et al. 2012).

*Sampling strategies*

Surveys for benthic samples were conducted during the summer in 2011 and 2012, using the following design: 5 zones per port × 4 elevations per zone (2 intertidal, 2 subtidal) × 4 random replicate samples per elevation. The port area and its surroundings, including both marine and estuarine habitats, were sampled. Different natural substrates were sampled in order to maximize coverage of coastal biodiversity based on shoreline characteristics that could be discerned from hydrographic charts and visual observations prior to sampling. The sampled elevations included two intertidal (high and low elevation) and two subtidal (shallow: 0–10 m, and deep: 10–20 m; at low tide). Random replicate samples were collected at each zone-elevation location using a 15 cm high × 10 cm diameter core and sieved to a minimum of 500 μm. The

**Table 1.** Detail of core samples taken at each port according to zones and replicates.

| Elevation | Iqaluit | | Churchill | | Deception Bay | |
|---|---|---|---|---|---|---|
| | Zones | Replicates | Zones | Replicates | Zones | Replicates |
| High intertidal | 5 | 4 | 5 | 4 | 5 | 4 |
| Low intertidal | Not available | | 5 | 4 | 5 | 4 |
| Shallow subtidal | 5 | 4 | 5 | 4 | 5 | 4 |
| Deep subtidal | 2 | 4 | 5 | 4 | 5 | 4 |
| Total of core samples | 48 | | 80 | | 80 | |

total number of samples collected at the port of Iqaluit (n = 46) was lower than in the ports of Churchill and Deception Bay (n = 80) due to variation in tidal conditions, weather, and time constraints that limited sampling opportunities at some locations (Table 1). All samples were preserved in 4% buffered formalin.

Samples were sorted and identified to the lowest taxonomic level possible, using updated literature and consulting with specialists, which included sending them samples for verification as necessary. All species names were standardized to the World Register of Marine Species (WoRMS, Appeltans et al. 2012b). The term 'taxa' refers to species and generic-level identifications unless otherwise noted.

*Cross referencing and data analysis*

The taxa identified were included in a cross-referencing protocol with the objective of detecting taxa that are out of their regular and described known range. This protocol included more than 40 references and was designed to allow for comparison of temporal changes in species presence through the compilation of a comprehensive historical database of benthic species from throughout the Canadian Arctic. The references used included historical primary publications and the following global biodiversity databases: Ocean Biogeographic Information System (Intergovernmental Oceanographic Commission of UNESCO 2013), Arctic Ocean Diversity (Sirenko et al. 2010), Global Biodiversity Information Facility (GBIF 2013) and Sea Life Base (Palomares and Pauly 2013), together with the Smithsonian National Museum of Natural History databases (NMNH 2012). Synonym names available in WoRMS (Appeltans et al. 2012b) were also cross referenced with the same protocol when necessary. Consulting with specialists on the taxa was done, when possible, regarding taxonomic and distribution characteristics, especially for new records in the region of study.

Five categories were used to define the subregions of closest records for the species found in the ports surveyed: 1) 'within region': previous records in the exact area where the port is located, 2) 'surrounding region': no previous records for the exact region where the port is situated, but previous records from neighbouring and close areas, 3) 'Arctic outside region': species' distribution known from elsewhere in the Canadian Arctic, but not specifically in the region of the port surveyed or its vicinity (surrounding region) and/or species records found in other neighbouring Arctic ecoregions according to the bioregionalization by Spalding et al. (2007), 4) 'circumpolar/ circumboreal distribution': species that have a wider Arctic distribution and have been found at several locations throughout the larger Arctic realm (Spalding et al. 2007), but have not previously been found within the ports surveyed or their surrounding regions, 5) 'wider distribution, including Arctic': species or genus that show a wide and extended distribution, present in other realms as well as in the Arctic realm, but not previously found in the surveyed ports or their surrounding regions (Figure 2). This information was used to infer if the occurrence of new species was likely due to range expansions, improved survey effort, or possible introduction in a particular area. More detailed information from literature searches was obtained for taxa corresponding to all categories except for the ones 'within region' and 'surrounding region'. Extensive lists of NIS available on the web and in research reports were consulted to identify if any were present in our species list.

The category of cryptogenic was given to taxa that were found to be new mentions for the whole Canadian Arctic and based on known distributional patterns, and NIS lists could not be confidently described as either native or introduced (Carlton 1996b).

Unbiased nonparametric estimator of species richness, Chao 2, for replicated incidence data (Chao 1984; Colwell and Coddington 1994) was

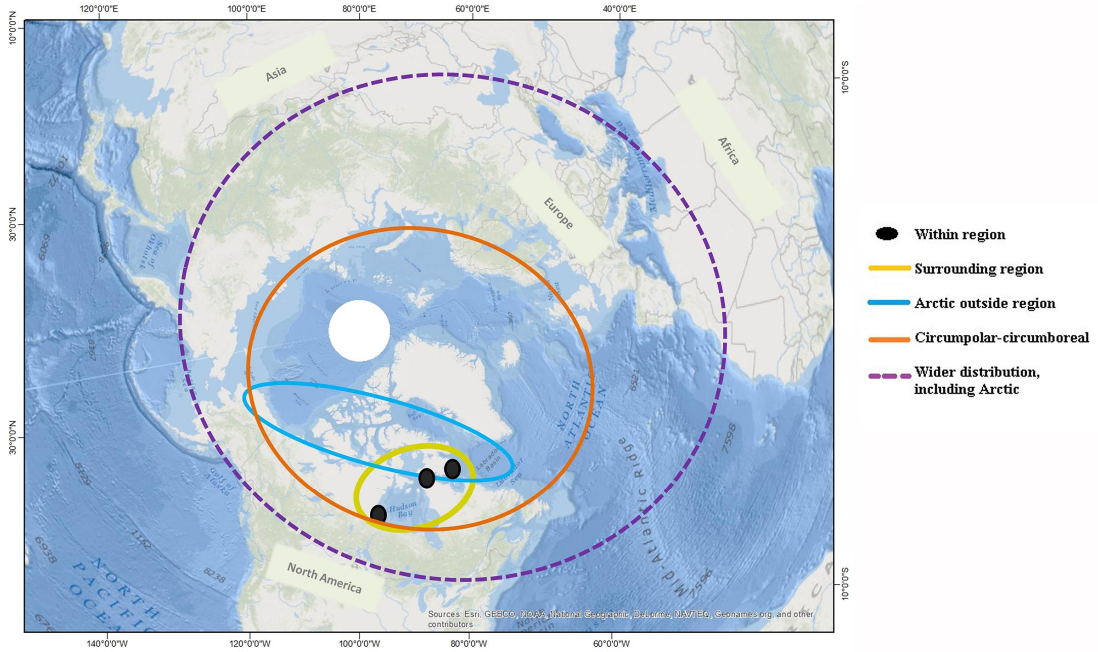


**Figure 2.** Schematic showing approximate regions corresponding to categories of distribution patterns used to define the closest records for the species found in the ports surveyed: 1) within region, 2) surrounding region, 3) Arctic outside region , 4) circumpolar / circumboreal, 5) wider distribution, including Arctic.

used to test adequacy of sampling effort in characterizing biodiversity in our study sites. It was calculated using PRIMER software (Clarke and Gorley 2006). This method predicts the expected number of species which would be observed for an infinite number of samples by extrapolating, based on the number of rare species in the available data. PRIMER was also used to calculate resemblance matrices between ports with Bray-Curtis distances in order to see the similarities between ports for species composition.

## Results

We identified 236 taxa from surveys in the ports of Churchill (Ch), Deception Bay (DB) and Iqaluit (Iq) (see supplementary Table S1 for the complete list of genus and species). Of the taxa identified, 14.4% were not previously recorded within a given port, while 7.2% (17 taxa, mostly Polychaeta), were not previously recorded from the larger surrounding regions of each port (Table 2). A total of seven species (3%) were records found for the first time in Canadian Arctic waters. The most widely represented phylum was Annelida (Polychaeta) in all three ports (Ch=56.2%, DB=47.8%, Iq= 44.8%), followed by Arthropoda (Crustacea) (Ch=13.5%, DB=18.2%, Iq= 26.4%), and Mollusca (Ch=12.4%, DB=20.1%, Iq= 19.5%) (Figure 3). The genus and species identified accounted for the 62.7% (n=142), 63.9% (n=249), and 62.6% (n=139) of the total taxa identified for Churchill, Deception Bay and Iqaluit respectively. Some groups like Oligochaeta, Nematoda, Nemertea and Copepoda (Harpacticoida and Calanoida) were not identified further due to the high level of specialization required to identify them, even though their presence and abundance were high in the three ports. A total of 10.2% of the taxa (mostly polychaetes) were shared among the three ports. The similarities between ports for species composition were: $S_{Ch\text{-}DB}$=40.3, $S_{Ch\text{-}Iq}$=33 and $S_{DB\text{-}Iq}$=39.8 (where S=0 when samples have no species in common and S=100 when they are identical).

The taxa accumulation plots for individual ports and the three ports combined did not reach an asymptote, suggesting that sampling effort is still insufficient for characterizing the full extent of biodiversity at these locations (Figure 4). When calculating the species richness estimator Chao2 for the three ports combined to estimate expected total species numbers, the expected number of species for an infinite number of samples was

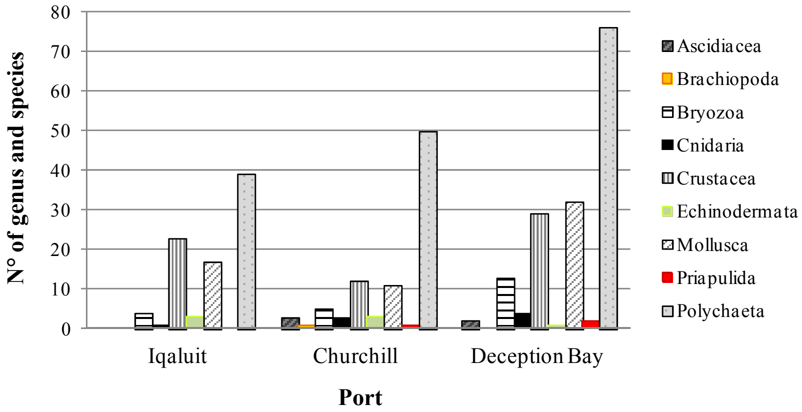


**Figure 3.** Histogram showing the taxonomic composition sampled by core for the ports of Iqaluit, Churchill and Deception Bay.

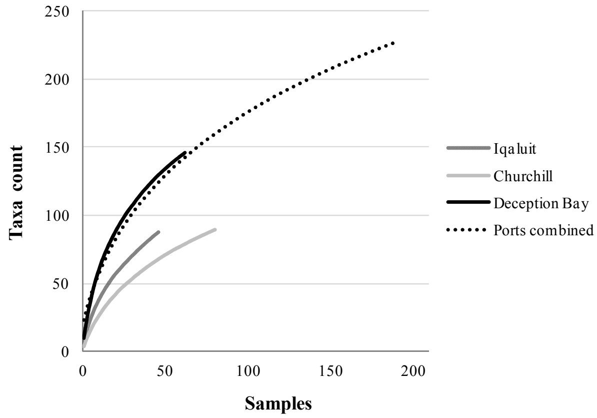


**Figure 4**. Randomized taxa accumulation curves found in sample data gathered from the three ports studied.

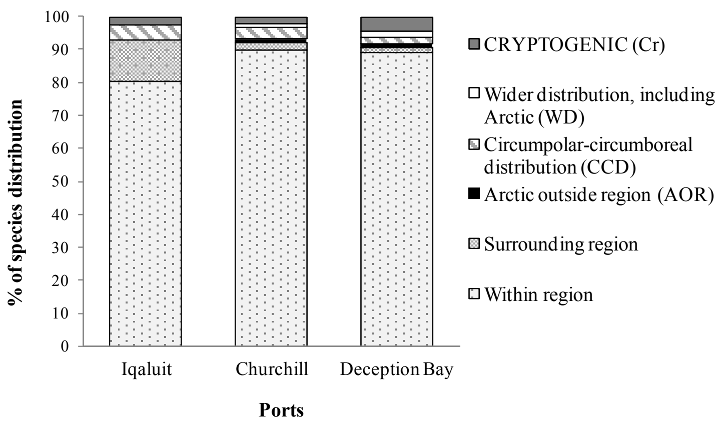


**Figure 5.** Percentage of species distribution by port, divided in categories of distribution patterns: 1) cryptogenic, 2) wider distribution, including Arctic, 3) circumpolar-circumboreal distribution, 4) Arctic outside region, 5) surrounding region, 6) within region.

346.2, exceeding the total number of observed species by almost 32%, clearly showing that expected number of genus and species is quite different from what was observed.

Overall, more than 80% of the taxa analyzed had historical records for being 'within region' (Figure 5). The remaining taxa were previously found in other Arctic regions, either in the 'surrounding' areas of the ports sampled, 'Arctic outside region', 'circumpolar-circumboreal' region or an even 'wider distribution including Arctic'. The majority of new records found are most likely explained by increased survey effort. None of the species were found to have only Temperate

**Table 2.** New species records with known closest region distribution and comments about presence in the region of study. Port: Churchill (Ch), Deception Bay (DB), Iqaluit (Iq). Regions of known distribution: Other Canadian Arctic Regions (CA), West Greenland (WG), European/Asian Arctic (EAA), Temperate North America (TNA), Other Temperate regions (OT). Category of distribution pattern: Arctic Outside Region (AOR), Circumpolar-Circumboreal Distribution (CCD), Wider Distribution including Arctic region (WD). Origin: Increased Survey Effort (ISE), Cryptogenic (Cr). References: Ocean Biogeographic Information System (OBIS), Sea Life Base (SLB).

| Taxa | Genus - Species | Port | Regions of known distribution | | | | | Distrib. pattern | Origin | References |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | CA | WG | EAA | TNA | OT | | | |
| **Polychaeta** | *Aricidea cf. hartmani* | Ch, DB | x | | x | | | | Cr | MacDonald et al. (2010), OBIS |
| | *Bipalponephtys neotena* | Ch, DB | x | | x | x | | WD | ISE | Appy et al. (1980); Atkinson and Wacasey (1989a); Cusson et al. (2007); MacDonald et al. (2010); OBIS |
| | *Dipolydora socialis* group | DB | | | | x | x | | Cr | Dahle et al. (1992); OBIS, SLB |
| | *Lumbrineris cf. zatsepini* | DB | | | x | | | | Cr | Oug 2011 |
| | *Owenia borealis* | Iq | | | x | | | | Cr | Koh and Bhaud (2003); Jirkov and Leontovich (2012) |
| | *Paradexiospira (Paradexiospira) violaceus* | DB | x | x | x | | | CCD | ISE | Wesenburg-Lund (1950); Knight-Jones (1991); Cusson et al. (2007); OBIS |
| | *Paraonides nordica* | Iq, Ch, DB | | x | x | | | | Cr | Strelzov (1979); OBIS |
| | *Pholoe longa* | Ch, DB | x | x | | x | | AOR | ISE | Pocklington (1989); Pettibone (1992); OBIS |
| | *Streptospinigera niuqtuut* | DB | x | | | x | | AOR | ISE | Olivier et al. (2013) |
| | *Syllides* sp. | Iq, Ch, DB | x | | x | | | CCD | ISE | Ramos et al. (2010); OBIS |
| **Crustacea** | *Onisimus sextoni* group | DB | | | x | | x | | Cr | Lowry and Stoddart (1993); Vader et al. (2005) |
| | *Rostroculodes schneideri* | DB | x | | x | x | | CCD | ISE | Stebbing (1906); Castillo (1976); Kennedy (1985); OBIS |
| **Bryozoa** | *Einhornia arctica* | Iq | x | x | x | x | | CCD | ISE | Kluge (1975) |
| | *Lichenopora crassiuscula* | Iq | x | x | x | | | CCD | ISE | Kluge (1975) |
| | *Schizoporella crustacea* | DB | x | x | x | | | CCD | ISE | Kluge (1975), OBIS |
| **Ascidiacea** | *Heterostigma* sp. | DB | | | x | x | | | Cr | Van Name (1945); OBIS |
| **Mollusca** | *Axinulus* sp. | DB | x | | x | x | x | WD | ISE | Bernard (1979); OBIS |

**Table 3.** List of species present in this survey reported as established NIS, cryptogenic or questionable elsewhere in the world. Modified from Çinar (2013).

| Species | Status in present survey | Status in other regions | References |
|---|---|---|---|
| *Celleporella hyalina* | Native | Cryptogenic in Alaska | Ruiz et al. (2006) |
| *Dipolydora socialis* | Cryptogenic | Cryptogenic in Australia – USA Pacific | Hayes et al. (2005); Boyd et al. (2002) |
| *Dipolydora quadrilobata* | Native | Cryptogenic in North Atlantic / North Pacific | Hines et al. (2000) |
| *Harmothoe imbricata* | Native | Established? / cryptogenic in USA Atlantic | Ruiz et al. (2000) |
| *Nephtys ciliata* | Native | Questionable in Black Sea | Gomoiu et al. (2002) |
| *Glycera capitata* | Native | Questionable in Black Sea | Gomoiu et al. (2002) |
| *Opercularella lacerata* | Native | Cryptogenic in Alaska | Hines and Ruiz (2000) |
| *Pygospio elegans* | Native | Cryptogenic in USA Atlantic and Pacific | Ruiz et al. (2000); Boyd et al. (2002) |

North America, Asia, or Europe as the closest region for previous records. Below we summarize and describe our findings for key taxa, in particular those which represent new records in a given location (for a complete list of species and distribution references see supplementary Table S1).

*Annelida (Polychaeta)*

Fifty-eight species and 43 polychaete genera were collected. Nine species and one genus represent new records within a given port region and adjacent surrounding region (Table 2).

Two species, *Streptospinigera niuqtuut* (Syllidae) found in Churchill and Deception Bay and *Pholoe longa* (O.F. Müller, 1776) (Pholoidae) found in Deception Bay, had their closest previous records in the Canadian Arctic outside the region, but do not appear to have a wider Arctic or circumpolar/ circumboreal distribution. Interestingly both species have also been recorded in temperate regions of North America and/or Europe.

One species and one genus had their closest previous records in other Arctic regions, including the European and Asian Arctic, the Canadian Arctic and West Greenland; both tended to have a more extensive circumpolar-circumboreal distribution. These included *Paradexiospira (Paradexiospira) violaceus* (Levinsen, 1883) (Spirorbidae) found in Deception Bay and *Syllides* sp. Örsted, 1845 (Syllidae) found in Iqaluit, Churchill and Deception Bay.

One species, *Bipalponepthys neotena* (Noyes, 1980) (Nephtyidae) found in Churchill and Deception Bay, had a wider historical distribution, including Temperate North American waters (Atlantic and Pacific) and other Arctic regions.

Five polychaetes species were found for the first time in Canadian Arctic waters, having historical records elsewhere. These included *Aricidea cf. hartmani* Strelzov, 1968 (Paraonidae) found in Churchill and Deception Bay, *Dipolydora socialis* group (Schmarda, 1861) (Spionidae) found in Deception Bay, *Lumbrineris cf. zatsepini* Averincev, 1989 (Lumbrineridae) found in Deception Bay, *Owenia borealis* Koh, Bhaud and Jirkov, 2003 (Oweniidae) found in Iqaluit and *Paraonides nordica* Strelzov, 1968 (Paraonidae) found in all three ports. Although *A. cf. hartmani* has previously been found in the Canadian Arctic, it was only recently recorded (2010) with uncertainty in its native status, and therefore is not considered a historical record.

Summarizing, most of the polychaetes listed above as being new records within the port regions, are unlikely to be non-indigenous since they have been found historically widely distributed throughout Canadian Arctic waters and in many cases, also in other Arctic or sub-Arctic waters. Exemptions to this are the *D. socialis* group, *L. cf. zatsepini*, *O. borealis* and *P. nordica* that were found for the first time in the Canadian Arctic; and *A. cf. hartmani* that was recently found in Arctic Canada Basin. Given that all these species come from complicated taxonomic groups and their distributions are not well known, we have classified them as cryptogenic, as is already the case for the *D. socialis* group, which has previously been reported as cryptogenic in USA Pacific waters (Table 3).

Five polychaete species having historical records within the port region and considered to be in their native range were found in different NIS lists in other parts of the world as cryptogenic, questionable status or established species (Table 3).

*Arthropoda (Crustacea)*

Forty-five arthropod taxa were collected. Two species, *Onisimus sextoni* group Chevreux, 1926 (Uristidae) and *Rostroculodes schneideri* (Sars G.O., 1895) (Oedicerotidae), were found in Deception Bay and represent new records within the port region and adjacent surrounding region (Table 2). *R. schneideri* has previously been found in other Arctic regions, including Canada, Europe, and Asia, extending into temperate areas along the Canadian north-Atlantic coast; thus, it is unlikely to be non-indigenous to the region. The case is different for *O. sextoni* group. This group appears to have a circumpolar-circumboreal distribution given that it has been recorded in high-latitude northern seas, Greenland, Iceland and Norway. However, given that the information on the distribution of this genus is limited and this is the first record of its occurrence in Canadian Arctic waters, we have categorized it as cryptogenic.

*Brachiopoda*

Only one species of Brachipoda was collected, *Hemithiris psittacea* (Gmelin, 1790) (Hemithirididae) found in Churchill, and is already known to occur within the port region.

*Bryozoa*

Nineteen bryozoans were identified. Three species represent new records within the ports regions and the adjacent surrounding region. These included *Einhornia arctica* (Borg, 1931) (Electridae) found in Iqaluit, *Lichenopora crassiuscula* Smitt, 1867

(Lichenoporidae) found in Iqaluit and *Schizoporella crustacea* (Smitt, 1868) (Schizoporellidae) found in Deception Bay (Table 2). These species have, however, been found in other Arctic regions (Archipelago of Canadian Islands, Davis Strait and West Greenland, including European Arctic), showing a circumpolar-circumboreal distribution. Thus, these species are unlikely to be non-indigenous to the region.

One bryozoan, *Celleporella hyalina* (Linnaeus, 1767) (Hippothoidae), having historical records within the port region and considered to be in their native range, was found on an NIS list elsewhere in the world as cryptogenic (Table 3).

*Cephalorhyncha (Priapulida)*

Two species and one genus of the Priapulidae family were found: *Halicryptus spinulosus* von Siebold, 1849 in Churchill, *Priapulus caudatus* Lamarck, 1816 in Deception Bay, and *Priapulus* sp. Lamarck, 1816 in Deception Bay. These taxa are known to be native and had previously been found historically within the region of each port.

*Chordata (Ascidiacea)*

Four taxa of sea squirts were identified. Three of them are known to occur within the port regions for Churchill and Deception Bay. The fourth species, *Heterostigma* sp. Ärnbäck-Christie-Linde, 1924 (Pyuridae), was new to the Deception Bay port region and adjacent surrounding areas (Table 2). This genus is likely to have a circumpolar-circumboreal distribution since it has been recorded from Norway and is described as having a wide Arctic distribution, reaching the Atlantic coast of North America. However, given that the information on the distribution of this genus is limited and this is the first record of its occurrence in Canadian Arctic waters, we have categorized it as cryptogenic.

*Cnidaria*

Four species of cnidarians were collected between Churchill and Deception Bay, and four specimens were identified to genus level between Iqaluit and Deception Bay samples. All specimens of Cnidaria had previously been found in the region of each port as well as in the larger surrounding region since they had been previously identified in the Hudson Complex, and are known to be native to the region.

One cnidarian, *Opercularella lacerata* (Johnston, 1847) (Campanulinidae), having historical records within the port region and considered to be in their native range, was found on an NIS list elsewhere in the world as cryptogenic (Table 3).

*Echinodermata*

Five echinoderm taxa were identified. All of them are known to be distributed throughout the area and have been frequently found historically within the port regions or adjacent surrounding regions.

*Mollusca*

Forty-five molluscan taxa were identified among the three ports. One genus, *Axinulus* sp. Verrill and Bush, 1898 (Thyasiridae), represents a new record within the Deception Bay port region and adjacent surrounding region. This genus is known for having an Arctic distribution, including Canadian Arctic and Alaska, extending into temperate areas along the north Atlantic and the Mediterranean Sea (Table 2). Thus this genus is unlikely to be non-indigenous to the region.

## Discussion

This study provides the first published benthic invertebrate survey for NIS in coastal regions of the Canadian Arctic (the longest coastline in the world) that incorporates historical survey information in order to identify new records. Approximately 15% of the taxa identified can be considered new records within the port regions surveyed and approximately 8% within the more extensive adjacent surrounding regions based on our criterion for cross referencing and comparing current and historical species lists. The most likely explanation for the majority of these new occurrences is increased survey effort in the various study locations, which is supported by our species accumulation curves that showed a much higher expected total number of species that the number actually observed. Taxa that were new for a given port, but were previously recorded in the surrounding region, are clearly the effect of increased survey effort. The occurrence of taxa that were previously recorded outside the surrounding region can also be explained with the same hypothesis when looking at their distribution patterns. It is likely that these species occurred previously in the region of study but were not sampled or identified due to the low sampling effort in the region. Further sampling would be expected to increase the number of taxa known to occur in the entire study area. Our results suggest that the coastal region of the Canadian Arctic might be much richer that we indicate here. The very low survey effort in the Arctic, the underestimated diversity, and expected increases in activity in the Arctic means a comprehensive understanding of marine biodiversity is more important today than ever (Archambault et al. 2010; Macdonald et al. 2010; Carr 2012; Snelgrove et al. 2012).

We identified one ascidia, *Heterostigma* sp., one amphipod, *Onisimus sextoni* group, and several polychaetes that represent new mentions for the Canadian Arctic, including: *Aricidea cf. hartmani, Dipolydora socialis* group, *Lumbrineris cf. zatsepini*, *Owenia borealis* and *Paraonides nordica*. These taxa have distributions elsewhere in the Arctic realm and in some cases within temperate waters (Van Name 1945; Strelzov 1979; Dahle et al. 1992; Lowry and Stoddart 1993; Koh and Bhaud 2003; Vader et al. 2005; Macdonald et al. 2010; Oug 2011; Jirkov and Leontovich 2012); however, distributional information is sporadic at best. Generally speaking, historical records for the majority of species in most shallow-water communities are unavailable (Carlton 1996b); hence, the fact that they have never been described for the Canadian Arctic may be a consequence of lack of sampling efforts. It has, however, been recommended that the discovery of previously unrecognized species in regions impacted by ballast water release should be viewed critically as potential invasions (Carlton and Geller 1993). Hence, as a result of the limited distributional information and the lack of population genetics information, we cannot confidently categorize these taxa as native or introduced and have therefore classified them as cryptogenic. Recent use of molecular techniques may help resolve some cryptogenic invasions, especially those involving sibling species complexes (Geller 1996). Indeed, of note, is that one of these taxa, the *D. socialis* group, is already considered to be a cryptogenic species in Australia and in some places in the Northeast Pacific (Boyd et al. 2002; Hayes et al. 2005). Also of note is the case of *A. cf. hartmani*, which has been collected in the Canada Basin by Macdonald et al. (2010). They explain that it is likely that this species has not been sampled before due to low sampling effort, but they postulate that its presence could also be due to range changes that have occurred because of climate change, dispersal of organisms through ballast water, or other mechanisms. Further research will be required to better understand the status of all of these cryptogenic taxa.

Among the major taxomic groups we identified by the core sampling, the polychaetes were the most diverse and abundant in all three ports and were the group for which we found the highest numbers of new records. There are also a number of interesting notes regarding the new records for this taxonomic group. Recently, Olivier et al. (2013) described a new Syllidae species, *Streptospinigera niuqtuut,* in the Canadian High Arctic archipelago and the northern Atlantic coast of the United States. Until now, it was only found in deeper stations (≥ 175 m), but we collected *S. niuqtuut* in shallow coastal waters (e.g., 10.6 m in the Deception Bay port).

Groups like Oligochaeta, Nematoda, Nemertea and Copepoda (Harpacticoida and Calanoida) were present and in high abundance in most of our samples. This is consistent with other studies which have shown these groups to be highly abundant. For example, Giere (2009) found that in meiofaunal samples, the number of species of nematodes often exceeded that of the other groups put together by an order of magnitude. Aside from nematodes, harpacticoid copepods are usually the next most abundant meiobenthic animal in marine samples (Giere 2009). Given this information, it is clear that we are missing a large part of the biodiversity in our sample analyses. However, these taxonomic groups require a high level of specialization to identify them morphologically, and genetic methods are frequently the only adequate means for achieving taxonomic distinction. Approximately 950 species of harpacticoid copepods belonging to 13 families are known to have invaded freshwater biotopes (Giere 2009), but for the other groups invasions are rarely reported (Rilov and Croocks 2009). This does not necessarily mean that invasions have not occurred, but may be related to the phenomenon referred to as the "smalls rule of invasion ecology," defined as an inverse correlation of body size with the ability to be recognized as non-native (Carlton 2009). These groups we are referring to here could easily be part of this phenomenon, raising concerns about the potential consequences of actually having NIS, but not being able to detect them for lack of information or adequate tools.

We have highlighted that the coastal region of the Canadian Arctic is likely to be at risk for introductions of NIS, but we also need to realize that the species native to the Arctic can also be non-indigenous elsewhere in the world, especially with the increasing shipping activity expected in the future (Smith and Stephenson 2013). Eight species found in our sampling have been found to be established NIS (non-native species with self-maintaining populations), cryptogenic, or have a questionable status somewhere else in the world (Table 3) (Carlton 1996b). All of these species, except one (*Dipolydora socialis* group), are within their historical native range. The knowledge that there are species in their native range in the Arctic that are on NIS lists in other parts of the world, poses a different point of view. Chan et al. (2013) emphasize the importance of estimating the relative invasion risk at major ports and identify risky transit pathways for the Canadian Arctic, and Casas-Monroy et al. (2014) indicate that it is unlikely that the Canadian Arctic serves as a source of NIS to other locations because the volume of ballast water leaving the Canadian Arctic to be dumped elsewhere is very low compared to other Canadian regions. Our findings, however, suggest we also need to explore a different perspective and be aware that the Arctic could be a potential source of NIS for ports elsewhere in the world, increasing the importance of establishing a baseline for these areas of the ocean.

Locke and Hanson (2009) propose a framework for rapid response for non-indigenous aquatic species in Canada that includes a series of pre- and post- invasion actions. One of the pre-invasion planning steps is the detection phase where they suggest conducting ecological inventories when necessary to establish baseline information on native and NIS populations. In order to determine if a species has newly arrived in a location, they state that it is absolutely necessary to know what was previously present. In order to do that, monitoring surveys should be designed to provide several years of baseline information for poorly studied areas or taxa. Our work clearly shows that we are still missing much of the baseline information required for even identifying which species are native. We found 34 new records within the three ports studied, which accounts for 14.4% of taxa found. Thus, we are still in one of the first stages in a pre-invasion framework. This highlights the importance of baseline studies such as this one, especially in remote places with a risk of invasion in the future. Since preventing the introduction of NIS remains the most effective course of management (Sylvester et al. 2011), surveys aimed at detecting incipient invasions are critical given that any kind of intervention can only proceed after an alien invasion has been detected (Bogich et al. 2008).

The number of non-indigenous species reported in Polar Regions is low compared with other temperate regions (Ehrlich 1989; Niimi 2004; Ruiz and Hewitt 2009) and may, in part, be due to insufficient research effort (Niimi 2004; Ruiz and Hewitt 2009). Nevertheless, we cannot take for granted that Polar Regions are exempt from introductions (Ashton et al. 2008; Ruiz and Hewitt 2009; Smith et al. 2012; Lassuy and Lewis 2013). Currently, access to Arctic ports is limited by a short navigation season but prospects for a longer navigation season are likely to improve with predicted future temperature and ice-free season increases, particularly at higher latitudes (Vermeij and Roopnarine 2008; Smith and Stephenson 2013). Under this scenario, the risk of introduction increases in Arctic regions (Cheung et al. 2009; Ware et al. 2013).

The Canadian Arctic is a vast region with a very high potential for resource exploitation. More than 25 large-scale marine-development projects are expected to be operational by 2020 in Canada’s North, which would represent up to 433 shipments per year (mining developments only), and the region is expected to experience an unprecedented increase in industrial development over the next 10 years (Gavrilchuk and Lesage 2013). At the same time, we know that this large region has undersampled coastlines, especially for invertebrate benthic fauna, whose distributions are still incompletely known. New species and distributions continue to be described (e.g., Olivier et al. 2013). Our study provides a benchmark for early detection for benthic invertebrates in coastal port regions of the Canadian Arctic and for the Arctic itself. It also demonstrates the importance of generating representative baseline data. Monitoring surveys and early detection efforts involve significant costs and are highly labor intensive but provide a great opportunity for identifying native and introduced taxa, crucial to analyzing the changes taking place along one of the longest coastlines in the world. While the present survey did not detect any known non-indigenous species, we encourage more studies like this one since significant discoveries are likely to be made regarding both native and non-indigenous species.

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**Supplementary material**

The following supplementary material is available for this article:

**Table S1.** Complete list of all genus and species identified in alphabetic order.

This material is available as part of online article from:
http://www.aquaticinvasions.net/2014/Supplements/AI_2014_Goldsmit_etal_Supplement.xls