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Assessing and mitigating the environmental impacts of shipping in the Arctic

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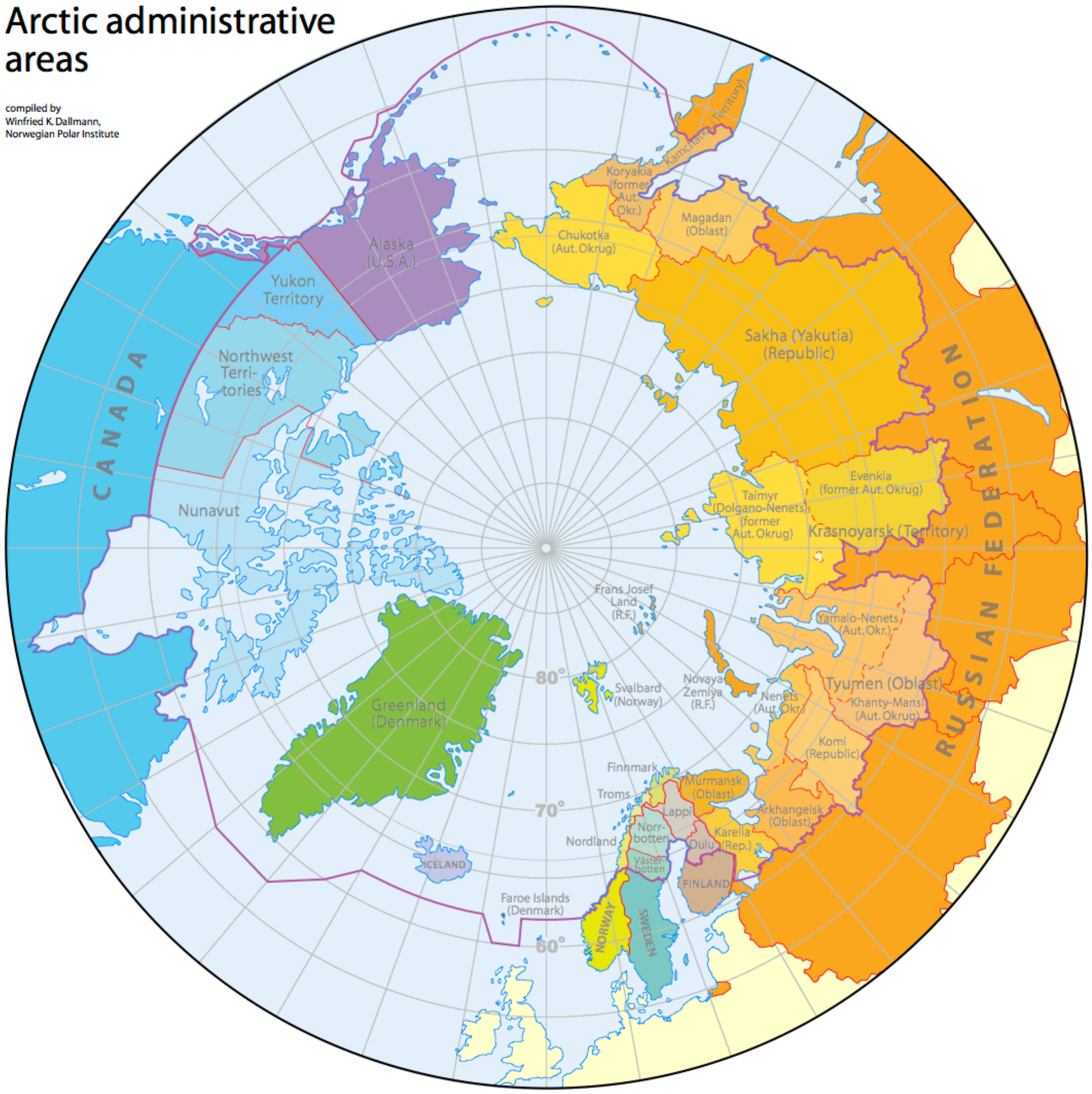
1. The Arctic Ocean

The Arctic is together with the Antarctic, the polar regions of the Earth, dominated by cold conditions and the presence of ice, snow, and water. These regions differ in that the Arctic is a frozen ocean surrounded by continental landmasses and open oceans, whereas Antarctica is a frozen continent surrounded solely by oceans. The landmass surrounding the Arctic Ocean belong to five nations: Canada, Denmark (Greenland), Norway, Russia, and USA (Alaska) (Figure 1).



Arctic administrative areas

compiled by
Winfried K. Dallmann,
Norwegian Polar Institute

Figure 1: Countries (and their regions) bordering the Arctic, the Arctic circle 60° latitude, and the Arctic Monitoring and Assessment Programme limit. Compiled by Winfried K. Dallmann of the Norwegian Polar Institute for the Arctic Council 2015.

The Arctic region is inhabited by two to four million people, depending on how the Arctic is defined, consisting of a mix between indigenous peoples and southern settlers (ACIA, 2005). The marine Arctic is characterized by a wide range of variability regarding environmental conditions. These marine areas are seasonally or permanently covered by ice and exposed to the extremes of solar radiation, which makes the Arctic Ocean a unique habitat compared to other marine regions (Eamer et al., 2013). The Arctic Ocean has the most extensive shelves of all oceans, covering about 50% of its total area (CAFF International Secretariat, 2013). The Arctic Ocean indirectly plays a key role in shaping the global biodiversity of marine and terrestrial ecosystems, as it plays an essential role in the Earth climate system. Similarly, water and sea ice leaving the Arctic Ocean influence the physical, chemical, and biological characteristics of the North Atlantic. In turn, the Arctic Ocean receives water from the Pacific and Atlantic Oceans, and any physical, chemical, and biological development in these oceans will propagate and impact the Arctic marine ecosystems.

1.1. Physiography

The Arctic Ocean is the smallest of the world's oceans, only covering around 10 million km^2 (Jakobsson et al., 2008). It consists of a deep central basin, the Arctic Basin, surrounded by continental shelves (Figure 2).

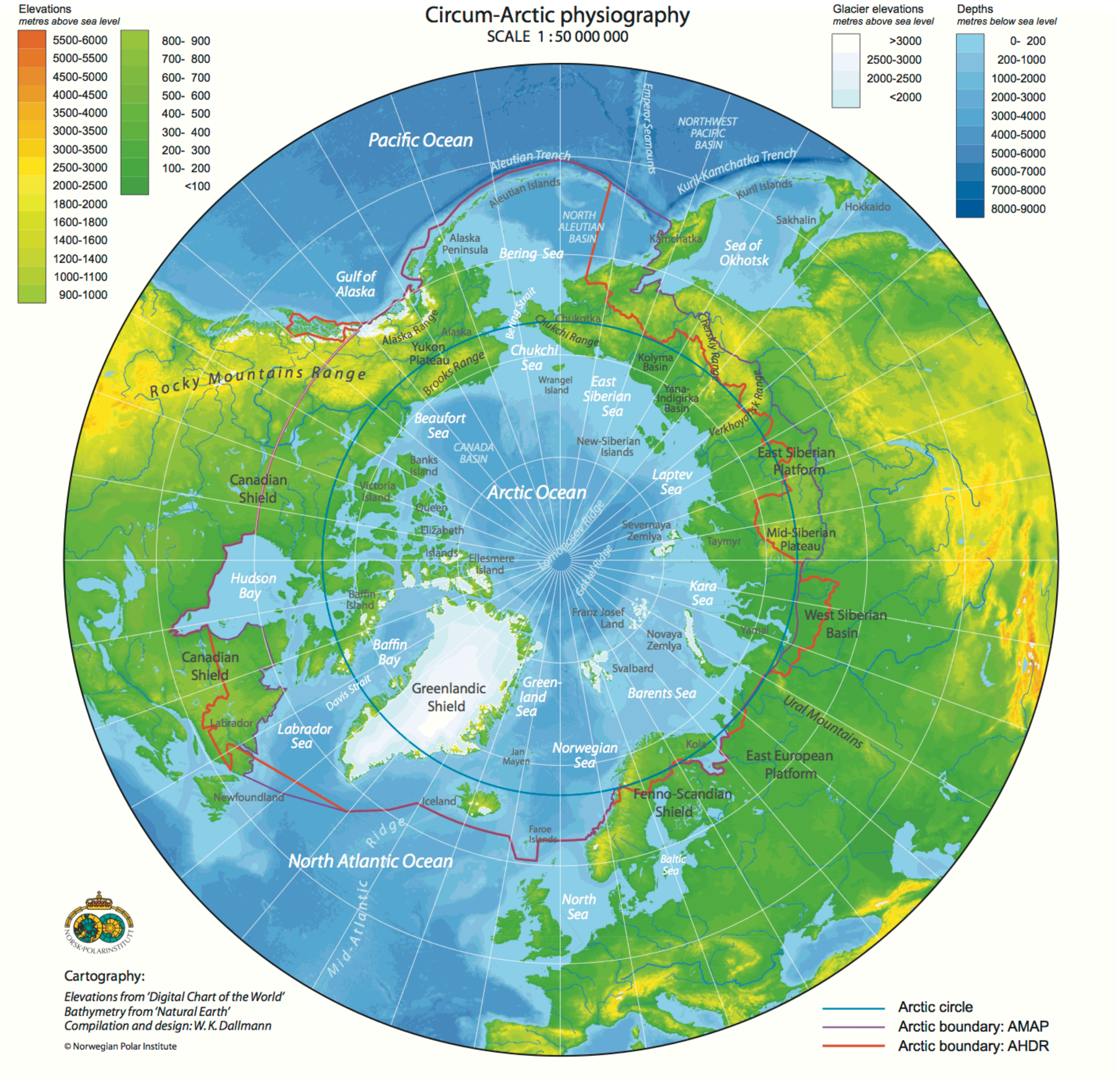


Figure 2: Circum-Arctic physiography with names, elevations and depth. Compiled by Winfried K. Dallmann of the Norwegian Polar Institute for the Arctic Council 2015.

The Arctic Basin is further divided into the Amerasian and Eurasian Basins, separated by the Lomonosov Ridge. The Amerasian Basin is further divided by the Canada Basin and the Makarov Basin, separated by the Alpha Ridge and Mendeleev Ridge. The Eurasian Basin is divided into the Amundsen Basin and the Nansen Basin, separated by the Gakkel Ridge, an extension of the North Atlantic Mid-Ocean Ridge system. The Amundsen Basin is the deepest of all Arctic basins in the Arctic, with the deepest point reaching 5,260 m (Jakobsson et al., 2008).

The seas associated with the shelves surrounding the Arctic Ocean comprise the Barents Sea, Kara Sea, Laptev Sea, East Siberian Sea, Chukchi Sea, Beaufort Sea, Canadian Arctic Archipelago, Lincoln Sea, and the Wandel Sea (Figure 2).

1.1.1. Barents Sea

The Barents Sea extends eastwards from the Norwegian Sea to Novaya Zemlya and northwards from the coasts of Norway and Russia into the Arctic Ocean. It covers approximately 1,424,000 km^2, with more than 50% of the seafloor reaching 200 to 500 m depth (UNEP, 2006). The average depth is approximately 230 m (CAFF International Secretariat, 2013). Warm saline Atlantic water is carried by the Norwegian Atlantic Current into the Barents Sea. The smaller Norwegian Coastal Current brings water with lower salinity along the coast of Norway in a northerly direction. In the northern part of the Barents Sea, cold Arctic water with low salinity flow in a northeast-southwest direction, separated from the warmer Atlantic waters by the Polar Front (Drinkwater, 2011)

The complex hydrography and circulation patterns in the Barents Sea strongly influence its biological production. In the permanently ice-free, Atlantic-water-influenced southwestern Barents Sea (i.e. where surface temperatures > 0 °C), the onset of thermal stratification in spring initiates the development of the phytoplankton bloom (Sakshaug, 2004). In contrast, the northern Barents Sea, which is influenced by Arctic waters, has a highly variable seasonal ice cover (both in duration and extent), and the phytoplankton bloom is typically associated with the retreat of the marginal ice zone. Production is significantly higher and shows less interannual variability in the Atlantic compared with the Arctic sector of the Barents Sea (Reigstad, Carroll, Slagstad, Ellingsen, & Wassmann, 2011; Sakshaug et al., 2009). The Barents Sea supports highly productive fisheries, one of the largest seabird concentrations in the world (Anker-Nilssen et al., 2000) and is host to 27 migratory or resident marine mammal species (ICES, 2013). Recent efforts in characterising the seabed nature and habitats also contribute invaluable knowledge on benthic habitat and diversity (Dolan et al., 2009).

1.1.2. Kara Sea

The Kara Sea extends between Novaya Zemlya, Franz Josef Land, and Severnaya Zemlya. It is connected with the Arctic Basin to the North, the Barents Sea to the west and the Laptev Sea to the east. The average depth is 127 m. The Kara Sea receives more than one third of the freshwater runoff, mainly from the Ob and Yenisei Rivers in Siberia (Russia) contributing to the low salinity surface layer of the Arctic Ocean.

With an average temperature below 0° C, the Kara Sea is typically cold throughout the year and ice-covered for most of the year. The salinity exhibits strong temporal and spatial variations due to fluctuations in river runoff, as well as ice formation and melt (Kulakov, Pogrebov, Timofeyev, Chernova, & Kiyko, 2006; Pivovarov, Hölemann, Kassens, Piepenburg, & Schmid, 2006). Interannual variability in sea ice cover is associated with wind forcing (Divine, Korsnes, Makshtas, Godtliebsen, & Svendsen, 2005).

Differences in species richness, abundance, biomass, and zonation patterns of phytoplankton, zooplankton, and benthic communities are related to the salinity gradient associated with the Ob and Yenisei outflows and differ between the two river systems (Deubel et al., 2003; Hirche et al., 2006).

1.1.3. Laptev Sea

The Laptev Sea has an average depth of 578 m and is located between the Kara Sea and the East Siberian Sea extending from Severnaya Zemlya to the west to the New Siberian Islands to the east (Figure 2). Similar to the Kara Sea, the Laptev Sea is also strongly influenced by large amounts of freshwater runoff from rivers, mainly by the Lena River. The main hydrographic features include a surface mixed layer of 5-10 m during summer (Pivovarov et al., 2006), variable circulation patterns that are mainly forced by winds, and an overall slow cyclonic surface layer motion in summer (Pavlov, 2001). The Laptev shelf exports more ice to the Arctic Ocean than any other shelf, feeding the transpolar drift with sediment-laden ice (Eicken et al., 2000; Rigor & Colony, 1997). As in the Kara

Sea, distribution patterns of planktonic and benthic communities are linked to salinity gradients associated with the river outflow, in addition to water depth, ice cover, and sediment characteristics (Abramova & Tuschling, 2005)

1.1.4. East Siberian Sea

The East Siberian Sea extends between the New Siberian Islands and Wrangel Island and is connected to the Laptev Sea to the west and the Chukchi Sea to the east (Figure 2). It is the largest and the shallowest of the Arctic Ocean shelves seas with an average depth of 52 m (Jakobsson, 2002).

The East Siberian Sea comprises two regions that are hydrographically distinct. To the west, surface waters are influenced by direct river input from the Lena River and relatively fresh water from the Laptev. To the east, surface waters are influenced by Pacific inflows and surface water from the Arctic Basin (Pivovarov et al., 2006).

The East Siberian Sea represents a distributional barrier for a wide variety of biota, but is also the most poorly described of the Russian shelves (Mironov & Dilman, 2010).

1.1.5. Chukchi Sea

The Chukchi Sea is located between Wrangel Island and the East Siberian Sea to the west and the Beaufort Sea to the east. To the south, it borders the Bering Strait between Siberia (Russia) and Alaska (USA), where it receives a high inflow of Pacific water, entering from Bering Sea (Figure 2). The Chukchi Sea is like the East Siberian Sea a shallow shelf sea with an average depth of 77 m. There is high inter-annual variability in the seasonal ice cover in the Chukchi, and highly productive polynyas (areas of open water surrounded by sea ice) are found along the coast.

This inflow of relatively fresh, cold and nutrient-rich waters constitutes a key structuring element of marine ecosystems in this broad (400 km) and shallow (average depth of approximately 50 m) sea.

Fuelled by the nutrient-rich inflow from the Bering shelf/Anadyr water, the production in hotspots of the southern Chukchi Sea ranks amongst the highest in the world’s oceans (Grebmeier et al., 2006).

The Chukchi Sea is, like the Barents Sea, an inflow shelf (Carmack et al., 2006). It is profoundly influenced by the interaction between Arctic and sub-Arctic (Pacific) waters, as well as by processes associated with the presence of the marginal ice zone (Darby, Polyak, & Bauch, 2006).

1.1.6. Beaufort Sea

The Beaufort Sea is located north of both Alaska and Canada. It borders the Chukchi Sea to the west and Banks Island and the Canadian Arctic Archipelago to the east (Figure 2). The continental shelf of the Beaufort Sea is narrow, with an average depth of 1,004 m.

The Beaufort Sea receives water from the Alaskan Coastal Current to the west, while to the east, the Canadian Beaufort Sea is strongly influenced by freshwater, as well as dissolved and particulate material input from the Mackenzie River in Canada. Water of Pacific origin enters through the Bering Strait form a halocline on the Beaufort shelf. Landfast sea ice, pack ice, and the presence of a flaw lead (a waterway opening between pack ice and fast ice) polynya are typical winter conditions in the Beaufort Sea (CAFF International Secretariat, 2013).

In summer, wind-driven upwelling enhances productivity in zones of hydrodynamic singularities at the shelf break (Williams & Carmack, 2008). Compared with the highly productive and strongly

Pacific- influenced Chukchi Sea shelf, biomass and numbers of Pacific-origin species sharply decrease towards the east (Dunton, Goodall, Schonberg, Grebmeier, & Maidment, 2005).

1.1.7. Canadian Arctic Archipelago

The Canadian Arctic Archipelago consists of 94 major islands and 36,469 minor islands and is, after Greenland, regarded as the largest High Arctic land area. It exhibits a complex array of islands and channels, stretching from Banks Island in the west to Baffin and Ellesmere Islands in the east (Figure 2) (CAFF International Secretariat, 2013). The depth of the channels between the islands range from less than 100 m to about 600 m in the eastern Lancaster Sound, with the continental shelf reaching from about 550 m depth in the west and north to 200 m in the east. The Canadian Arctic Archipelago is a transit region for waters from the Arctic Ocean flowing into the Labrador Sea and the North Atlantic.

These waters, mainly of Pacific origin, are modified by physical (e.g. mixing, freezing and sea ice melt) and biochemical processes during their transit. The Canadian Arctic Archipelago is covered by ice year-round in places, with a mix of locally-produced first-year ice and multi-year pack ice from the Arctic Ocean. A number of small polynyas are also present, many of which occur together with tidally-enhanced mixing in the narrow channels of the archipelago (Hannah, Dupont, & Dunphy, 2009).

As a result of the interaction of currents, the sound is rich in nutrients and supports a biologically varied community of birds, mammals, and fish. Major seabird colonies and summering areas for migrant whales are concentrated in Lancaster Sound, Barrow Strait and adjacent waters. Little is known of most of the Canadian Arctic Archipelago outside of the Northwest Passage (from Banks Island to Baffin Bay) (CAFF International Secretariat, 2013).

1.1.8. Lincoln Sea and Wandel Sea

The Lincoln Sea has an average depth of 257 m and is located between Cape Colombia in the Canadian Arctic Archipelago to the west and Cape Morris Jesup in Greenland to the east.

East of the Lincoln Sea is a body of water called the Wandel Sea, stretching from the northeast of Greenland to the west, to Svalbard and Barents Sea to the east. The Wandel Sea also connects to the Greenland Sea to the south through the Fram Strait (Figure 2).

There are limited studies of the Lincoln and Wandel Seas, as both are covered with ice throughout the year (Haas, Hendricks, & Doble, 2006). The most recent studies in the Lincoln Sea were performed during 2004 and 2005, where ice/snow thickness and the dynamic of ice movement were examined. The study presented data showing that thickness of multiyear ice and snow south of 84° N was in average 3.9 m and 0.30 m respectively during 2004 and 4.2 m and 0.35 m respectively in 2005. Surveys also showed considerable amounts of 0.9 to 2.2 m thick first year ice, mostly representing ice formed in the recurring, refrozen Lincoln Polynyas. The ice movement was examined with drifting buoys showing a mean southward drift of the ice pack of 83 ± 18 km in the period May 2004 and April 2005, in the direction towards the coast of Ellesmere Island and Nares Strait (Haas et al., 2006).

The first ever oceanographic and ice and snow survey over the Wandel Sea was performed in April-May 2015 by researches from the Arctic Science Partnership (ASP) (Dmitrenko et al., 2016). ASP is a collaboration and partnership between Greenlandic-Danish and Canadian researchers within the Center for Earth Observation Science (CEOS). With Conductivity-Temperature-Depth (CTD) instrument, Ice-Tethered Profiler (ITP), and Acoustic Doppler Current Profiler (ADCP), the researchers studied the origin of water masses and aims to reveal the seasonal changes in temperature, salinity and currents beneath the ice as well as ice growth and melt processes (Dmitrenko et al., 2016). This is an ongoing study and data is still processed and yet not presented.

There are few studies performed on the marine ecosystem in the Lincoln Sea and Wandel Sea area, much due to the logistic constraints of biological sampling in an environment dominated by thick multi-year ice. The common perception is that the limiting factors for organisms living within and under ice are light penetration, nutrients, and salinity (Arrigo, Mock, & Lizotte, 2010). A survey performed in the Lincoln Sea during springtime 2010-2012 have shown that the combination of ice and snow have a strong inhibiting effect on algal growth under the ice. However, it appears that it is primarily snow that has the most inhibiting effect on light transmission (Lange et al., 2015).

1.2. The dynamic waters of the Arctic

1.2.1. Ocean circulation

The condition and circulation of water masses of the Arctic Ocean is mainly powered by the water exchange with the Atlantic Ocean and (to a minor extent) the Pacific Ocean, the interaction of seasonal freezing and melting processes and river run-off (Rudels, Larsson, & Sehlstedt, 1991).The waters from the Atlantic Ocean are relatively warmer and more saline (around 35 psu, estimated of mean salinity of the Nordic Seas) (Aagaard & Carmack, 1989), as it originates from the Gulf Stream and enters the Arctic Ocean through the Fram Strait and the adjacent Norwegian and Barents Seas. The colder and less saline (33 psu) water from the Pacific Ocean enters through the narrow and shallow (50 m) Bering Strait (Coachman & Aagaard, 1988) (Figure 3).

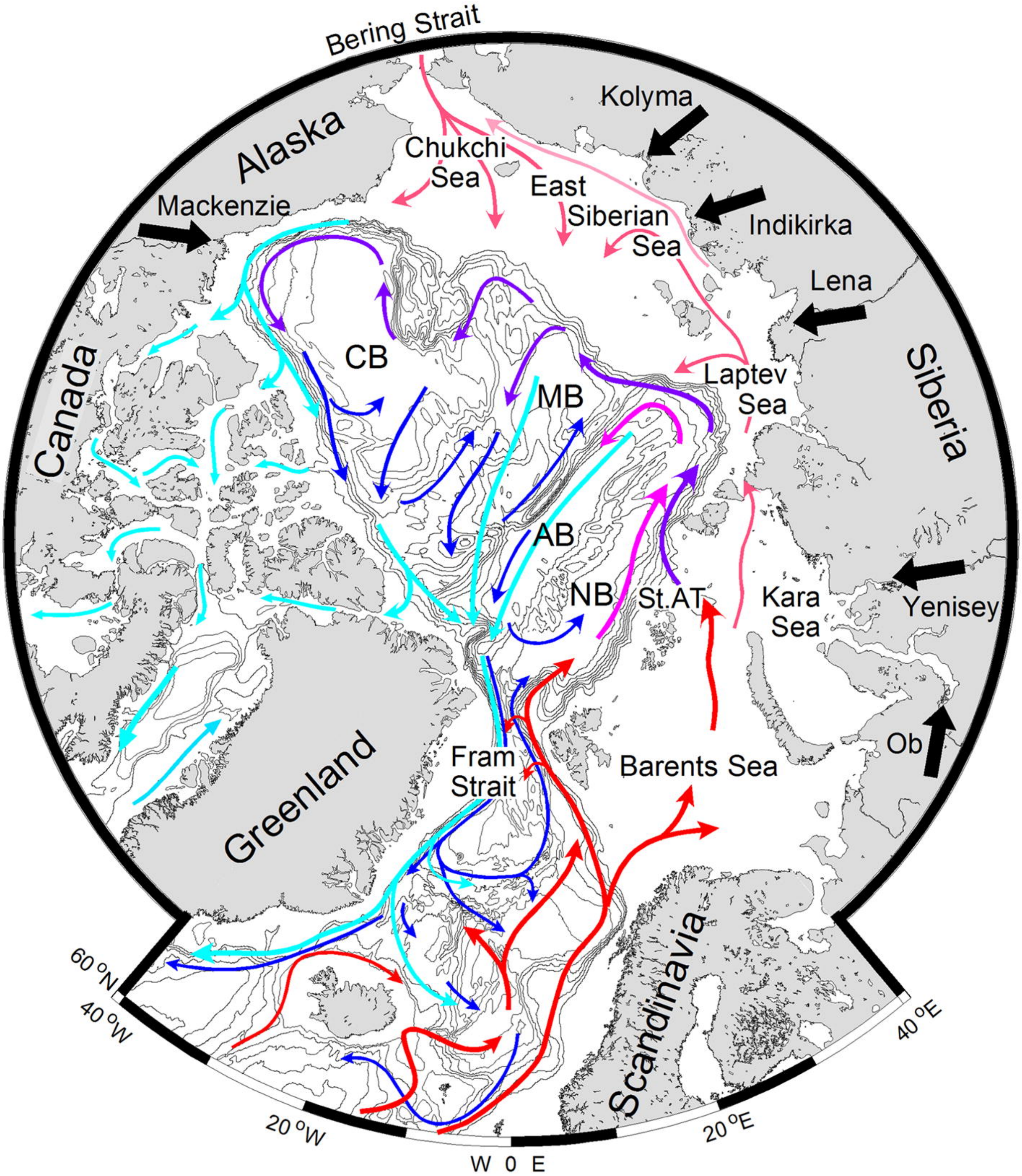


Figure 3: Arctic Ocean currents with warm surface currents in red and cold surface currents in light blue. Intermediate currents in burgundy and deep currents in dark blue. CB is Canadian Basin, MB is Makarov Basin, AB is Amundsen Basin, NB is Nansen Basin, and St. AT is St. Anna Trough (Anderson & MacDonald, 2015).

Additionally, a large amount of freshwater from rivers and sea ice melt add to the influx of water to the Arctic Ocean (CAFF International Secretariat, 2013).

1.2.2. Stratification

The variation of salinity combined with temperature gradients contribute to the stratification of the Arctic Ocean. The surface layer, the polar mixed layer (Figure 4), reaching down to 50 m depth, with low salinity (about 32.7 psu close to the Fram Strait and somewhat lower in the Beaufort Sea) and freezing temperature (Rudels et al., 1991).

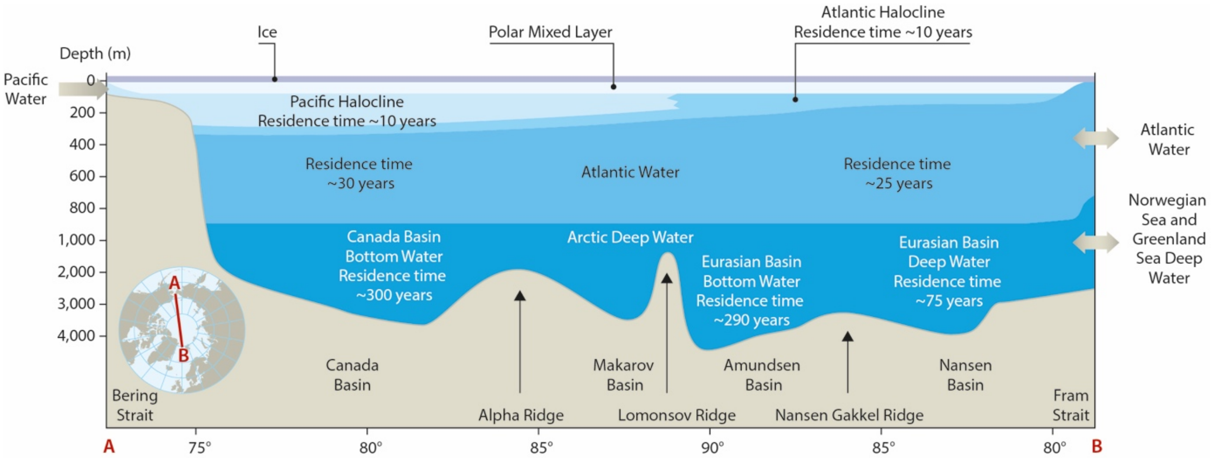


Figure 4: Water stratification across the Arctic Ocean (CAFF International Secretariat, 2013).

Beneath the Polar mixed layer, the halocline reaches from about 50 m to 250 m depth with salinities ranging from below 33 to 34.4 psu (Rudels et al., 1991). It comprises of water originating from the Atlantic and Pacific Oceans that cools down in combination with a mixing with less saline waters when entering the cold Arctic, contributing to higher density and formation of the halocline beneath the Polar mixed layer (Figure 5) (Rudels, Anderson, & Jones, 1996).

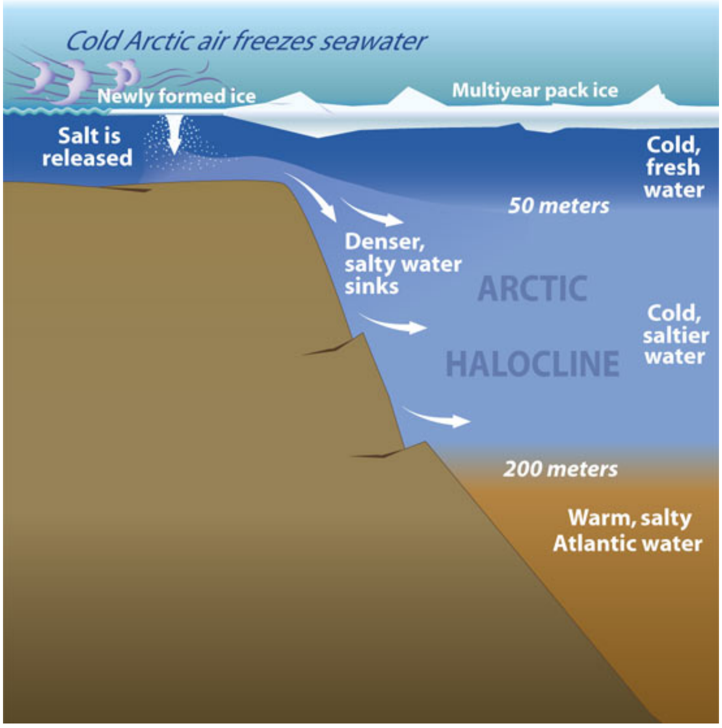


Figure 5: Arctic halocline, showing the rapid change in salinity (Lippset, 2005).

This layer contains the greatest change in salinity and its characteristic is variable across the Arctic Ocean, depending largely if the water masses originate from the Atlantic or Pacific Ocean. The Atlantic layer beneath the halocline is about 400 to 600 m thick with temperatures above 0° C. As the name refers, the water characterising this layer originates from the warmer Atlantic Ocean that flow into the Arctic through the Fram Strait and the Barents Sea. The transition layer between the halocline and the temperature maximum in the Atlantic layer is designated as the thermocline. The salinity in the Atlantic layer increases with depth from 34.4 to 34.9 psu. Below 800 to 1000 m, colder water with salinities ranging from 34.93 to 34.95 psu from the North Atlantic Ocean, is the Arctic deep water layer. In and outflow from the Arctic deep water is only possible through Fram Strait as the passage is deep enough (Rudels et al., 1991).

1.2.3. Water movement in the Arctic

Roughly ten to twenty times (by volume) more Atlantic water than Pacific water enters the Arctic Ocean. Within the Arctic Ocean one of the dominant features of the surface circulation is the Beauford Gyre that is predominantly rotating clockwise, extending over the Canadian Basin.

Another surface current is the Transpolar Drift that flows from the Siberian coast out through the Fram Strait (Figure 3). Both currents are strongly influenced by wind forcing. The surface currents along the coast are principally counter clockwise, moving from Atlantic to Pacific on the Euroasian side and from Pacific to Atlantic on the North American side. The subsurface circulation is also counter-clockwise and influenced by the inflow from the Atlantic and Pacific Oceans. Water exit primarily through the Fram Strait and Canadian Archipelago (Figure 3) (Anderson & MacDonald, 2015).

1.2.4. Arctic ice

The ice is an important regulator of the exchange of heat and other properties between the atmosphere and ocean. Together with snow cover, ice determines the penetration of light into the sea. Approximately 70% of the Arctic Ocean is ice-covered throughout the year (McBean et al., 2005), although there is a clear interannual variability in sea ice extent in the Arctic. This seasonal cycle sees the ice at its maximum in March and minimum in September (Parkinson, Cavalieri, Gloersen, Zwally, & Comiso, 1999). In addition, there are ten year and less than ten year fluctuations in the areal sea ice extent due to changes in the atmospheric pressure patterns and their associate winds, continental discharge, and influx of Atlantic and Pacific water (Gloersen, 1995; Kauker et al., 2009; Mysak & Manak, 1989; Polyakov et al., 2003). On average 10% of the Arctic Sea ice exits through the Fram Strait each year (Halvorsen, Smedsrud, Zhang, & Kloster, 2015).

There are several variants and formations of Arctic sea ice that have specific characteristics. First-year ice (seasonal ice) and multi-year ice (perennial ice) are the two primary forms of ice in the Arctic. First-year ice is often defined as ice formed in its first winter of growth or first summer of melt. If not affected by compaction of drifting ice and ridging that normally doubles the thickness of ice; the first-year ice thickness ranges from about few decimetres near the southern margin of the cryosphere, to 2.5 m in the High Arctic at the end of winter. Some first-year ice survives the first melt in summer and becomes multi-year ice.

The thickness of multi-year ice may vary depending on its age and formation, ranging from about 3 m up to about 6 m along the shores of northern Canada and Greenland (Bourke & Garrett, 1987). The general pattern of sea ice thickness has been determined, but it is subjected to variations and uncertainties that have not been well quantified. Sea ice thickness generally increases from the Siberian side of the Arctic to the Canadian Archipelago, largely in response to the mean pattern of sea ice drift and convergence (although air temperature is also generally lower on the Canadian side of the Arctic Ocean) (ACIA, 2005).

A transpolar drift carries sea ice from the Siberian shelves to the Barents Sea and Fram Strait. It merges on its eastern side with clockwise circulation of sea ice within Canada Basin.

Fast ice (or land-fast ice) is ice growing seaward from a coast and remains immobilised throughout the winter, up to 10 months each year. Typically, it is stabilised by grounded coastal geometry or by grounded ice ridges called stumukhi. There are a few hundred meters of fast ice along all Arctic coastlines in winter. Commonly within the Canadian Archipelago, some of the ice is trapped for decades as multi-year fast ice (Reimnitz, Eicken, & Martin, 1995). Another important formation in the Arctic are polynyas. Polynyas form when oceanic heat flux is locally intense or because existing ice is carried away by wind or currents (Winsor & Björk, 2000).

1.3. Arctic and climate change

The Arctic climate is a complex system with several interactions with the global climate system through the atmosphere, oceans, and rivers. The primary role of the global climate system is simplified as the balance of the heat gain at low latitudes and the heat loss in the high latitudes.

1.3.1. The warming of Arctic

Climate change has a greater impact on the Arctic compared to most other regions, as the Arctic is expected to warm at a rate approximately twice the global average (IPCC, 2013).

Since 1978, satellites have monitored sea ice growth and retreat, and they have detected an overall decline in Arctic sea ice. Data from the monthly average ice extend in November from 1979 to 2016 show a decline of 5% per decade (Figure 6) (NSIDC, 2017).

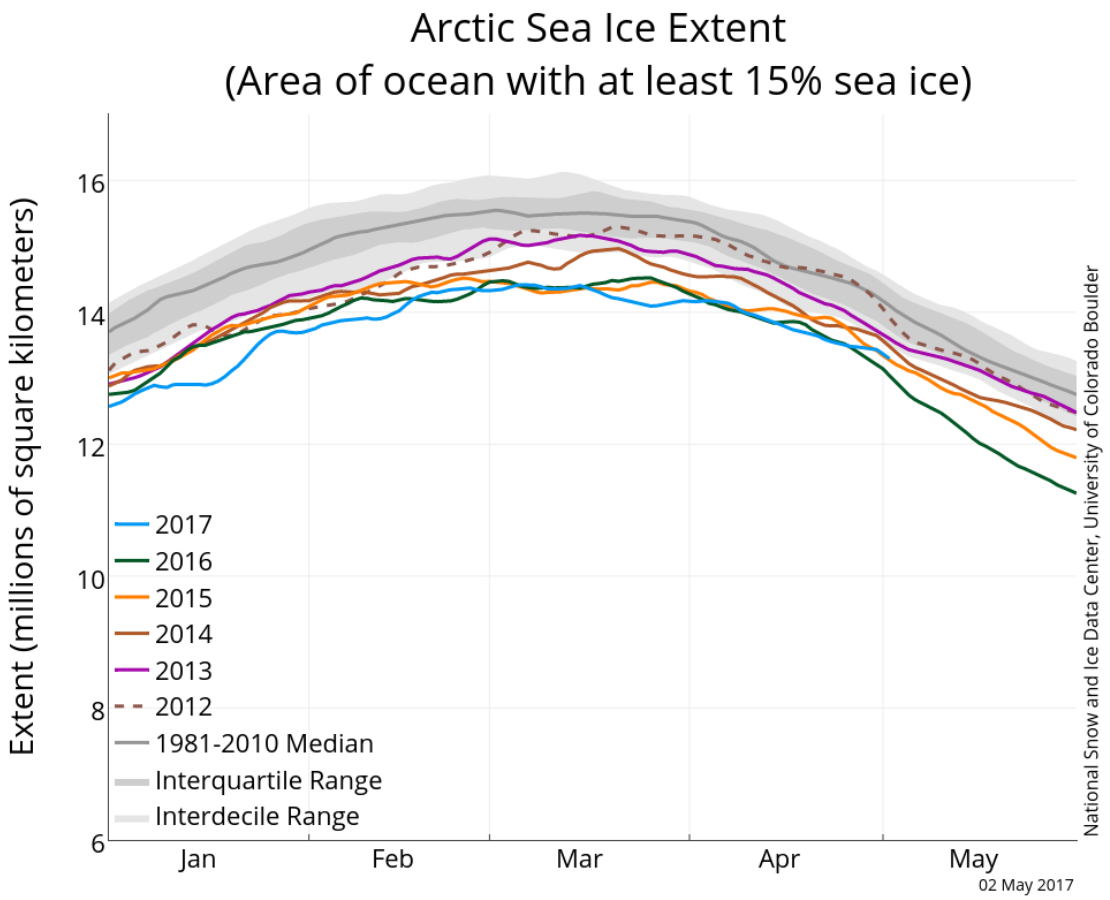


Figure 6: Arctic Sea ice extent from 1981 until 2017 (NSIDC, 2017).

The amplified warming of the Arctic is thought to be caused by feedback effects often associated with temperature, water vapour and clouds. With data and climate models, different scenarios are considered to understand the complexity of weather and climate change, giving the possibility to anticipate the consequences of a warming Arctic. A feedback often cited as the main contributor to amplifying factors is the albedo feedback (Taylor et al., 2013). Ice and snow reflects most of the solar radiation back into space. When Arctic is warming and sea ice melts, more heat enters the ice-free ocean, thus melting more sea ice and increasing warming. Other feedback mechanisms monitored are the greenhouse gas feedback and thermohaline feedback. The greenhouse gas feedback considers the large amounts of methane and carbon dioxide that are trapped in the permafrost and hydrate layers of the Arctic margins (Dolman et al., 2017; Zimov et al., 1997). With warming, Arctic coastal lakes will act as vents releasing these greenhouse gas sources and further intensify warming. The thermohaline feedback scenario is considered when warming of the Arctic contributes to an increase export of fresh water from the Arctic Ocean. This would reinforce the stratification of the North Atlantic with a possible consequence of a slowdown of the Thermohaline Circulation (THC). This could have a cooling effect particularly in the North Atlantic Ocean (Anthoff, Estrada, & Tol, 2016; Manabe & Stouffer, 1994; Stouffer et al., 2006; Vellinga & Wood, 2002).

One significant change in the Arctic region in recent years has been the rapid decline in perennial sea ice (Figure 7) (Starr, 2016). Perennial sea ice, also known as multi-year ice, is the portion of the sea ice that survives the summer melt season. Perennial ice may have a life-span of nine years or more and represents the thickest component of the sea ice; perennial ice can grow up to four meters thick.

By contrast, first year ice that grows during a single winter is generally at most two meters thick.

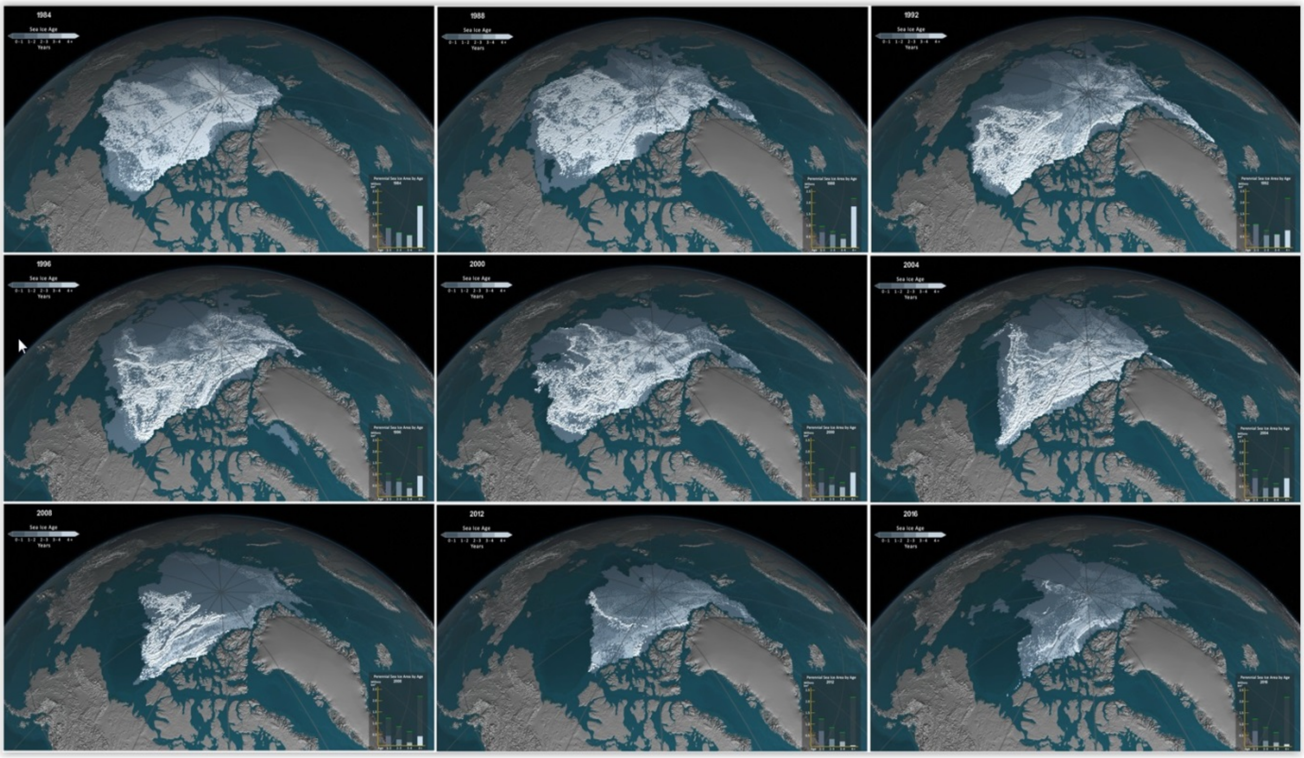


Figure 7: Arctic sea ice age from 1984 to 2016. First-year ice, is shown in a dark shade of blue and four years or older ice is shown as white. (Starr, 2016).

1.3.2. Modelling and prediction of climate change

To be able to estimate future development of the Arctic marine environment various climate models are used. To estimate changes in the Nordic Seas (i.e. the Denmark Strait, Norwegian Sea, and Greenland Sea) and Barents Sea, the Bergen Climate Model (BCM) was used (Furevik et al., 2003). The model integrates a 1% per year increase in CO_2 concentrations in the atmosphere, during an 80-year period. Due to a relatively high spatial resolution in these area, this model is believed to give reliable projections. However, in similarity with other such models, its predictive capability is limited and the results should be seen as possible, rather than likely outcomes (ACIA, 2005).

1.3.2.1. Sea surface temperature

A minor cooling is projected from present years to 2020 over most of the area. Some of this cooling is likely to be associated the weaker westerlies (Furevik, Bentsen, Drange, Johannessen, & Korablev, 2002). A maximum cooling of 1°C is projected in Denmark Strait.

By 2050 all Nordic Seas are projected to become warmer (with the exception of a small area in the Denmark Strait. An average warming of 0.5° C, with the largest increase in the northeast Barents Sea and to the south of Iceland.

By 2070, the surface temperatures in the Nordic Seas are projected to increase by 1 to 2° C, when a doubling of the CO_2 concentration is assumed. The highest temperature increase is projected in the Barents Sea, and the least warming is projected in the Denmark Strait.

1.3.2.2. Salinity

Except from areas influenced by coastal runoff and melting sea ice, salinity changes in the Nordic Seas are projected to be small.

By 2020, the model output indicates a salinity decrease of 0.1 to 0.3 psu in the southeast Barents Sea and the Kara Sea. A weaker freshening is expected along the East Greenland coast.

By 2050, the freshening of the sea continues. A salinity reduction north of Siberia is projected in the range of 0.1 to 0.5 psu. A significant salinity reduction is also projected in the Arctic Ocean in the range of 0.3 to 0.5 psu.

By the 2070s, the projection reveals a decrease of salinity by 0.5 to 1.0 psu in the Arctic Ocean and a tongue of fresher water along the East Greenland coast.

The projection models for the North American Arctic (i.e. the Chukchi, Beaufort, Bering and Labrador Seas, the Canadian Archipelago, Baffin and Hudson Bays), are uncertain as many important aspects of these regions are not included in the climate models. Aspects as fast ice, strong seasonality and complex water structures as well as that these seas more southerly latitude and contact with terrestrial systems, may lead to a perhaps greater and faster change compared to the model projection (ACIA, 2005). Below you can find a summary of some of the changes projected in Arctic Ocean condition according to the five designated ACIA models.

1.3.2.3. Sea Ice

By 2020, the winter sea ice extent would be reduced by 6% to 10%. There will likely be no summer sea ice on the shelves and there will be some reduction in multi-year ice.

By 2050, the winter sea ice extent will be reduced by 15% to 20%. The summer sea ice will likely reduce by 30% to 50%. There will be a significant loss of multi-year ice and no multi-year ice on the shelves.

By 2080, the winter sea ice will be absent from high Arctic (Barents Sea and possibly Nansen Basin). The summer sea ice will be strongly reduced and there will be little or no multi-year ice.

1.3.2.4. Light exposure

More areas will be exposed to sunlight in correlation to the decrease of sea ice duration and areal extent during the period 2020 to 2080.

1.3.2.5. Nutrient levels

By 2020, there will be substantial increase of nutrients over the shelf regions due to retreat of the sea ice beyond the shelf break.

By 2050 and 2080, there will be high levels of nutrients on the shelves and in the deep arctic basins, due to deeper mixed layer in areas of reduced ice cover.

1.4. Ecosystems of the Arctic, climate change and invasive species

1.4.1. The Arctic ecosystems

In the Arctic Ocean, primary production is dependent on the complex interactions between the amount of light and nutrients available. The amounts of nutrients available is in turn regulated by stratification of the water column (Popova et al., 2010). As a consequence, productivity in Arctic waters is greatly dependent on the sea ice extent. It not only restricts light, but also acts as a mixing-barrier in the water column. Sea ice also provides freshwater, which, since being lighter than salt water, induces stratification. Freshwater will float on top and inhibit resupply of nutrients from below and thereby presents a constraint on primary production (Popova et al., 2010). Observations have shown significant primary production occurring both beneath the sea ice and at the thermocline. A phenomenon called ice-edge blooms occur when the nutrient rich water brought in during winter gets exposed to sunlight during spring. As the solar irradiance increases and the ice cover shrinks, favourable conditions for phytoplankton growth are established.

Nutrients available for primary production at the surface are primarily supplied either by winter mixing or horizontal exchange with the Pacific and Atlantic. Additional mechanisms supplying nutrients are for example periodical supplies through storms or internal waves eroding the halocline. Of the nutrients affecting primary production in the Arctic, nitrogen has been shown to exhaust first, and is therefore the most important limiting factor.

Arctic and sub-Arctic marine waters are home to more than 400 marine and diadromous fish species. Most of the Arctic fishes are demersal/benthic. The Arctic cod is the most northerly distributed gadid, occurring roughly between 60° N to the North Pole (ArcOD, 2017). This is a key species feeding on amphipods, euphausids, copepods, and pteropods. The Arctic cod is preyed on by a range of marine mammals and marine birds. Where there are freshwater inflows into the Arctic Ocean, there are a number of different species of salmonides (*Onchorynchus, Salmo, Salvelinus*) who spend most of their life in the ocean, but migrate into the rivers and streams for spawning. Other dominant fish families include several species of cod, eelpouts, snailfish, sculpins, perch, and various flatfishes.

Although there is significant and highly productive fishing in the Barents Sea and Bering Sea, there is little commercial fishing in the seas of the High Arctic. Therefore, there is a lack of detailed knowledge about the biodiversity and abundance of fish in these areas. Through the ArcOD project some progress has been made in exploring the fish fauna of the high Arctic (ArcOD, 2017).

There are 34 species of marine mammals to be found in the Arctic Ocean. Most of these migrate to lower Arctic latitudes or the sub-Arctic during the winter. Several of these species are very sensitive during their migration and breeding periods. The mammals include 10 species of baleen whales, 13 species of toothed whales, 11 species of seals including walrus, and the polar bear and the sea otter (AMAP, CAFF International Secretariat, SDWG, 2013). IUCN Red List of threatened species lists about 14 of these species as either endangered, vulnerable, or near threatened (Table 1) (IUCN, 2017).

Table 1: List of threatened, vulnerable or endangered Arctic marine mammals (AMAP et al., 2013; IUCN, 2017).

Category in the Red List	Species	Latin name
Endangered	North Atlantic right whale	*Eubalaena glacialis*
Endangered	North Pacific right whale	*Eubalaena japonica*
Endangered	Blue whale	*Balaenoptera musculus*
Endangered	Fin whale	*Balaenoptera physalus*
Endangered	Sei whale	*Balaenoptera borealis*
Endangered	Sea otter	*Enhydra lutris*
Vulnerable	Sperm whale	*Physeter macrocephalus*
Vulnerable	Hooded seal	*Cystophora cristata*
Vulnerable	Northern fur seal	*Callorhinus ursinus*
Vulnerable	Polar bear	*Ursus maritimus*
Near Threatened	Beluga	*Delphinapterus leucas*
Near Threatened	Steller sea lion	*Eumetopias jubatus*
Near Threatened	Narwhal	*Monodon monoceros*

About 200 seabirds, waterfowl and wader birds are found in the Arctic and sub-Arctic area (AMAP et al., 2013). True marine birds are auks, gulls, terns, skuas, cormorants, petrels, shearwaters, and albatrosses. Although some of them are found in areas covered with ice, most of these species are found in areas where the water is open. Some geese, ducks, and swans, as well as a number of waders breed in the Arctic area while others migrate through.

1.4.2. Climate change and invasive species impact on the Arctic ecosystem

The changes in the marine environment due to climate change are having consequences for the various trophic levels in the marine Arctic. The retreating sea ice in the Arctic has led to an increase in primary productivity (Pabi, van Dijken, & Arrigo, 2008), but also to a decrease in habitats for various ice-dependent organisms such as marine invertebrates, fish, and mammals (Laidre et al., 2008; Meier et al., 2014). A predicted consequence of the ocean warming, i.e. changes in sea temperature and the changing nature of the sea ice, with less multi-year ice and less seasonal coverage, is the migration of species from boreal regions. These invaders are likely to benefit from the rise of sea temperature being able to extend their biogeographic distribution range to the north. This has been reported for several fish species in the northeast Atlantic (Brander et al., 2003) and the Bering Sea (Grebmeier et al., 2006). Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) (Renaud et al., 2012), Atlantic snake pipefish (*Entulerus aequoreus*) (Fleischer, Schaber, & Piepenburg, 2007), and Atlantic mackerel (*Scomber scombrus*) (Berge et al., 2015) are examples of species that have shifted their distributions poleward into Svalbard waters.

As for all introduced and alien species, there is a concern that they will be invasive and have negative impact on the populations of native species, for example through predation, competition, parasitism, hybridization, and/or facilitating the spread of pathogens. Some of these impacts are expected when considering the documented shift in distribution of polar cod (*Boreogadus saida*) and capelin (*Mallotus villosus*). The polar cod is mainly distributed in the cold sub-zero Arctic waters and is one of few fish species associated with sea ice year-round. However, polar cod is also found in a range of habitats including ice-free waters and the water column further south (Christiansen, Hop, Nilssen, & Joensen, 2012). The capelin is a sub-Arctic species with a more southerly distribution than the polar cod, but is also associated with ice edges, where the productivity is very high during spring. As low temperature is a limiting factor for capelin, its distribution extends further north only in warm years and to some extent, the distribution overlaps with the polar cod (Hop & Gjøsæter, 2013). A study of the diet of seabirds in the Canadian Arctic over a period of 30 years, displayed the variation of fish species hunted by seabirds (Provencher, Gaston, O'Hara, & Gilchrist, 2012). The study showed that capelin is extending its distribution northward and polar cod is retreating from the southern regions of the Arctic in response to the warming climate and a declining sea ice extend. Polar cod feed on amphipods and other sea ice associated invertebrates (Grainger, Mohammed, & Lovrity, 1985) and the decreasing sea ice would reduce this source of food. Polar cod would have to adapt and compete for food with pelagic fish species, such as capelin, herring, and juvenile haddock (Renaud et al., 2012). It is also assumed that the effects of loss of sea ice as a protective habitat would likely result in an increased vulnerability to predators and cause reductions in polar cod populations in the high Arctic (Hop & Gjøsæter, 2013).

The Bering Sea is an example where an ecosystem shift can be observed. It is moving away from an ice-dominated ecosystem with bottom feeding birds and mammals as the top predators in a foodchain depending on carbon input to the benthos from algae growing under the sea ice. Under more ice-free conditions, this ecosystem is turning into a system dominated by phytoplankton and pelagic fish (Grebmeier et al., 2006). Other signs of major regime shifts in the Arctic Ocean are the evidence from satellite monitoring of increased phytoplankton biomass in response to more open water and a longer open water season (Arrigo, van Dijken, & Pabi, 2008). Such regime shifts will affect the food webs and result in impacts on all trophic levels above the first. Hence, marine mammals and birds will be affected both from direct and indirect effects (Meier, Gerland, Granskog, & Key, 2011; WWF, 2009).

Seabirds such as guillemots, puffins, and petrels breed in large numbers during the short Arctic summer, living from the abundant food resources that become available as the sea ice melts. Based on research carried out in Canada and Norway, a milder Arctic climate will affect these birds for example by altering the timing of the ice melting which will have an impact on the birds breeding success. The maximum productivity of the sea should coincide with the period when the young birds require maximum feeding. In the case of the Brunnich’s guillemot in northern Hudson Bay, the ice melting has advanced about seventeen days since early 1980s, but the timing of the hatching of the birds’ eggs has only advanced by five days (Gaston, Gilchrist, & Hipfner, 2005). As a consequence, there is now a mismatch between the peak of food supplies and the maximum food requirement. Another impact on marine birds is that the food they normally consume will change with climate change. The Arctic cod is the main fish consumed by birds, as well as many marine mammals. With the melting ice and the shift from ice-benthic food chains to pelagic ones, pelagic fish such as capelin has become the dominant species. These fish have different nutritional characteristics and this together with mismatches in peak food supplies has had consequences both for adult mass and chick growth (Gaston et al., 2005; WWF, 2009).

The Arctic Ocean is home to three endemic cetaceans which are characterized by their permanent presence in the Arctic: the bowhead whale, the only truly Arctic baleen whale, and the two toothed whales: the narwhal and the beluga. Several other whale species enter the Arctic seasonally but only these three species are considered endemic. Climate change is likely to affect these whales in a number of different ways due to disruption of normal oceanographic features such as stratification, surface water temperatures, and ice loss. The impacts may be due to changes in the food webs but perhaps even more important, the increased presence of humans and human activities in the Arctic, in the form of increasing number of vessels and the development of hydrocarbon deposits (Reeves et al., 2014). The sensitivity of these whales to industrial activity has been the subject of studies in northern Alaska and Canada. They are all sensitive to noise at low (received) levels from ships, noise-generating activities from drilling, and especially seismic surveying (Reeves et al., 2014). There are indications that these endemic Arctic whales are both well adapted to life in ice-infested Arctic waters and at the same time have low genetic diversity, for narwhals particularly low, which may make them particularly vulnerable to rapid climate change (WWF, 2009). Signs of the impacts of Arctic Ocean warming and earlier ice break-up is the decline in condition and reproductive success of polar bears in the western Hudson Bay (Durner et al., 2009; Regehr, Lunn, Amstrup, & Stirling, 2009). Similar effects have been reported from Svalbard both for polar bears and seals.

Some species of seals are particularly dependent on sea ice habitats. The ringed seal is one such species and the retreating sea ice will limit this species to areas where the sea ice is predicted to remain longer, such as in the Canadian Arctic (WWF, 2009). Such compression of the range of these species will make them more vulnerable to competition for food and space. In general, a decline in the sea ice will become detrimental to ice-adapted species and advantageous to seasonal migrant species (Moore & Huntington, 2008). It is predicted that the initial responses of ice-associated seals will be that they become unable to find ice habitats in traditional areas at the respective breeding times, their northward ranges will contract, or there will be a shift to breeding earlier in the season (Würsig, Perrin, & Thewissen, 2008). However, according to Kovacs (2008) such a shift in behaviour, from breeding on ice to terrestrial breeding, would require a remarkable degree of behavioural plasticity that has not been seen to date in regions and years where ice reductions have been rapid and major.

Also, walruses use sea ice floes as resting platforms over foraging areas and substantial declines in their populations are predicted as a result of the reduction in Arctic Ocean sea ice (Jay, Marcot, & Douglas, 2011). Walruses are already spending more time at landbased haul-outs than on ice floes. A dramatic change in the behaviour of walruses in the Bering Strait into the Chukchi Sea have been reported (WWF, 2009), changes that are linked to the Arctic climate change. When walruses start to haul-out on land they overuse the nearby feeding areas. The individuals that continue to haul-out on the ice risk ending up over deep waters far from suitable feeding areas.

2. Characteristics of shipping in the Arctic

As the Arctic sea ice is melting rapidly, it is expected that within the next decade the polar warming may transform the region from largely inaccessible into a seasonally navigable ocean, opening up for new opportunities for human activities with increasing shipping, resource extraction, commercial fishing and tourism.

2.1. Resources in the Arctic

The global warming has put the Arctic on the map as a hotspot for global economic interest. It is expected to open up possibilities of extraction of previously inaccessible natural resources, such as oil and gas, as well as open up for shorter shipping routes between the Atlantic and the Pacific Oceans. Climate change and its rapid development in the Arctic also raise several concerns among experts about its impact not only on the Arctic ecosystems and its inhabitants but also the risks and consequences of an increasing human activity in the area.

2.1.1. Oil and gas

There is not a clear/uniform system how to define the geographic area of the Arctic and how much of the oil and gas reserves can be found within the Arctic region. *Shipping in Arctic Waters* use a definition complied with the IMO Guidelines of 2002, including the waters of the Barents and White Seas (Østreng et al., 2013). It is assumed that the extensive Arctic continental shelves may constitute the geographically largest unexplored prospective area for petroleum globally (USGS, 2008), but all estimates of oil and gas and reserves are difficult to calculate. They involve uncertainties dependent on the reliability of geologic and engineering data and the interpretation of these data. The U.S. Geological Survey (USGS) assessment showed that the Arctic potentially has about 22% of all undiscovered and technically recoverable oil and gas resources in the world (USGS, 2008).

Oil and gas are produced in four Arctic states: Russia, United States (Alaska), Canada (Northwest Territories), and Norway (Figure 8). Of the total proved Arctic oil reserves in 2010, 53% is found in Russia, followed by Canada and Alaska with 22% and 21% respectively, and 5% in Norway (BP, 2011; Østreng et al., 2013). When it comes to natural gas, Russia holds 80% of the proved reserves in the Arctic, corresponding to 30% of the world reserves. Alaska comes second with 14%, followed by Norway and Canada with 4% and 3% respectively.

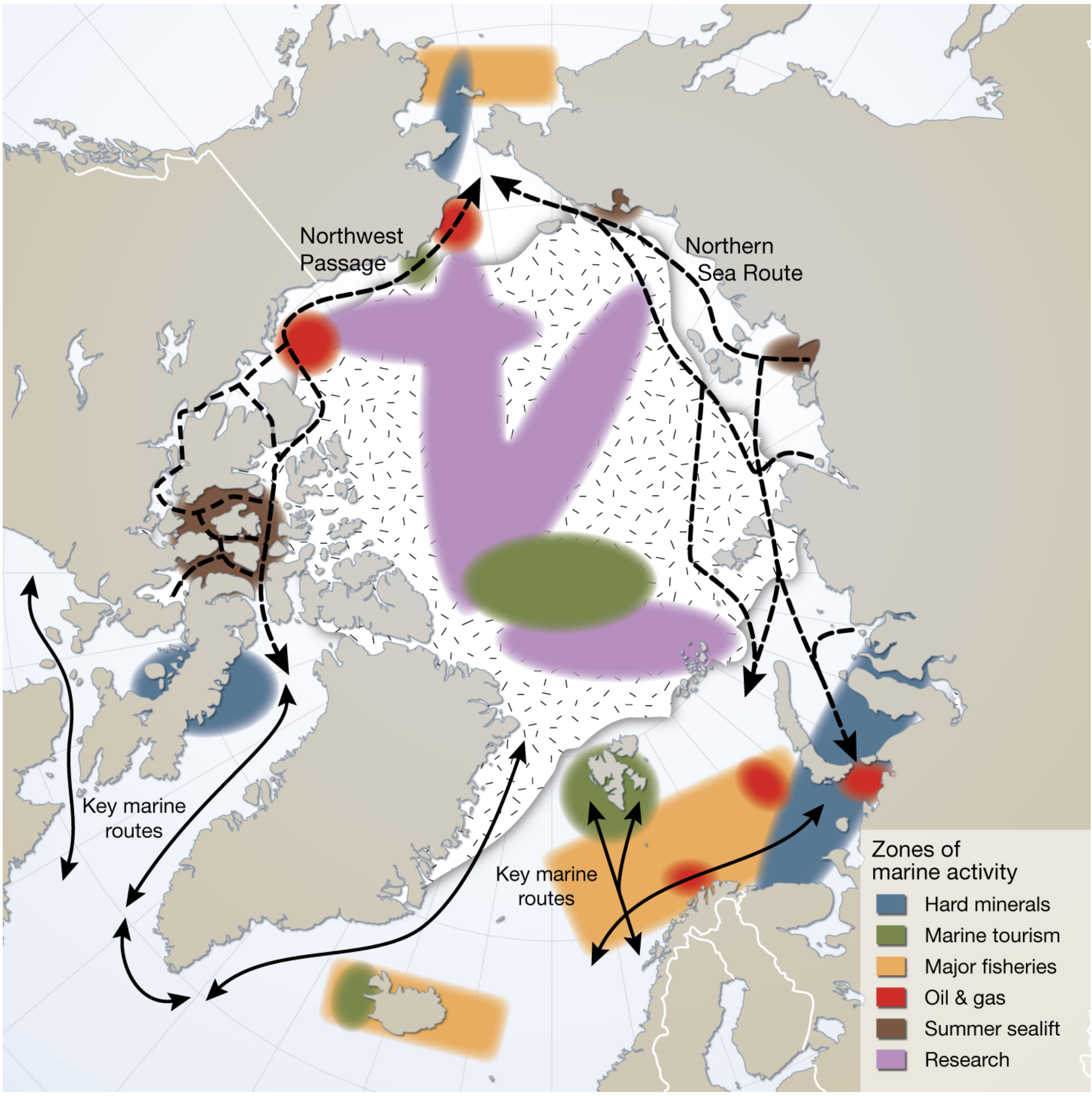


Figure 8: Zones of marine activity in the Arctic (CAFF International Secretariat, 2010).

In the Arctic, about 33% of the undiscovered oil is found in Alaska. Of the presumed undiscovered natural gas sources, about 39% can be found in the West Siberian Basin (USGS, 2008).

Barents Sea is presumably the Arctic area that is most accessible and least costly regarding exploration and recovery of the natural resources, regardless of sea ice presence or water depth (USGS, 2008; Østreng et al., 2013). However, the exploration of oil and gas in the Arctic is very costly and any investment must factor in the ongoing low oil price. Factors that strongly regulate the intensity of the exploitation of natural resources are technology, climate change, and environmental regulations, as well as a variety of political, economic, and social factors.

2.1.2. Minerals

The largest reserve of minerals can be found in Russia, although it is difficult to accurately determine how much of the Russian minerals can be found in the Arctic. The area that is believed to have the richest abundance of minerals is Northwest Russia (Figure 8). On the Kola Peninsula alone, over 700 different minerals have been found. Nickel-copper ores, alumina, titanium, and phosphor-bearing ore are examples of large reserves that have been found (Østreng et al., 2013). In Alaska, there are several mineral productions of zink, lead, silver, and gold. The Arctic mining areas in Alaska are mostly situated in the northwest (Figure 8). The Canadian mining industry is world leading and a major exporter of minerals and mineral products. However, only about 5 % of the total mining is conducted in is taking place inside the Canadian Arctic (Østreng et al., 2013). In Norway, about half of the nation’s mining industry production is situated in the northern part of mainland and on Svalbard, where the magnesium silicate mineral olivine has a large share of the world production.

2.1.3. Fishing

The key areas where most of the reported fishing vessel activity takes place are the Barents Sea, Bering Sea, and the west coast of Greenland. A high fishing activity also takes place in the southern Arctic regions around Iceland and the Faroe Islands (Figure 8) (Arctic Council, 2009).

2.2. Arctic shipping

The Northern Sea Route (NSR), North-West Passage (NWP), the Transpolar Sea Route (TSR), and to a lesser extent the Arctic Bridge Route (ABR), are the main shipping routes through the Arctic (**Fel! Det går inrte att hitta någon referenskälla.**).

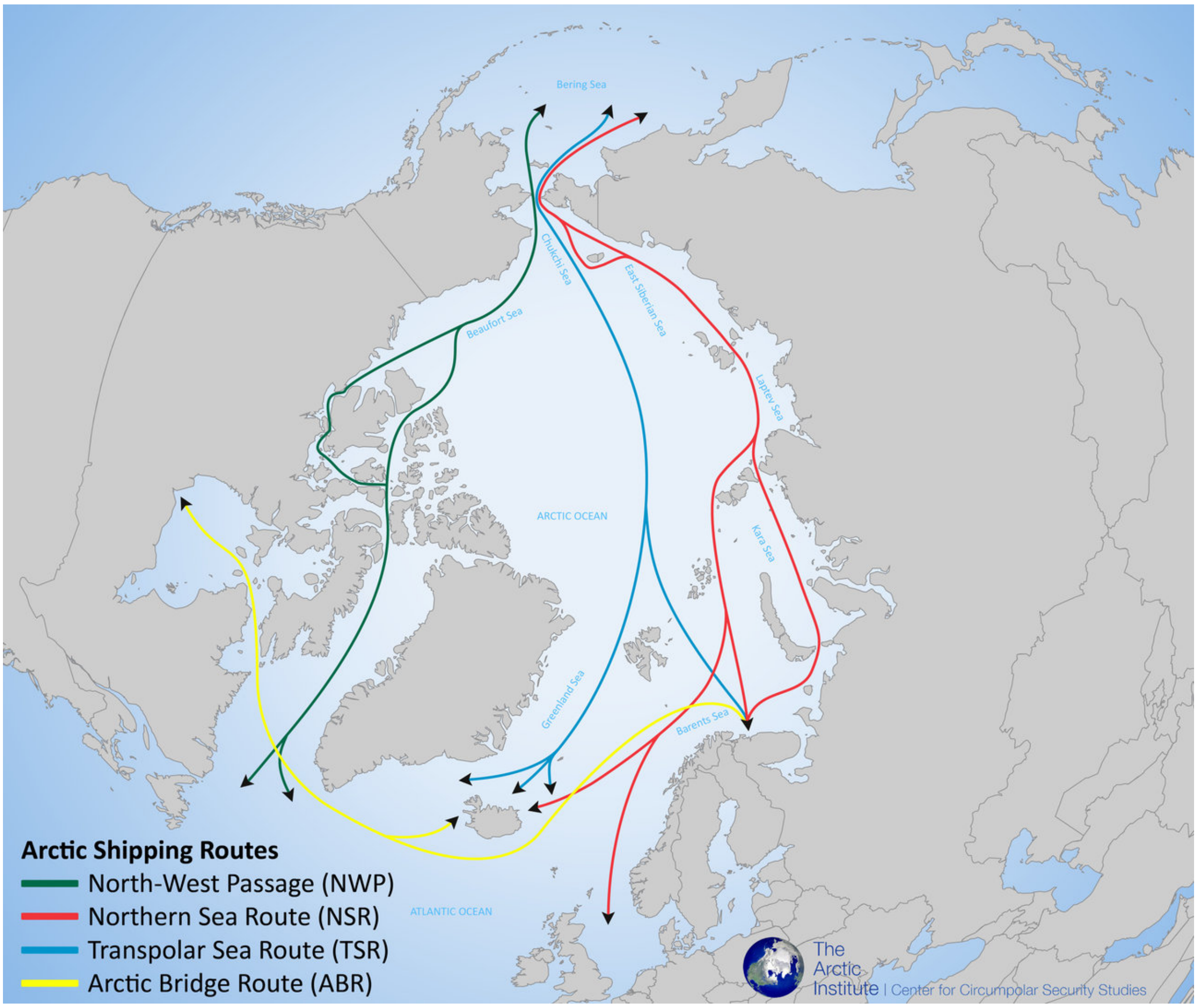


Figure 9: Arctic shipping routes visualised by the Arctic Institute 2013.

The Northern Sea Route traverses the Barents Sea, Kara Sea, Laptev Sea, East Siberian Sea, and Chukchi Sea from the North Atlantic to the Pacific, or the other way around.

The North-West Passage is the name of a set of routes connecting the Pacific and Atlantic Oceans, along the coast of North America, via waterways through the Canadian Arctic Archipelago. There are seven main alternative routes going through the Canadian archipelago, between Baffin Bay and Beaufort Sea. The channel used is based on which one offers the best sea ice conditions at the time of passage. Sea ice condition within the archipelago varies dramatically from year to year, contributing to unpredictability to any ship operation (Østreng et al., 2013).

The Transpolar Passage is the shortest of the Arctic shipping routes crossing the center of the Arctic Ocean. In contrast to the NSR and NWP that are both coastal routes, it largely avoids the territorial waters of Arctic states, where the freedom of navigation applies. However, this is mostly uncharted water, with an added risk of grounding on unknown reefs in an area far from help.

There is a considerable distance advantage using the Arctic Ocean between ports in the Pacific Ocean and the Atlantic Ocean compared to transit through the Suez Canal or the Panama Canal. For example, the distance between the port of Yokahama in Japan and Hamburg in Germany is nearly halved if taking the NSR compared to the route through the Suez Canal (Østreng et al., 2013). A distance saving of 3,350 nm can be made using the NSR instead of the Panama Canal between the town of Tromsø in northern Norway and Vancouver on the Canadian west coast. When considering the geographical distance, most of the routes through the NWP and the NSR are comparable, although some routes through the NWP presents a greater navigational challenge. Using the TSR will save an additional 700 nm compared to the NSR and NWP (Østreng et al., 2013).

Due to the presence of sea ice in the Arctic Ocean, none of the routes can offer ships a predetermined navigation lane to follow. Ships are forced to use the route that currently offers the best ice and navigational conditions. As long as sea ice is a dominant feature of the Arctic Ocean, it makes navigation unpredictable. The varying icebreaking capabilities of the ships further add to the route-finding uncertainties. This makes choosing the most optimal route for an Arctic transit very difficult. Presently, sea ice condition, ship type, and geography are the main factors deciding the length of any voyage. Therefore, ice conditions and ship types must be part of the calculations, when planning these routes. Looking at the variation of the Arctic sea ice extent and comparing the areas and ice conditions of the Arctic routes, it is claimed that the NSR and NWP are more favorable routes than the TSR, as the thinner and easier-to-brake first-year ice is more frequent in coastal areas than in the central Arctic Ocean.

It is also expected that sea ice conditions will improve more rapidly in the NSR than in the NWP, as multi-year ice, complex straits, and pingos (underwater ice formations protruding from the sea bed) make navigation more difficult in the NWP (Yoshikawa et al., 2006; Østreng et al., 2013). The lack of first-year ice near the coasts will allow much more freedom of movement of the older and thicker multi-year ice that composes a major hazard to shipping. As long as multi-year ice is a source in the Arctic Sea, it will continue to drift against and through the Canadian Archipelago and therefore impose an impediment for ships going through the NWP (Østreng et al., 2013). Mainly limited to summer, navigation along NSR is relatively easier, owing to lower overall ice extent and open water in the Barents Sea.

2.3. Present and future development of shipping in the Arctic

2.3.1. Shipping characteristics

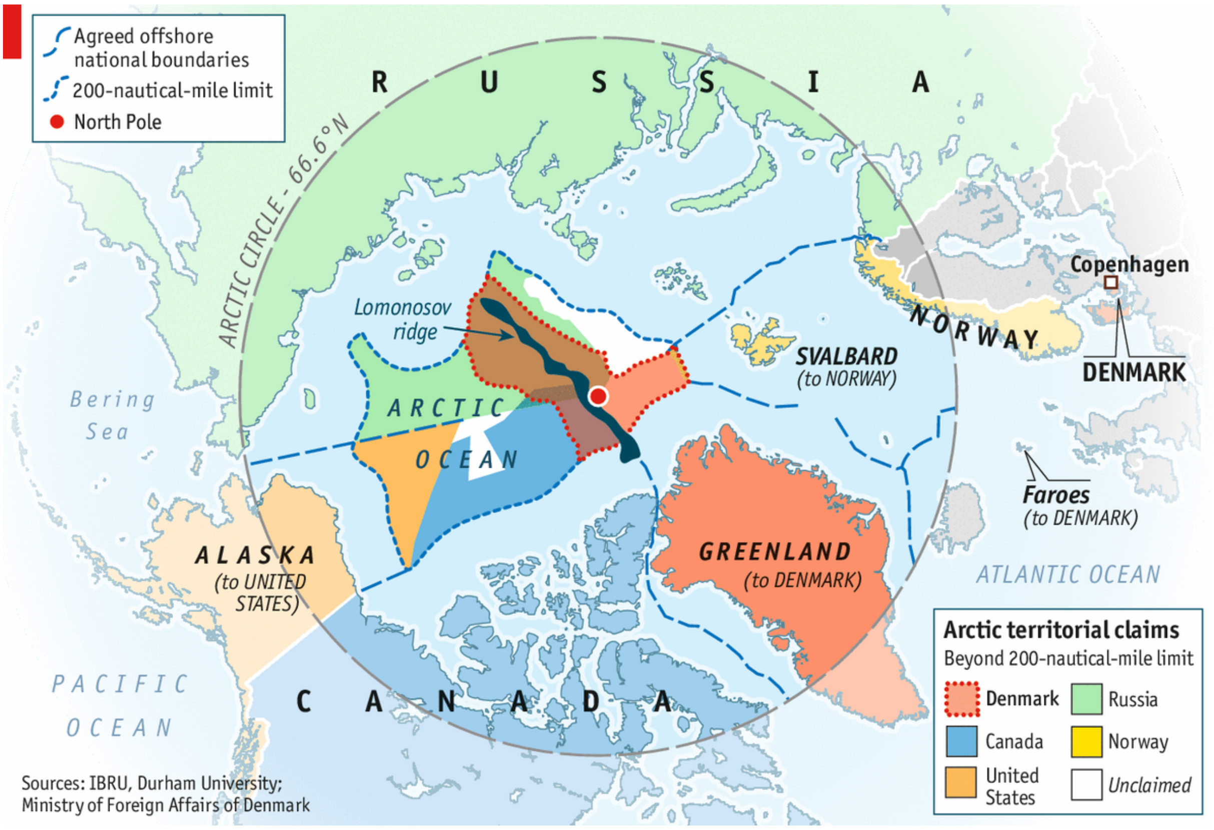
Four types of shipping transport have been differentiated by Arctic Marine Shipping Assessment (AMSA) as typically used within the Arctic passages (Arctic Council, 2009):

- Destination transport - sailing between harbours inside and outside of the Arctic region
- Intra-Arctic transport - sailing between locations within the Arctic
- Trans-Arctic transport - sailing between harbours in the Pacific and Atlantic crossing the Arctic Ocean.
- Cabotage – Transport of gods and passengers between ports within the same Arctic State.

Presently, the NSR has the highest frequency of shipping traffic, both in term of Destination transport and Trans-Arctic transport. The shipping on the NWP is mostly characterised by Intra-Arctic transport. In the future, the destination transport may increase moderately on the NWP.

The Norwegian National Coastal Administration, Kystverket, has developed a web-based map and data service: Havbase, making historical shipping activity data from the North Sea and Arctic Sea available to the public (PAME, 2017). The ship traffic information is based on AIS (Automatic Identification System, a ship transponder required by all vessels above 300 gt) data. To compare and visualise the shipping traffic in the Artic, data have been extracted from Havbase, divided into Exclusive Economic Zones (EEZ). The EEZ is the maritime zone of a State, reaching no more than 200 nautical miles out from the coastal baseline, extending seaward beyond and adjacent to the territorial sea. The coastal state has sovereign property rights to the specific EEZ, for the purposes of research, environmental protection, management, and extraction of natural resources, living or nonliving. All other States have the right of Innocent Passage in other countries' EEZ.

The NSR lies within the Russian EEZ, the NWP lies within the Canadian, Danish (Greenland), and United States' EEZ. The TSR lies outside of most EEZs, but in contested areas. Included is also Svalbard´s Fisheries Protection Zone (FPZ), a marine area around Svalbard under Norwegian sovereignty. Svalbard´s FPZ was created in 1977 as an alternative to the EEZ, as many nations issued reservation to the Norwegian unilateral exploitation of the Svalbard resources.



Sources: IBRU, Durham University; Ministry of Foreign Affairs of Denmark

Figure 10: Arctic territorial claims based on information from IBRU, Durham University, and Ministry of Foreign Affairs of Denmark (Economist, 2014).

AIS data from Havbase (PAME, 2017) shows that out of the total distance sailed, the Russian EEZ has the longest journeys by far (Figure 11).

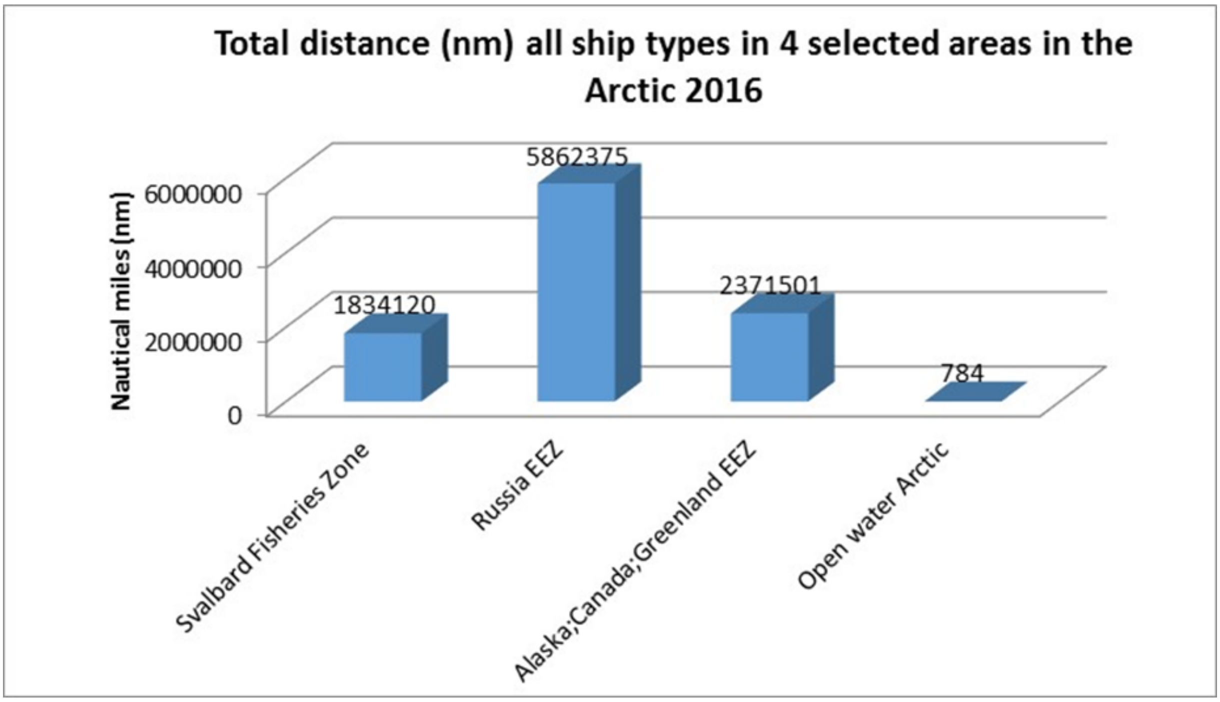


Figure 11: Total distance (nm) sailed in four selected Arctic areas during 2016 based on AIS data from Havbase (Kystverket, 2017).

AIS data from Havbase (Kystverket, 2017) shows that the ship type dominating is fishing vessels, ship for other activity, dry cargo ship, passenger ship, and oil tanker Figure 12.

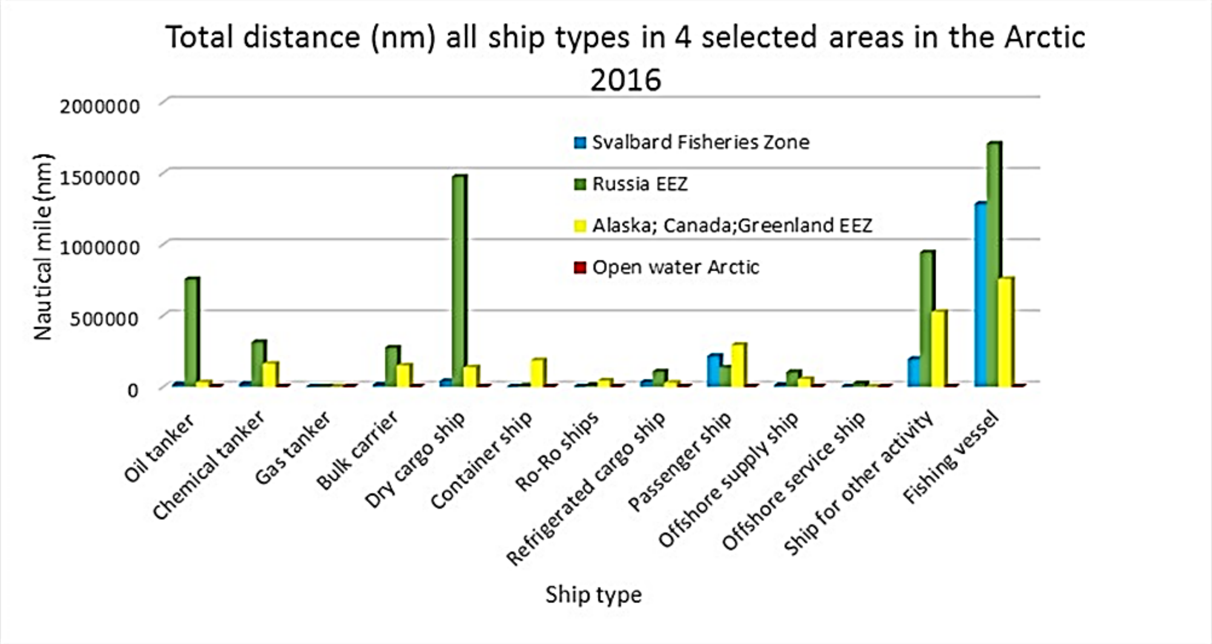


Figure 12: Total distance sailed separated into different ship types in four selected Arctic areas during 2016 based on AIS data from Havbase (Kystverket, 2017).

The Canadian Archipelago will most likely not open for high volumes of international transit shipping or seriously compete with the NSR in Arctic destination shipping in the near future. Shipping through these waters will remain risky even during summer in the foreseeable future. It is not likely that the TSR will be used as a regular transport corridor, even in a long time perspective (Østreng et al., 2013).

The state of sea ice at any one time will decide if the distance advantage of using TSR instead of alternatives will attract the interest of international shipping. The ice cover in the central Arctic Ocean is not a static unbroken surface, but it is in constant motion. It is breaking into pieces, and building up pressure ridges above and below the surface where floes grind together. The sea ice varies in shape, thickness, age, and hardness, presenting different challenges to navigation (Østreng et al., 2013).

2.3.2. Shipping route economy

Of the three Arctic routes, the TSR comes out as the most economic, simply because crossing the pole is the shortest route if ice is not too much of an obstacle. However, it is also the least accessible route without icebreaker support (Østreng et al., 2013). The NSR seems marginally better than the NWP, depending on the icebreaker fees. The NSR is the only one of the routes where sailing fees have already been introduced, primarily based on icebreaker support. This fee system has changed several times, where the principle has been that the total traffic should cover the total costs (Østreng et al., 2013).

2.3.3. Arctic shipping governance

The question of governance has raised disputes regarding both the NSR and NWP. Since a large part the NSR runs through Russian territory, Russia claims the straits within and between the Russian Arctic archipelagos and the mainland as part of its internal waters. Similar for the NWP, Canada has claimed that the routes going through the Canadian Archipelago are within Canadian internal waters, which have been disputed by the United States and EU.

The governance of NSR has developed considerably in the late 20th and early 21st centuries. The main sources of governance are the United Nations Convention on the Law of the Sea (UNCLOS), the Arctic Council (AC), the International Maritime Organization (IMO), and the domestic legislations of the Arctic nations. In combination, they cover territorial claims, economic exploitation, technical shipping requirements, environmental protection, and search and rescue responsibilities (Buixadé Farré et al., 2014).

2.3.4. Trends in Arctic shipping

There is a doubling of fishing vessel sailing distance in the Russian EEZ between 2012 and 2016, whereas fishing vessel sailing distance in Svalbard and Alaska, Canada, and Greenland EEZs have remained more even after 2013 (Figure 13).

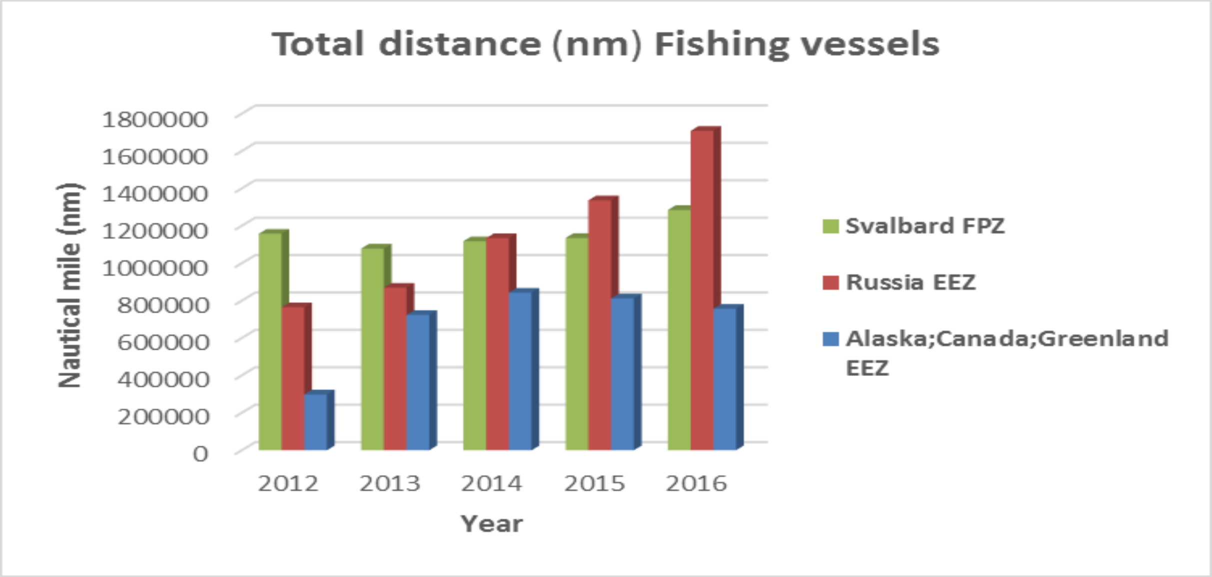


Figure 13: Total distance of fishing vessels in different Arctic jurisdictions (Kystverket, 2017).

Similarly, the sailing distance of oil tankers in the Russian EEZ have more than doubled between 2012 and 2016, owing to increased oil extraction in the Russian Arctic and sub-Arctic (Figure 14).

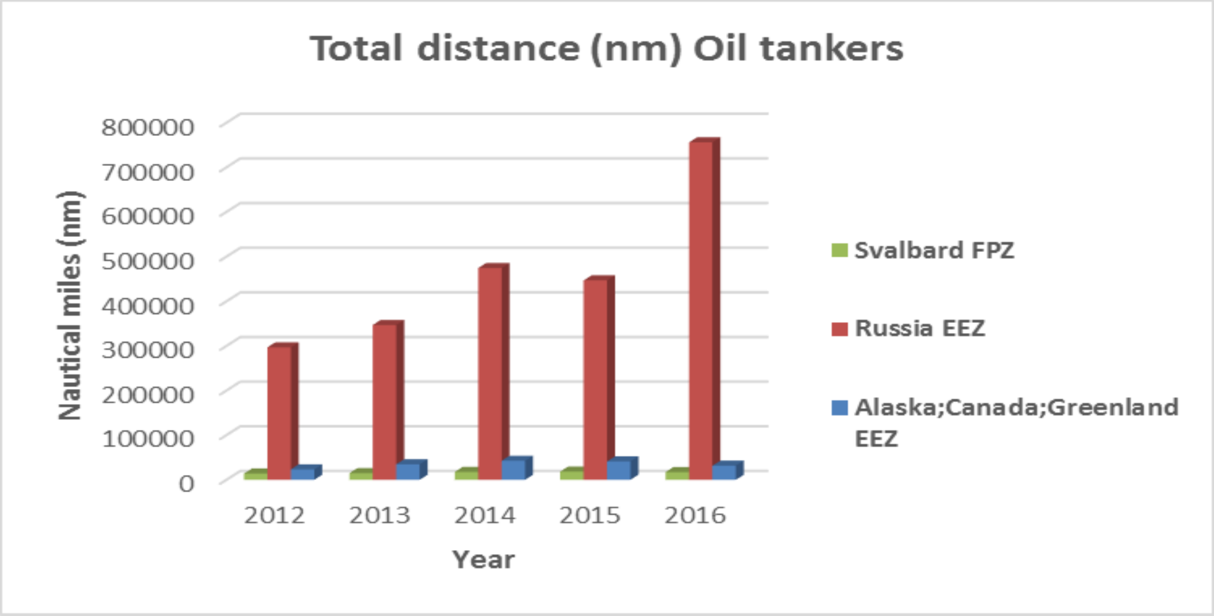


Figure 14: Total distance of oil tankers in different Arctic jurisdictions (Kystverket, 2017).

Another ship type that has increased substantially is passenger ships, where sailing distance in Svalbard and Alaska, Canada, and Greenland EEZs have increased five-fold, with a more moderate increase in the Russian EEZ (Figure 15).

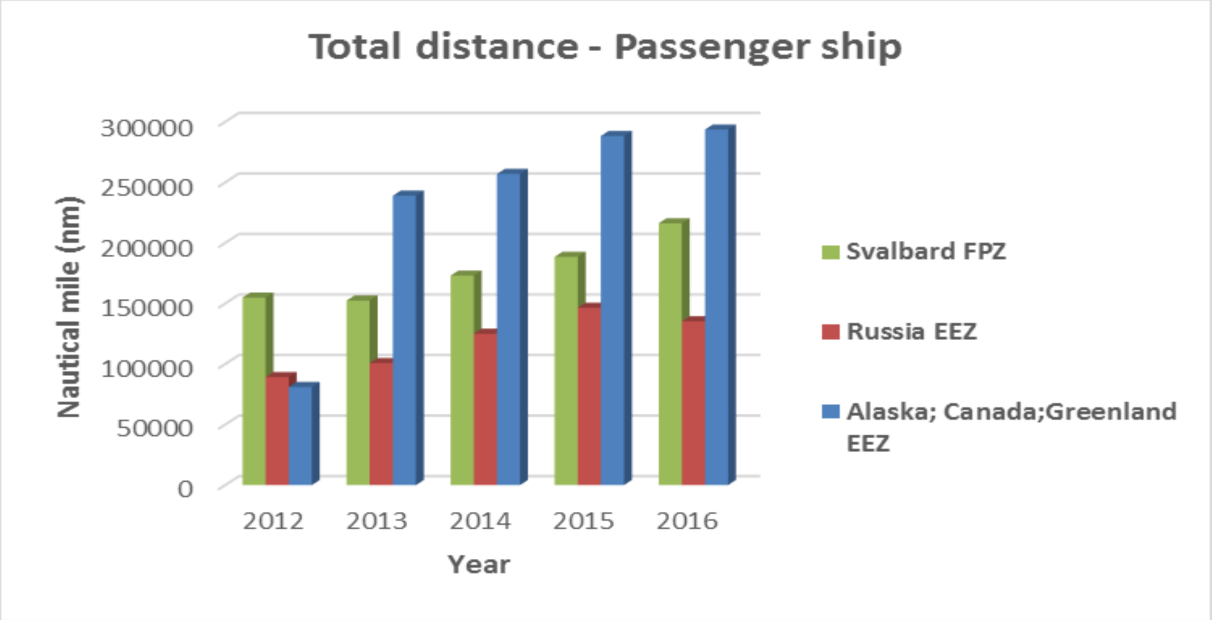


Figure 15: Total distance of passenger ships in different Arctic jurisdictions (Kystverket, 2017).

Expedition cruise ship traffic in the Arctic has shown a clear positive trend in the past decade and the global demand for tourism experiences at one of the world's true last frontiers is still growing (Dawson, Johnston, & Stewart, 2014).

Some authors have expressed the view that the projected possibilities for shipping Arctic route options have been overstated. Issues and challenges such as jurisdictional disputes, political uncertainties, shallow waters limiting ship size, lack of deepwater ports, expensive ship construction and operation, lack of search and rescue capabilities, unpredictable and rapidly changing weather conditions, and navigational challenges among free-floating ice, are thought to slow down Arctic shipping advances (Buixadé Farré et al., 2014). The need for precise schedules and predictability vary greatly among various types of vessels. For example, bulk cargo ships, with less precise schedules fare much better than container ships operating under a just-in-time system.

In a global context, the increase in Arctic shipping has not been as large as ongoing debates may have led us to believe. While voyages through the NSR increased from zero to 44 between 2008 and 2013, it can hardly be said to constitute a shipping-boom. Largely, the modest rate with which Arctic shipping is increasing is thought to be due to lack of predictability compared with the traditional routes (Buixadé Farré et al., 2014).

3. Arctic and the legal framework

3.1. Governing bodies and organizations

3.1.1. The International Maritime Organization (IMO)

IMO is the UN's global standard-setting authority for the safety, security, and environmental performance of international shipping. Its main role is to create a regulatory framework for the shipping industry that is fair and effective, universally adopted, and universally implemented (IMO, 2013).

Shipping is an international industry that can only operate effectively if the regulations and standards are agreed, adopted, and implemented on an international basis. With 170 Member States and three Associate Members (June 2013), IMO is the forum at which this process takes place. IMO measures cover all aspects of international shipping, including ship design, construction, equipment, manning, operation, and disposal, to ensure that this vital sector for remains safe, environmentally sound, energy efficient and secure.

IMO is a technical organization and most of its work is carried out in a number of committees and sub-committees: the Maritime Safety Committee (MSC), the Marine Environment Protection Committee (MEPC), the Legal Committee, the Technical Co-operation Committee, and the Facilitation Committee. There are seven sub-committees dealing with: Human Element, Training, and Watchkeeping (HTW); Implementation of IMO Instruments (III); Navigation, Communications, and Search and Rescue (NCSR); Pollution Prevention and Response (PPR); Ship Design and Construction (SDC); Ship Systems and Equipment (SSE); and Carriage of Cargoes and Containers (CCC).

IMO has promoted the adoption of some 50 conventions and protocols and adopted more than 1,000 codes and recommendations concerning maritime safety and security, the prevention of pollution and related matters.

3.1.2. Soft-law institutions

Arctic soft-law institutions have three distinctive features in common: 1) they are explicitly soft-law based, i.e. they cannot make legally binding decisions, 2) many of them were set up in the late 1980s to reduce the tension between east and west in the region and to build cooperative structures involving Russia, and 3) they tend to have a programmatic approach, conducting their work in working groups with relevant expertise and administrative competence (Stokke, 2012).

The importance of soft-law organizations and Non-Governmental Organisation (NGOs) in the Arctic should not be underestimated. State frameworks are rarely sufficient in such remote areas as the Arctic, distances are extreme and the lack of resources in the form of both personnel and equipment makes effective monitoring and enforcement of environmental regulations very difficult. Not only can soft law organizations and NGOs help in assuring adherence to the law, but corporate social responsibility standards have been shown to be an important complement in remote regions (Timo Koivurova, 2013).

3.1.3. The Arctic Council

The most well-known of the many Arctic soft-law organizations is the Arctic Council (AC). The first collaborative efforts that later resulted in the formation of the AC began with the development of the Arctic Environmental Protection Strategy (AEPS). The AC is not a regulatory body and therefore has no regulatory authority. Moreover, it is not considered as an international organization with a legal personality and describes itself as a high-level forum intended to provide a means for promoting cooperation among Arctic states. Its principalfunction is to facilitate cooperation between its member states and provide an intergovernmental forum for reaching consensus-based decisions (Buixadé Farré et al., 2014; Chircop, 2014).

The Arctic Council Working Group on Protection of the Arctic Marine Environment (PAME) has in its 2009 Arctic Marine Shipping Assessment (AMSA) (Arctic Council, 2009) produced the most ambitious evaluations of environmental policy priorities in the Arctic to date. The report explores a vast amount of Arctic issues and makes recommendations on how the Arctic states, jointly or individually, can for example improve marine safety, safeguard the wellbeing of indigenous peoples, protect the environment, and improve infrastructure (Stokke, 2012). The AMSA report has had a significant impact on fostering Arctic regional cooperation, including adoptions of new legal arrangements. The first Arctic cooperation agreement was adopted in 2011 on Aeronautical and Maritime Search and Rescue with the objective of strengthening search and rescue operations and coordination of efforts (Arctic Council, 2011). Further adding to the impact of the AMSA report was that three of the Arctic coastal states: Canada, Russia, and the United States, launched new Arctic strategy documents which more or less coincided with the report release. This indicated the receptiveness of these states to the findings of the report (Stokke, 2012). Additionally, the publication of the AMSA report coincided with reports that the Arctic is expected to be ice-free during summer sooner than originally thought. 2009 was also a year when two German heavy-lift vessels transited NSR, shortening the journey from Europe to South Korea by 3,000 nm and 10 days. The vessel operator is said to have claimed possible future savings by up to $600,000 per vessel trip (Kramer & Revkin, 2009). The report also identifies gaps in the governance and the legal framework and serves as a roadmap for the improvement of the Arctic shipping governance and framework. It urges Arctic Coastal states to explore possibilities for harmonization of national regulations to achieve uniform standards. With regards to ballast water the report urges risks to be assessed and measures to be taken within national jurisdictions.

3.2. International legal framework

The main elements of Arctic governance of shipping can be said to consist of the United Nations Convention on the Law of the Sea (UNCLOS), the Arctic Council (AC), the International Organization (IMO), and the domestic legislations of the Arctic states. An issue of concern for remote Arctic shipping is that IMO regulations are dependent on flag state enforcement, something that can open up for risks of non-compliance due to lack of enforcement under so called “flags of convenience” or open registries.

3.2.1. UN Convention on the Law of the Sea (UNCLOS)

As the basic legal framework governing the uses of the oceans and seas, the 1982 United Nations Convention on the law of the sea (UNCLOS) holds provisions for the protection and preservation of marine ecosystems together with the Convention on Biological Diversity (Borja, 2006). As such, UNCLOS takes a leading role when it comes to establishing environmental measures in the Arctic region as it provides the framework for the littoral states in conjunction with other instruments such as MARPOL (Donald R Rothwell, 2013).

In accordance with UNCLOS, states "*have the obligation to protect and preserve the marine environment*" and are directed to take all measures "*necessary to prevent, reduce and control pollution of the marine environment from any source*". Pollution is defined as an introduction of substances or energy into the marine environment which results or is likely to result in "*deleterious effects such as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and any other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities*".

In order to prevent, reduce and control pollution from vessels, international organizations shall develop rules and standards. Further, states shall adopt laws and regulations regarding vessels flying their flag which have at least the same effect as corresponding generally accepted international rules and standards. Whenever a state finds that international rules are inadequate in meeting special circumstances of a defined area within its EEZ, the state may direct a communication to the relevant international organisation, which shall then determine if the state may adopt laws and regulations for that special area.

Regarding certain issues, UNCLOS will define minimum standards (for example fishing) However, for shipping the situation is quite the opposite. UNCLOS sets regulatory ceilings and maximum standards for requirements states may put on vessels flagged by another state. Generally, further away from the coastline the regulatory ceilings are lower (Stokke, 2012).

In the territorial sea, states have the right to adopt laws and regulations for the prevention, reduction, and control of marine pollution from foreign vessels. However, they may only do so as long as it does not impede on the right of innocent passage or go beyond Generally Accepted International Rules and Standards (GAIRAS) regarding design, construction, manning, or equipment of foreign ships. Within the EEZ, states may not regulate beyond GAIRAS and standards set by the competent international organization, i.e. IMO. Thus, internal waters and territorial seas fall under coastal state sovereignty but are subject to the international right of innocent passage. Within the EEZ, there is freedom of navigation, but this is subject to the special coastal state power to regulate international navigation for the purposes of vessel-source pollution.

3.2.1.1. UNCLOS Article 234

The development of Article 234 dates back to 1970 when Canada advocated for a radical shift in the international regime of the sea to provide a license for the exercise of an extensive national legislative and enforcement jurisdiction over the global transboundary shipping activities in the Arctic via Arctic Waters Pollution Prevention Act of 1985. From a general standpoint, Article 234 of UNCLOS relates to ice-covered areas is often described as the "Arctic exception" and has been referred to as its most controversial article (Solski, 2013). Article 234 states that "*Coastal States have the right to adopt and enforce non-discriminatory laws and regulations for the prevention, reduction and control of marine pollution from vessels in ice-covered areas within the limits of the exclusive economic zone, where particularly severe climatic conditions and the presence of ice covering such areas for most of the year create obstructions or exceptional hazards to navigation, and pollution of the marine environment could cause major harm to or irreversible disturbance of the ecological balance. Such laws and regulations shall have due regard to navigation and the protection and preservation of the marine environment based on the best available scientific evidence".* The controversy of article 234 lies in its implicit recognition of some sovereign control over the free navigation. The wording of the article has left it open to interpretation and the intent of the drafters is often a topic of debate. However, as its provisions were negotiated, primarily among Canada, the Soviet Union, and the United States, it was included in the treaty drafts without opposition (Kraska, 2014). Article 234 is *lex specialis*, granting additional power within the EEZ, something both Canada and the Russian Federation have long used it in their establishment of national laws and regulations. It also implies that the principles of reason and logic must follow as not to interfere with international navigation and to have due regards to protect and preserve the marine environment based on what is termed as "best available scientific evidence". Russia has chosen to legislate on safety and pollution-prevention requirements for shipping using the NSR, setting standards for polar classes, ship inspection, emergency and repair supplies, ice-navigation qualifications of the master, pilotage requirements, ice-breaking, civil liability for pollution damage, a compulsory notification system including advance permission to use the route, and fees for services. With the exception of Annex VI, Russia is a party to MARPOL but still has higher standards for vessel-source pollution. It must however be remembered that to use article 234, the severe climate conditions and ice cover must exist for most of the year, as must the obstructions or hazards to navigation (Donald R Rothwell, 2013).

3.2.2. Polar Code

The road towards a mandatory Polar Code (PC) started in 2009 after a proposal from Norway, Denmark, and the United States to the Maritime Safety Committee (IMO, 2009). The negotiations were intended to harden the soft law provisions of the then current polar shipping guidelines and to significantly develop and strengthen new rules especially on environmental protection (Stokke, 2012). The Polar Code does not address ballast water or hull fouling issues.

3.2.3. The Ilulissat Declaration

The 2008 Ilulissat declaration is a two-page declaration from the five Arctic coastal states. In it, they declare their continued commitment to the current extensive legal framework applying to the Arctic Ocean. It is stated that the framework provides a solid foundation for responsible management by the five coastal states and other users of the Arctic Ocean through national implementation and application of relevant provisions. It also states that the *"Arctic Council and other international fora, including the Barents Euro-Arctic Council, have already taken important steps on specific issues, for example with regard to safety and navigation, search and rescue, environmental monitoring and disaster response and scientific cooperation, which are relevant also to the Arctic Ocean*". The five Arctic states further commit to take steps in accordance with international law both nationally and in cooperation among the five states and other interested parties, to ensure the protection and preservation of the marine environment of the Arctic Ocean. The cooperation extends to the states' participation in the IMO. Through the Ilulissat declaration, the littoral Arctic states clearly declared that they see no need for the development of a new comprehensive international legal regime to govern the Arctic Ocean. This is an approach that also has been favoured by the EU in their Communication on the EU and the Arctic.

3.2.4. Marine Pollution (MARPOL) Convention

As the Arctic falls under the jurisdiction of IMO and its rules for international shipping, the International Convention on the Prevention of Pollution from Ships, 1973/78 (MARPOL) is applicable. Under MARPOL, IMO has the right to designate "special areas" which are defined as sea areas where, for recognised technical reasons in relation to its oceanographic and ecological condition, and to the particular character of its traffic, the adoption of special mandatory methods for the prevention of sea pollution is required. When requested by a member state, IMO can address the special protection needs of a special area through the adoption of special mandatory measure and/or through designating it as a Particularly Sensitive Sea Area (PSSA) and attach Associated Protective Measures (APMs) to it. Antarctic waters, the Baltic Sea, and the North Sea are examples of designated special areas. However, presently no special area, PSSA, or AMPs have been assigned to the Arctic. In absence of being a special area, the Arctic is subject to normal MARPOL restrictions, meaning that certain discharges of wastes in small quantities are allowed at a certain distance from nearest land (IMO, 1978).

3.2.5. Convention for Biological Diversity (CBD)

The Ballast Water Management Convention (BWM Convention, see below) was initiated after the issue of invasive species had already been raised in several other forums. One of the most significant mentions came in the 1992 United Nations Convention on Biological Diversity (CBD), the only global treaty addressing introduction of alien species across all vectors, groups, and continents (Fasham & Trumper, 2001). Upon its entry into force in 1993, the CBD covers both intentional and unintentional introductions of alien species, focussing on prevention, control, and eradication as control methods. Contracting parties are required to, as far as possible and appropriate, prevent the introduction of, control or eradicate alien species which threaten ecosystems, habitats, or species.

Biological diversity under the CBD is defined as “*the variability among living organisms from all sources, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems*”. Although there is no article specifically dealing with *marine* biodiversity, the issue has been addressed at the second Conference of the Parties (COP). The Jakarta mandate on the conservation and sustainable use of marine and coastal biological diversity marked the first policy decision containing principles and thematic areas to be implemented through a program described in COP 4. Alien species in marine waters are mentioned as one of the program’s five key elements (CBD, 1998).

The relevance of the BWM Convention, and specifically its relevance to the CBD was discussed during the preparations for COP 7. Ballast water was singled out as a significant mechanism of transfer of organisms into habitats where they may be harmful and invasive and it was therefore established that the effective implementation of the BWM Convention constitutes an important feature of the work towards reaching the objectives of the CBD and the Jakarta mandate.

3.2.6. Ballast Water Management (BWM) Convention

Ballast water first entered the international arena as a high priority issue in 1992. The United Nations (UN) held a conference in Rio de Janeiro, the UN Conference on Environment and Development, with one of the issues on the agenda being the threat posed by marine invasive species. IMO was called upon to take action, and in response voluntary guidelines were adopted. Increased awareness of the magnitude of the problem prompted the development of a legally binding instrument: the Ballast Water Management Convention (BWM Convention).

Recalling the obligations under international instruments such as UNCLOS and CBD in its preamble, the 2004 International Convention for the Control and Management of Ships’ Ballast Water and Sediments (BWM Convention) marks the first serious efforts to provide an international legally binding regulation on ballast water. Parties to the BWM Convention are required to prevent, minimise and ultimately eliminate transfers of harmful aquatic organisms and pathogens through the control and management of ships' ballast water and sediments. States are encouraged to cooperate in promoting effective implementation, compliance and enforcement of the Convention and, consistent with international law, they may prescribe more stringent measures than those set out in the convention. The convention is applicable to all ships designed or constructed to carry ballast water and flying the flag of, or operating under the authority of, a Party. Ships which are only operating under the jurisdiction of one party or one party and the High Seas are excluded. Parties are to develop national policies, strategies, and programs for ballast water management in their ports and water and they shall ensure that their ports have adequate reception facilities for sediments. Scientific and technical research shall be promoted and effects of ballast water management shall be monitored. Each Party is further obligated to survey and certify its ships as well as develop adequately severe sanctions for any violation of the requirements of the Convention.

When arriving in a port of a Party, ships may be subjected to inspections by authorized officers but the inspections are limited to verifying that there is a valid certificate on board, inspection of the ballast water record book and sampling the ballast water. If a ship is lacking a valid certificate or if the crew is unfamiliar with the ballast water management procedures, a detailed inspection may be carried out and discharges may be prevented until it is made certain that it can be done without threatening the environment, human health, property, or resources. If a ship is found to be in violation of the Convention, the state whose flag it is flying or in whose port it is operating, may warn, detain, or exclude the ship. When carrying out these procedures, all possible efforts shall be made to not unduly detain ships, in which case they are entitled to compensation for any loss or damage.

Detailed regulations on ballast water management and control are found in the Annex to the Convention. It is stated that ballast water discharges shall always be conducted in accordance with the provisions of the Annex, unless it is to ensure the safety of the ship in an emergency situation, minimise pollution, or is the result of accidental damage to the ship. Discharges of ballast water originating from the High Seas or from the same location where it is to be released, are exempt from the demands. The provisions of the Annex require that each ship has a ballast water management plan, containing e.g. detailed safety procedures, procedures for disposal of sediments, and reporting requirements. Each vessel is further obligated to have a ballast water record book with information on every ballast water operation conducted. Parties are responsible for warning vessels within their jurisdiction of areas where ballast water uptake is unsuitable due to factors like known infestations or close proximity to sewage outfalls. Additional measures necessary to prevent, reduce, or eliminate transfer of harmful aquatic organisms may be determined as long as they are in accordance with international law. However, except in emergency or epidemic situations, the intention to establish additional measures and their details shall be communicated to IMO and adjacent parties and states that could be affected by the new standards or requirements at least six months prior to the date of implementation.

Ballast water exchange shall, whenever possible, be conducted at least 200 nm from nearest shore and in waters at least 200 m deep. When unable to discharge in accordance with this requirement, exchange shall be conducted as far away from land as possible but always at least 50 nm from nearest land and still in waters at least 200 m deep. In areas where no such locations exist, the port state may designate areas where ships can conduct their exchange. Ships are not required to deviate from their intended voyage in order to comply with these requirements, nor are they required to comply if the safety or stability of the ship, its crew, or its passengers are threatened because of adverse weather, ship design, or stress, equipment failure, or any other extraordinary condition.

The Convention's ballast water exchange standard, the D-1 standard, requires the volumetric exchange to be at least 95% or for the flow-through method, three times the entire volume of the tanks. The Convention's second standard, the ballast water performance standard or D-2 standard, states that discharges of ballast water must contain less than 10 viable organisms that are greater than or equal to 50 µm in minimum dimension per cubic metre and less than 10 viable organisms per ml that are less than 50 µm and equal to or greater than 10 µm in minimum dimension, in order to meet the standards of the Convention. Further, certain limits regarding colony forming units (cfu) are set for indicator microbes, such as *Escherichia Coli*.

Finland's accession to the BWM Convention in 2016 brought the combined tonnage of contracting states to 35.1 percent, with 52 contracting parties. The convention stipulates that it will enter into force 12 months after ratification by a minimum of 30 States, representing 35% of world merchant shipping tonnage, which will be 8 Sep 2017 (Maritime Executive, 2016).

3.2.7. The Anti-Fouling Convention (AFC)

The 2001 International convention on the control of harmful anti-fouling systems on ships (the Anti-Fouling Convention or the AFC), predates the BWM Convention having entered into force on 17 September 2008. The convention came in the wake of research showing that toxicity from anti-fouling systems risked chronically impacting ecologically and economically important marine organisms and human health. It was noted that the use of anti-fouling systems to prevent the build-up of organisms on the surface of ships is of critical importance to efficient commerce, shipping, and to impede the spread of harmful aquatic organisms and pathogens. It was also noted that development of effective and environmentally safe systems to substitute harmful ones must continue. An anti-fouling system is any coating, paint, surface, or device that is used on a ship to control or prevent attachment of unwanted organisms.

Parties to the AFC are required to prohibit or restrict the application, re-application, installation, or use of harmful anti-fouling systems and shall take effective measures to ensure compliance with those requirements. The AFC bans the application or reapplication of organotin compounds which act as biocides in antifouling systems since 2003. Further, ships shall not bear such compounds on their hulls or external parts of surfaces, nor bear coatings that form a barrier to such compounds leaching form the underlying non-compliant anti-fouling systems.

3.3. Regional legal frameworks

3.3.1. Oslo-Paris (OSPAR) Convention

The Convention for the Protection of the Marine Environment of the Northeast Atlantic (OSPAR convention) with its commission consists of 15 governments and the EU. The Northeast Atlantic area covered by the convention is vast, stretching from the Greenland coast to the North Sea and from the North Pole to the straits of Gibraltar. The Arctic constitutes OSPAR's most northern region as Region I. OSPAR of today is the result of a merger between two separate conventions in 1992, the 1972 Convention on the prevention of marine pollution by dumping from ships and aircraft (Oslo convention) and the 1974 Convention for the prevention of marine pollution from land-based sources (Paris convention). Since its entering into force in 1998, the OSPAR convention reinforces legal principles such as the precautionary principle, the polluter pays principle, best available technique, and best environmental practice for the marine environment.

In seeking to regulate *all* sources of marine pollution in one single instrument, the OSPAR convention has represented a new approach to the protection of the marine environment. From a ballast water and invasive species point of view, the most interesting part of this regional cooperation is not the convention itself but the joint initiatives taken together by the OSPAR and Helsinki Commissions to safeguard the marine environment from invasive species, called the General guidance on the voluntary interim application of the D1 ballast water exchange standard in the North-East Atlantic and the Baltic Sea (OSPAR Commission, 2008). The initiatives are directly in line with article 13(3) of the BWM Convention, stating that "*Parties with common interests to protect the environment, human health, property and resources in a given geographical area, in particular, those Parties bordering enclosed and semi-enclosed seas, shall endeavour, taking into account characteristic regional features, to enhance regional cooperation, including through the conclusion of regional agreements consistent with this Convention*". The voluntary guidelines are addressed to ships flying the flag or operating under the authority of a party and are applicable until the point where a ship is in a position to apply the D-2 Standard or until the BWM Convention enters into force and there is a mandatory obligation to apply the D-2 Standard.

Vessels are recommended to have a ballast water management plan and they should keep records of all their ballast water operations. The guidelines ask that ships exchange their ballast tanks after the D-1 Standard of the BWM Convention, at least 200 nm from the nearest land and in waters at least 200 m deep, *before* entering the Northeast Atlantic (this does not apply to vessels entering the area from the Mediterranean Sea). If the exchange takes place within the North-East Atlantic, vessels are still expected to conduct it at least 200 nm from the nearest land and at a depth of at least 200 m. If not possible, exchange should be conducted as far away from land as possible but never closer to land than 50 nm and still in waters at least 200 m deep.

3.3.2. Paris and Tokyo MoUs on Port State Control

In response to the 1978 *Amoco Cadiz* oil spill and due to frustration with highly varying implementation of existing commitments among flag-of-convenience states, the maritime authorities of 14 European countries drew up the 1982 Paris Memorandum of Understanding (MoU). Today the Paris MoU is an administrative agreement between 27 maritime authorities covering the waters of the European coastal states and the North Atlantic basin from North America to Europe. This MoU covers the commitments of its members to relevant international conventions, inspection procedures, investigation of operational procedures, exchange of information, structure of the organisation, and amendment procedures.

The Paris MoU has been very successful and inspired other similar arrangements in other parts of the world. The cooperative efforts have made port state control coordinated and cost-efficient since vessels usually call at several ports within a region before beginning their return voyage. Under the coordinated efforts, non-compliant ships where the violation constitute a threat is to be detained until corrective measures have been taken (Stokke, 2012). The Paris MoU publishes a targeting factor for each vessel, based on frequencies of inspection and detainment. A high factor increases the likelihood of a vessel being targeted for inspection. By making this information public, vessel operators are exposed to ship brokers, insurers, and charterers, reducing their competitiveness. The targeting mechanism now also includes information on a vessel's classification society and if applicable, charterer, thus "sharing the blame" with other actors with the possibility of influencing compliance. Some authors have suggested the possibility of negotiating an Arctic MoU or adjusting the adjacent port state control arrangements of the Paris and Tokyo MoU to cover Arctic shipping and its compliance monitoring and enforcement.

3.4. National implementation

Arctic shipping is predominantly destinational and port state jurisdiction therefore has the potential of providing a powerful basis for strengthening regulatory measures (Stokke, 2012). Several of the Arctic littoral states are already today using their sovereignty over ports and internal waters to obtain compliance with regulations that in some cases are stricter than those agreed globally. A good example of such unilateral port-sovereignty-based action is the adoption of the 1990 Oil Pollution Act (OPA90) in the United States, following the 1989 *Exxon Valdez* oil spill in Alaska. This act phased in double-hull requirements for oil tankers, which was subsequently enforced by IMO as well. It has been suggested that one or a subset of Arctic coastal states could choose unilateral action quite successfully and without obtaining agreement with the members of the Arctic Council, as long as they obtain agreement with the major commercial ports in the region (Stokke, 2012). This study has been performed with the help of several national experts listed in Annex 1 – National experts.

3.4.1. Canada

3.4.1.1. The Canada Shipping Act

Canadian ballast water control is governed by Ballast Water Control and Management Regulations under the Canada Shipping Act. The Canada Shipping Ac of 2001t (CSA 2001) is the principal legislation governing shipping and protection of the marine environment. Prior to its 2001 update, the Canada Shipping Act was one of the oldest pieces of legislation in Canada, based on the British Merchant Act of 1894. With the updated CSA 2001 came the introduction of a new administrative enforcement scheme designed to encourage and promote compliance. One of its key objectives is to establish an effective inspection and enforcement program. In order to avoid Marine Safety having to go through the criminal court system to deal with contraventions, CSA 2001 opened for an alternative administrative approach. The Administrative Monetary Penalties Regulation came into force in 2008 and comes with a national Compliance and Enforcement Policy (Transport Canada, 2014) to outline the process that should be followed upon the detection of contraventions. Those that become subject to penalties under the Administrative Monetary Penalties Regulations may appeal the decision reviewed by the Transportation Appeal Tribunal of Canada (TATC), an independent body created by the Transportation Appeal Tribunal of Canada Act.

3.4.1.2. The Canadian Ballast Water Program

The ballast regulations were updated in 2011 (Transport Canada, 2012). The Canadian ballast water regulation applies to Canadian vessels everywhere and non-Canadian vessels in water under Canadian jurisdiction. Vessels operating exclusively in waters under Canadian jurisdiction, or that operate exclusively in waters under Canadian jurisdiction and in the US waters of the Great Lakes Basin or the French waters of the islands Saint Pierre and Miquelon. Persons responsible for ensuring that the requirements are met are the authorized representative and the master of Canadian vessels and the authorized representative of foreign vessels.

Managed ballast water refers to ballast water that has been exchanged, treated, transferred to a reception facility (includes sediment), or is retained on board the vessel. Ballast water taken on board a vessel outside waters under Canadian jurisdiction must be managed in order to minimise the release of harmful aquatic organisms or pathogens, and to remove or render harmless the organisms within the ballast water. Ballast water taken on board outside waters under Canadian jurisdiction must not be released in Canadian waters unless it has been exchanged in an area at least 200 nm from shore and where the water depth is at least 2,000 m. Alternative exchange areas have been designated in specified cases where the requirements for exchange cannot be met in a feasible manner or without compromising the stability or safety of the vessel. Since ballast water exchange in waters at least 50 nm from shore and at a depth greater than 500 m is not always possible, two alternate sites have been designated in the Arctic. Vessels that proceed to Hudson Bay ports can perform ballast water exchange in the Hudson Strait in areas east of 70° west longitude that are at least 300 m deep. In the higher Arctic, vessels can perform ballast water exchange in Lancaster Sound in areas east of 80° west longitude and at depths of at least 300 meters. For vessels not navigating beyond 200 nm from shore where the water depth is at least 2,000 m, exchange can be conducted in waters at least 50 nm from shore where the water depth is at least 500 m (and the same High Arctic alternative exchange area applies). Canadian standards for ballast water exchange as well as treatment mirror those adopted by the IMO under the BWM Convention.

3.4.2. The United States

The severe consequences of the marine invasions of the Great Lakes have forced the United States to be at the forefront of ballast water regulations. There is no single instrument exhaustively covering the whole of the country. Instead, the issue is dealt with through a mix of federal and state laws, regulations, and guidelines with the main responsibility of enforcement having been entrusted to the Environmental Protection Agency (EPA) and the United States Coast Guard (USCG).

In 1999, former President Clinton put invasive species higher on the agenda, when he issued Executive Order (EO) 13112 to improve the federal coordination and response to the growing problem of invasive species. This EO aimed to prevent the introduction of invasive species, to provide for their control and minimise the economic, ecological, and human health impacts that they cause. The EO required any federal agency whose actions could affect the status of invasive species to identify such actions and establish relevant programs and authorities in order to prevent introductions, detect, and rapidly respond in a cost-effective and environmentally sound manner, as well as monitor and provide for restoration of ecosystem conditions. Actions likely to cause of promote introductions were not to be authorised unless the relevant agency had determined that the benefits of those actions clearly outweighed the potential harm and measures to minimise the risk of harm were taken. The EO further established the Invasive Species Council to provide national leadership regarding invasive species, to oversee the implementation of the order, and make sure the activities conducted were coordinated, complementary, cost-efficient, and effective. Additionally, the Invasive Species Council was tasked with developing recommendations for international cooperation and the preparation and issuance of a National Invasive Species Management Plan.

3.4.2.1. The Clean Water Act

With a national goal to eliminate discharges of pollutants into the navigable waters, the 1972 Federal Water Pollution Control Amendments, more commonly known as the Clean Water Act (CWA) after the 1977 amendment, is the principal federal law regarding water pollution in the United States. The CWA prohibits the discharge of any pollutant, unless lawful according to an exemption. The term "*pollutant*" is defined broadly, including for example solid wastes, sewage, discharged equipment, biological materials, and even rocks and sand. However, it does not include "*sewage from vessels or a discharge incidental to the normal operation of a vessel of the Armed Forces*".

For the purpose of meeting the goals of the CWA and controlling pollution, the development and implementation of national programs is required. Since the CWA is administered by the EPA, they are the ones to develop such programs and regulations. One of the regulations issued by the EPA has been the cause of some controversy regarding this act and ballast water. The CWA states that the EPA administrator shall issue permits for the discharge of pollutants into the navigable waters of the United States. Any discharge of pollutants is therefore prohibited, unless beforehand having obtained a National Pollutant Discharge Elimination System (NPDES) permit from the EPA. The controversy here is found in a regulation from the EPA, exempting any "*discharge of sewage from vessels, effluent from properly functioning marine engines, laundry, shower, and galley sink wastes, or any other discharge incidental to the normal operation of a vessel*" (not only for vessels of the Armed Forces) from such requirements. Since the EPA considered ballast water discharges to be incidental to the normal operation of a vessel, such discharges did not require a permit. Several environmental groups petitioned the EPA to repeal this provision and include ballast water in the permitting requirements under the CWA. The petition was denied by the EPA and a lawsuit was filed under the U.S. district court for the northern district of California. The plaintiffs claimed the EPA exemption to be in conflict with the CWA, which itself does not exempt "*discharges incidental to the normal operation of a vessel*" from the NPDES requirements and that the EPA had overstepped its statutory authority under the CWA which would make the promulgation unlawful (US District Court, N.D. California, 2006). The court found in favour of the plaintiffs, stating that congress had "directly spoken" through the CWA and specifically required the NPDES permits for vessels discharging pollutants into U.S. waters and E the PA had therefore acted in excess of its statutory authority and was ordered to repeal the regulation which exempts discharges incidental to the normal operation of a vessel from permit requirements.

Recently, a federal appeals court in New York has ordered the government to rewrite its ballast water discharge rules. Petitioners claimed that the EPA had acted arbitrarily and capriciously in their issuing of the 2013 Vessel General Permit under the CWA, and requested that it be set aside.

Permits must establish limits on discharges that will lead to compliance with water quality standards. Since no states have established numeric water quality criteria for invasive species, the EPA had to establish Water Quality Based Effluent Levels (WQBEL) and the permit then mandates best management practices to control pollution. The court found that in failing to set Technology Based Effluent Standards (TBES) that reflect the Best Available Technology (BAT) when it chose the IMO standards for the TBES, the EPA had in fact acted arbitrarily and capriciously in some aspects. The EPA had failed to explain why standards higher than the IMO standard should not be used given available technology (the EPA Science Advisory Board report (SAB report) had identified technologies that can achieve standards higher than the IMO standards for one or more organisms size class: the Ecochlor, BalPure, and PeraClean systems). Seeking to find systems that are *more* capable than current standards is in line with the technology forcing aspects of the CWA. The court found that the EPA should have adjusted the standard in accordance with the BAT listed in the SAB report. The BAT is defined as requiring a commitment of the maximum resources economically possible to the ultimate goal of eliminating all pollution discharges. The court further found that records suggested that onshore systems were technologically possible at the time but that the EPA had failed to discuss and develop the necessary information to evaluate availability. "Available" is said to mean technologies that *could* be used for a particular discharge, even if it is not currently being used by the industry in question. In failing to consider onshore ballast water treatment systems, the EPA had again acted arbitrarily and capriciously.

3.4.2.2. The Non-indigenous aquatic nuisance prevention and control act

The 1990 Non-indigenous Aquatic Nuisance Prevention and Control Act (NANPCA) was long the United States' main protection against invasive species in general, and in particular, against those arriving through ballast water. Recognising that the discharge of untreated ballast water has resulted in the establishment of non-indigenous species in U.S. waters (particularly the Great Lakes) and lead to severe economic and ecological consequences, the NANPCA aims to prevent unintentional introductions and dispersal of such species through ballast water management and other requirements. Research, prevention control, information dissemination, and other related activities are to be coordinated, conducted, and authorised at federal level.

The issuance of voluntary guidelines, ensuring to the maximum extent practicable that ballast water containing aquatic nuisance species would not be discharged into the Great Lakes, were to be developed within six months of the enactment. It was further required that the guidelines would be replaced by binding regulations to be issued within two years from the enactment. The regulations, applicable to all vessels equipped with ballast water tanks entering a United States port on the Great Lakes after operating on the waters beyond the EEZ, require vessels to either carry out exchange beyond the EEZ prior to entry, exchange the ballast water in other waters where the exchange does not pose a threat of infestation or spread of aquatic nuisance species or use environmentally sound alternative ballast water management methods found to be as effective as ballast water exchange in preventing infestations. The NANPCA also established an intergovernmental organisation called the Aquatic Nuisance Species task force (ANS task force) of which, among others, the administrator of the EPA and the commandant of the USCG are members. The main function of the ANS task force is the development and implementation of a program to prevent introductions and dispersals of aquatic nuisance species, to monitor, control, and study such species and to disseminate related information. The program is to identify goals, priorities, and approaches for aquatic nuisance prevention, monitoring, control, education, and research. Also, it is to direct the USCG to issue further regulations to prevent introductions and spread of aquatic nuisance species into the Great Lakes through ballast water. Violations of the regulations may lead to civil and criminal penalties. The penalties are however subjected to exceptions and the liability does not apply when the safety or stability of the vessel, its crew or passengers, is threatened or the record-keeping and reporting requirements are complied with. Another important aspect of the NANPCA is the encouragement of the development of regional panels to conduct activities such as identifying priorities, make recommendations to the task force, provide advice to the public and encourage state or interstate invasive species management plans to identify areas or activities for which funds or technology is needed. Since the provisions under the NANPCA were of a voluntary nature, except in the Great Lakes, they were criticised and deemed inadequate. In 1996, the act was re-authorised and amended by the National Invasive Species Act (NISA) which slightly expanded it. After NISA, the scope has been widened to cover all of the U.S. waters and the focus is now less on the Zebra mussel and more on aquatic nuisance species in general.

3.4.2.3. The USCG Ballast water management program

The USCG was directed by NISA to establish national voluntary ballast water management guidelines, which, if deemed inadequate, were to be transformed into a mandatory national program. Since the rate of compliance was found to be too low and vessel operators often failed to submit the mandatory ballast water reports, the program was converted into mandatory regulations in 2004. These were updated with their Final Rule on Standards for Living Organisms in Ships’ Ballast Water

Discharged in U.S. Waters (published in the Federal Register on 23 March 2012). The updated USCG Final Rule is consistent with the IMO standards.

3.4.3. Russia

In 2012, President Putin signed a Federal Law on the commercial navigation in the waters of the Northern Sea Route (NSR), replacing the previous ”*Rules for sailing along the Northern Sea Route*” from 1990. The law introduced compulsory insurance of civil liability of owners of vessels for pollution damage, as well as providing tariffs for icebreaking support and ice pilotage along the NSR. The new law established a single instrument controlling the NSR and is supposed to bring a modern infrastructure providing a safe environment for vessels sailing these waters. Vessels will now get navigation, hydrographic, and hydrometeorological service, icebreaking and ice pilotage support (Marchenko, 2013). Russia acceded to the BWM Convention by Resolution No 256. of the Russian Federation Government from 28 March, 2012.

3.4.4. Norway

The High Arctic archipelago Svalbard is regarded as one of the most pristine marine environments in the world. To date, no invasive species have been found, although it should be noted that sampling efforts have been low (Ware et al., 2014). Norway’s High North strategy pledges to base management of living marine resources on the rights and duties set out in UNCLOS (Stokke, 2012).

Norway acceded to the BWM Convention 29 March 2007 and has modelled its ballast water requirement after the convention and its guidelines. The Convention is implemented into Norwegian law through regulations issued by the Ministry of the Environment pursuant to the Act of 16 February 2007 No. 9 relating to Ship Safety and Security (the Ship Safety and Security Act) Sections 2, 6, 31, 32 and 33, and entered into force 1 January 2010.

Norway has a national local regulation banning Heavy Fuel Oil (HFO) within the Svalbard archipelago. Fuel shall be within the DMA quality (marine gas oil) according to the ISO 8217 fuel standard. An exemption applies for the shortest, most secure route via:

- The Northwest part of South Spitsbergen national park, for sailing to and from the Svea mine.
- The northern part of Forlandet national park and the southern part of Northwest Spitsbergen national park for sailings to and from Ny-Ålesund up to 1 January 2015.
- North-West Spitsbergen national park for sailings to Magdalenefjorden up to 1 January 2015.

3.4.5. Denmark (Greenland)

Greenland is the world’s largest island, but also one of the world’s least densely populated areas. The first people arrived in Greenland more than 4,000 years ago and since, Greenland has been inhabited by different Inuit peoples and cultures. The Norse settlers arrived later, around year 1000, with modern colonisation taking place in 1721 with a purpose of re-Christianising the island. The travels of the Norwegian-Danish missionary, Hans Egede, was covered by the Danish Crown, leading to Greenland becoming a Danish colony. After being administered by the Danish Government, without the inclusion of Greenlandic councils, local councils began to see the light of day by the mid-nineteenth century. The local councils later turned into elected municipal and provincial councils and finally Greenland received representation in the Danish Parliament following a change of the Danish Constitution in 1953 (Kleist, 2016).

Regarding international policy, Greenland's status can seem unclear. Pertaining to international conventions, Greenland's status has its basis in Denmark's obligations. Foreign- and security policy is an area that still fall under Danish jurisdiction according to the constitution. However, the Danish government has traditionally involved the Greenlandic Home Rule in foreign affairs and security matters of interest to the island. This was somewhat softened in 2005 as the Danish Folketing adopted Act. no 577 "*Concerning the conclusion of agreements under international law by the Government of Greenland*", providing full statutory power to conclude certain international agreements on behalf of Denmark.

3.4.5.1. Greenland's self-government

Greenland was for a long time administratively a Danish province but following the entry into force of the Act on Greenland Self-Government 21 June 2009, Greenland authorities exercise legislative and executing power in the fields where they have taken over responsibility. The legislative power lies with Inatsisartut, the Greenland Parliament, and the executive power with Naalakkersuisut, the Greenland government, and the judicial power with the courts of law. The administration of the Government of Greenland performs its tasks within a framework of acts and appropriations adopted by the Greenland Parliament. Additionally, the Government must comply with the Danish Constitution, the Act on Greenland Self-Government, and international conventions.

The Greenlandic assumption of responsibility is done gradually according to a schedule containing fields of responsibility. 21) Ship registration and maritime matters and 24) Marine environment are both listed and it is stated that "*Fields of responsibility that appear from List II of the Schedule shall be transferred to the Greenland Self-Government authorities at points in time fixed by the Self-Government authorities after negotiation with the central authorities of the Realm*".

3.4.5.2. Order 654

On the topic of ballast water, a Danish partnership consisting of the Danish Nature Agency and the Danish Maritime Authority has been formed. Both hold legal responsibilities for regulating ballast water in Denmark. Denmark ratified the BWM Convention through the Danish order on ballast water management 30 June 2012. The Danish Nature Agency (DNA) shall monitor compliance with the provisions of the ballast water order. The DNA may take non-representative samples and conduct indicative analysis of ship's ballast water if there is any doubt whether a ship is compliant. If the analysis indicates a ship may be non-compliant, the DNA may request the Danish Maritime Authority to detain the ship until a representative sample has been taken. However, the detention shall not cause any unnecessary delay of or cost for the ship. The DNA shall forward the sample to an independent laboratory for a detailed analysis. Ships are not allowed to discharge ballast water until so can be done without any danger of damage to the environment, human health, or property. The DNA may grant exemptions from the requirements for ballast water exchange or management to ships on specific voyages and where at least one port call is in Denmark. If discharges within the waters of another Party, the exemption shall also be granted by that Party. Exemptions shall be granted only if the DNA considers the risk of invasive species transfer to be low.

Unless more severe penalties are due under other legislation, anyone carrying out specified tasks are liable to punishment by fine. Among the specified tasks are for example: anyone who manages ballast water in violation of the order, who violates the conditions of any exemption granted, or who supplies incorrect information in connection with an application for exemption. Penalties may be increased to imprisonment for a term not exceeding two years if the violation has been made intentionally or grossly negligently and if the violation has caused damage to the environment or risk of such damage, or the violation has produced or has been intended to produce financial benefits to the contravener or other, including cost savings. Penalties involving imprisonment are not applicable to violations committed by foreign ships unless the violations have been made in inner territorial waters. As for violations committed by foreign ships in outer territorial waters, the penalty may be increased to imprisonment for a term not exceeding two years in case of intentional or serious pollution of the marine environment. Companies and other “legal personalities” may be liable to punishment according to the provision of part 5 of the Penal Code - Straffeloven.

4. Ship biofouling in the Arctic

As the ongoing climate change and warming of the Arctic is predicted to continue, the expectation is also the shipping activity will increase in the region. There is concern that this will lead to an increased risk of introduction of non-indigenous species and invasive species in the Arctic Ocean. Climate change may result in more favourable environmental conditions for southern species and a considerable increase in the shipping activity increases the risk of transportation and introduction of invasive species. Hull fouling and discharge of ballast water are the main source of spreading marine alien species to new geographic areas (Drake & Lodge, 2007; Endresen, Lee Behrens, Brynestad, Bjørn Andersen, & Skjong, 2004). Despite the clear role of ships in coastal invasions, the relative importance of ballast water and hull fouling remains difficult to estimate.

Many species have both planktonic life stages that can be transferred in ballast water, as well as sessile or sedentary life stages that can occur on ship hulls (McGee, Piorkowski, & Ruiz, 2006). If these species survive to establish a reproductive population in the host environment, they may become invasive and outcompete native species and multiplying to such an extent that host ecosystems are disturbed (Bax, Williamson, Aguero, Gonzalez, & Geeves, 2003). IMO has taken a leading role in the effort of internationally addressing the transfer of invasive aquatic species through shipping (IMO, 2016). In 2004 the IMO Member States made a clear commitment to minimise the transfer of invasive aquatic species by shipping with the adaption of the International Convention for the Control and Management of Ship´s Ballast Water and Sediments (BWM Convention). The BWM Convention is specifically targeting ballast water and will enter into force on 8 September 2017 after being ratified by 30 states.

Biofouling is the unwanted attachment of microorganisms, plants, algae, and animals on submerged structures, mainly shiphulls, and is also considered one of the main vectors for transferring invasive species. The transfer of invasive aquatic species through ships' biofouling was first brought formally to IMO's attention in 2006, leading to an international recognition of the problem. The following year the Sub-Committee on Bulk Liquids and Gases (BLG) was given the task to develop guidelines with the aim to provide a globally consistent approach to managing biofouling by delivering useful recommendations on general measures to minimise the risks associated with biofouling for ships. The Biofouling Guidelines, the "*Guidelines for the control and management of ships´ biofouling to minimize the transfer of invasive aquatic species*", was adopted by the Marine Environment Protection Committee (MEPC) in 2011 (IMO, 2011). As recreational crafts of less than 24 m are particularly disposed to biofouling, due to their large numbers and their operating profile, the Biofouling Guidelines were further complemented with guidance for them. The new complemented guidelines were approved by MEPC at its 64th session in October 2012 and circulated as MEPC.1/Circ.792 (IMO, 2012).

The Biofouling Guidelines addresses that all ships have some degree of biofouling, even those which may have been recently cleaned or had a new application of an anti-fouling system (IMO, 2011). The biofouling process may begin within the first few hours of a ship's immersion in water. The biofouling that can be found on a ship is influenced by a range of factors, such as:

- design and construction, particularly the number, location, and design of niche areas (e.g. sea chests, bow thrusters, hull appendages, and protrusions etc.);
- specific operating profiles, including parameters such as operating speeds, ratio of time underway compared with time alongside, moored, or at anchor, and where the ship is located when not in use (e.g. open anchorage or estuarine port);

- places visited and trading routes (e.g. depending on water temperature and salinity, abundance of fouling organisms etc.); and
- maintenance history, including the type, age, and condition of any anti-fouling coating, installation and operation of anti-fouling systems, and dry-docking/slipping and hull cleaning practices.

A first step in assessing the potential risk of invasions associated with shipping (both biofouling and ballast water) is to characterise the magnitude of ship arrivals, the volume of ballast delivery, and origin for both arrivals and ballast (McGee et al., 2006). A good knowledge of the shipping network of routes and ports is important, as the spreading of non-native species may also be done gradually when species carried from the original environment is established in visiting ports and areas along the route to the new geographical area. This spreading or invasion of species through the so-called "stepping stone" is defined as an invasion that occur when individuals first become established beyond the native range and are then introduced geographically step by step to a new location of study (Keller, Drake, Drew, & Lodge, 2011).

The spreading of non-native species to the region of Barents Sea and Svalbard may occur through active transport like shipping or by a natural northward immigration of species due to climate change-driven warming of the Arctic. However, the questions are how compatible the introduced species are to their new Arctic environment and how their ability to adapt and reproduce will change.

The red king crab (*Paralithodes camtschaticus*) is an example of an alien species introduced to the Barents Sea ecosystem. This crab species occurs originally in the North Pacific, from the Sea of Japan and the Sea of Okhotsk, to the western and eastern Bering Sea as far north as Norton Sound and was intentionally introduced to the Barents Sea in the 1960s to establish a new commercial fishery (Donaldson & Byersdorfer, 2005). The original area of introduction was the waters of the southern Barents Sea, mainly in the Kola Bay and adjacent areas of Western Murmansk in Russia (Kuzmin & Gudimova, 2002). Since then, the red king crab has established and spread to the Norwegian coast and northeast of the Kola Peninsula. The first findings in the White Sea have recently been reported, confirming its continuing expansion (A. Dvoretsky & Dvoretsky, 2014). The northernmost finding was recorded in 2002 at 72°40' N, which is midway between Nordkapp on the Norwegian mainland coast and Bjørnøya, although it have not yet been observed in Svalbard waters (Sakshaug et al., 2009). Commercial fishing in Russian waters started in 2004 (A. G. Dvoretsky & Dvoretsky, 2015). The adult red king crab are opportunistic, omnivorous, and feeds on the most abundant benthic organisms available: molluscs, polychaetes, and echinoderms, but also on fish offal if available in areas of intensive multispecies fishing.

The snow crab (*Chinoecetes opilio*) is also a subarctic crab species originally from the North Pacific that have established in the Barents Sea as an alien species. It initially occurred in the Sea of Japan, the Sea of Okhotsk, and the Bering Sea north of the Alaska Peninsula. The snow crab is also found in the northwestern Atlantic Ocean, from southern Greenland and Canada south to Casco Bay in Maine, as well as the Arctic Ocean: the Beaufort Sea, Laptev Sea, and the East Siberian Sea (Jadamec, Donaldson, & Cullenberg, 1999). A few specimens of snow crab was first recorded in the Barents Sea in 1996, when captured by Russian fishing vessels (Kuzmin, Akhtarin, & Menis, 1998). It is still uncertain how this species was able to enter the Barents Sea, but spreading by ballast water has been proposed as a possible vector (A. G. Dvoretsky & Dvoretsky, 2015). It is also suggested that the crab might have migrated independently from the Chukchi Sea in eastern Russia, since examples of the crab have been found both in the East Siberia Sea and the Laptev Sea (Fernandez, Kaiser, &

Vestergaard, 2014). Recent studies comparing genetic relationship between different populations of snow crab indicate the lowest variance between crabs in the Barents Sea, Bering Sea, and Eastern Canada (Dahle, Agnalt, Farestveit, Sevigny, & Parent, 2014). Since it first was discovered in the Barents Sea, the snow crab has increased in numbers and spread to most part of the northern Russian EEZ and part of the international waters of Barents Sea. It has also been observed in the Svalbard Fishery Protection Zone (FPZ) and along the coast of northern Norway (Fernandez et al., 2014). Due to its lower temperature preference, it is expected that the snow crab will continue to spread further north and west in the Barents Sea (Fernandez et al., 2014). Most likely, the crab will be found around the whole Svalbard and Franz Josef archipelago in the future. The increase and spread of the snow crab population in the Barents Sea has taken place at a much higher rate than the red king crab population in these areas and a commercial fishery started in 2013 (Sundet & Bakanev, 2014). The dominant diet of the snow crab is, as in similarity to the red king crab, benthic fauna such as polychaetes, crustaceans, molluscs, and echinoderms (Fernandez et al., 2014).

The impacts of these two alien species are not completely understood, but researcher have shown that the red king crab are able to reduce the abundance of benthic organisms, especially when appearing in high density aggregation (Pavlova, 2008). The similarity of the native environmental preference of the red king- and snow crab to the new environmental conditions in the Barents Sea has been crucial for their successful spreading in the area. There is a concern of a similar impact on the benthic fauna when it comes to the snow crab due to the species high spread rate (Sundet & Bakanev, 2014). Another concern is that alien crabs in the Barents Sea have a negative impact on commercially important species for fisheries. A study where cross-correlation analysis was on these two crab species and cod, haddock, saithe, capelin, and the northern shrimp (A. G. Dvoretsky & Dvoretsky, 2015). The analysis showed that neither crab species had a negative impact on the stocks of economically important fish species. However, a potential negative impact of snow crab on the northern shrimp population could not be rejected due to their overlapping distribution and predatory pray interaction. In recent years, there is an overall high abundance of commercial fish stock that indicates of a high productivity in the Barents Sea (A. G. Dvoretsky & Dvoretsky, 2015). This is likely associated with the warming Arctic region and no clear indication of an adverse impact of the alien crab species was detected. However, this does not rule out negative effects on other parts of the ecosystem, especially as the peak of the snow crab spreading yet not have been documented.

4.1. Svalbard sampling study

In order to analyse the impact of biofouling from ships in the Arctic, Ms. Jennie Folkunger (World Maritime University, Sweden) and Mr. Michael Palmgren (Sea-U, Sweden) performed a sampling study on Svalbard during 2014 and 2015.

The choice of Svalbard and the port of Longyearbyen as a sampling site is due to its ecological importance to the Barents Sea Large Marine Ecosystem (LME), while being one of the most heavily trafficked areas in the Arctic.

The aim was to investigate the species composition and abundance of biofouling on ships that uses the port of Longyearbyen. The study also reviewed and analysed the environment, shipping patterns, and operational profile of the investigated vessels. Sampling was conducted at two separate occasions; at the end of the summer season as well as the beginning, allowing for basic analysis of temporal changes throughout the season.

4.1.1. Svalbard geography and history

Svalbard is an archipelago located approximately 1,200 km from the geographic North Pole. It consists of the islands of Spitsbergen, Nordaustlandet, Barentsøya, Edgeøya, Kong Karls Land, Hopen, Prins Karls Forland, Bjørnøya, as well as other smaller islands and rocks between 74° and 81° northern latitude and 10° and 35 ° eastern longitude (NPI, 2017) (Figure 16).

Figure 16: The Svalbard archipelago with approximate ice cover (Mappery, 2008).

Svalbard has been referred to in Icelandic texts as early as 1194, but upon its discovery by Willem Barentsz in 1596, it was established as a site for international whaling, initially Russian and later Norwegian all-winter hunting. The name Svalbard refers to the whole of the archipelago, while the name Spitsbergen only refers to its largest island (named by Willem Barentsz). Longyearbyen, the largest settlement on Svalbard, was named after American John M. Longyear, who in 1906 established the first mine there. Norway has been granted sovereignty of Svalbard since 1925 after the signing of the 1920 Svalbard Treaty by 12 countries (Visit Svalbard, 2017b).

About 60% of Svalbard’s landmass is covered by glaciers of varying size and vegetation only covers 6-7%, with the most fertile areas being located in the inner fjord regions. Despite of the constant permafrost and harsh conditions, Svalbard has a flora of around 170 species. Almost all of the animal life on Svalbard however, is found in the Barents Sea, the only common land mammals being the Svalbard reindeer, the Arctic fox, Sibling vole, various seal species, whales, walruses, and of course the polar bear (Visit Svalbard, 2017a). The majority of Svalbard’s environment is untouched and preserving it as such, allowing natural ecological processes and biological diversity to develop in a manner unaffected by human activity, is a goal explicitly expressed by the Governor of Svalbard (The Governor of Svalbard, 2012).

4.1.2. Svalbard marine ecosystem

A series of studies was conducted by a Norwegian-Polish team during the 1990s, examining the intertidal zone of Svalbard and Bjørnøya, looking at environmental conditions, macroorganisms, and meiofauna (Weslawski, Wiktor, Zajaczkowski, & Swerpel, 1993). Ice conditions around Svalbard appeared to have its maximum in April as most coastal areas at that time is covered with fast ice lasting for approximately 3-9 months a year depending on location. Inner fjords and sheltered areas of the eastern coast is often areas where ice melts away last (Szymelfenig, Kwaśniewski, & Węsławski, 1995; Weslawski et al., 1993). The west coast of Svalbard is usually ice-free during summer, as the areas are affected by the warmer West Spitsbergen Current deriving with higher salinity from the north Atlantic (Figure 17) (Nilsen, Skogseth, Vaardal-Lunde, & Inall, 2016; Szymelfenig et al., 1995; Weslawski et al., 1993).

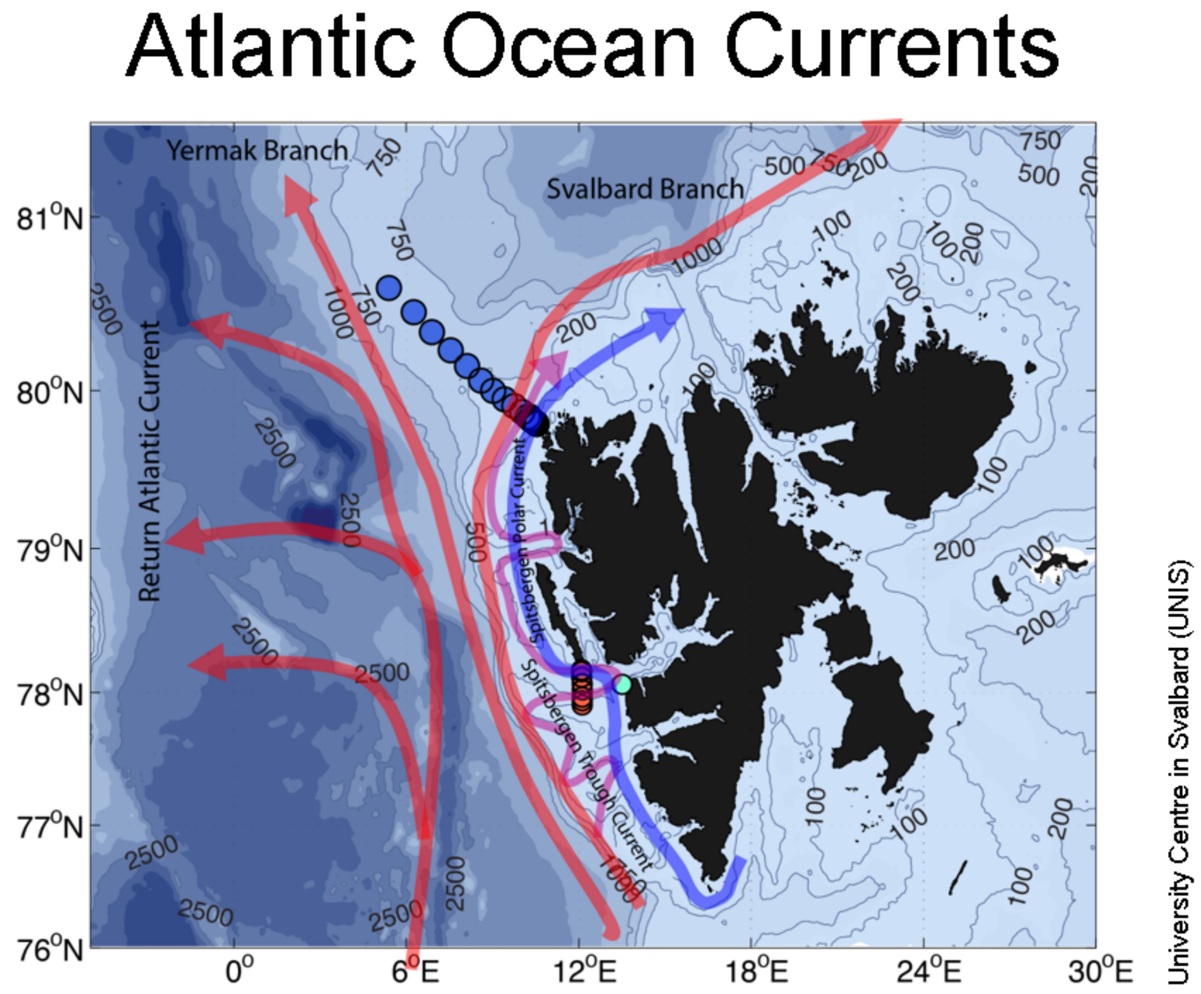


Figure 17: Atlantic currents around Svalbard, with the warmer West Spitsbergen Current in red (Nilsen et al., 2016).

The eastern coast of Svalbard is commonly influenced by drifting pack-ice even in August, as that area encounters the colder and less saline Sorkapp Current and Barents Current from the North.

The most common morphology of the Svalbard coast consists of low gravel beaches, although there are several other types of substrata (Szymelfenig et al., 1995; Weslawski et al., 1993).

Bjørnøja is the southernmost island of the Svalbard archipelago and is situated half-way between the Scandinavian Peninsula and Spitsbergen. The island is also affected by the two major water masses, the West Spitsbergen Current and the Barents Current. The most common coastal morphology are high rocky cliffs with a beach of coarse sand and large gravel at their foot (Weslawski, Zajaczkowski, Wiktor, & Szymelfenig, 1997). The observed water temperatures put Svalbard between Subarctic Western Greenland and Franz Josef Land (Weslawski et al., 1993). In general, salinity in the Arctic littoral zones, for example Svalbard, show a large variation, likely depending on the variability of influx of freshwater from runoff areas and melting ice (Weslawski et al., 1993).

The number of species of macrofauna found in the Svalbard intertidal zone is similar to that noted on Baffin Island and Greenland, where 30 to 50 species have been observed (Madsen, 1936). The key species *Balanus*, *Littorina*, *Fucus,* and *Gammarus* are common on most of the Arctic coasts and have been reported in Alaska (Feder & Kaiser, 1980), Greenland (Madsen, 1936), and Arctic Canada (Ellis & Wilce, 1961; T. A. Stephenson & Stephenson, 1949). The set of species observed in the Svalbard littoral also indicates its subarctic character. The border between the subarctic and the Arctic province runs through Sornset at the southern tip of Spitsbergen. The division into two zoogeographical zones is probably caused by temperature, salinity, and ice factor (Weslawski et al., 1993). The species richness and biomass of the littoral zone appeared in the study to be highest on the open oceanic western coast of Svalbard, whereas the eastern coast and inner fjords were less biologically productive.

4.1.3. Svalbard port logistics

The main logistic point for vessels arriving in Spitsbergen is the Port of Longyearbyen, where its proximity to the airport as well as the city centre is advantageous. Longyearbyen has today three quays; Gamlekaia, Kullkaia, and Bykaia. Bykaia is owned and operated by the local government of Longyearbyen and is used by cruise ships and tourist vessels, as well as fishing, research, cargo vessels, and the Coast Guard (Kystvakten). Due to the steady increasing number of port calls (Figure 18), there are plans to expand the harbour area and increase its capacity, to which 400 million Norwegian crowns was dedicated (Longyearbyen Lokalstyre, 2014).

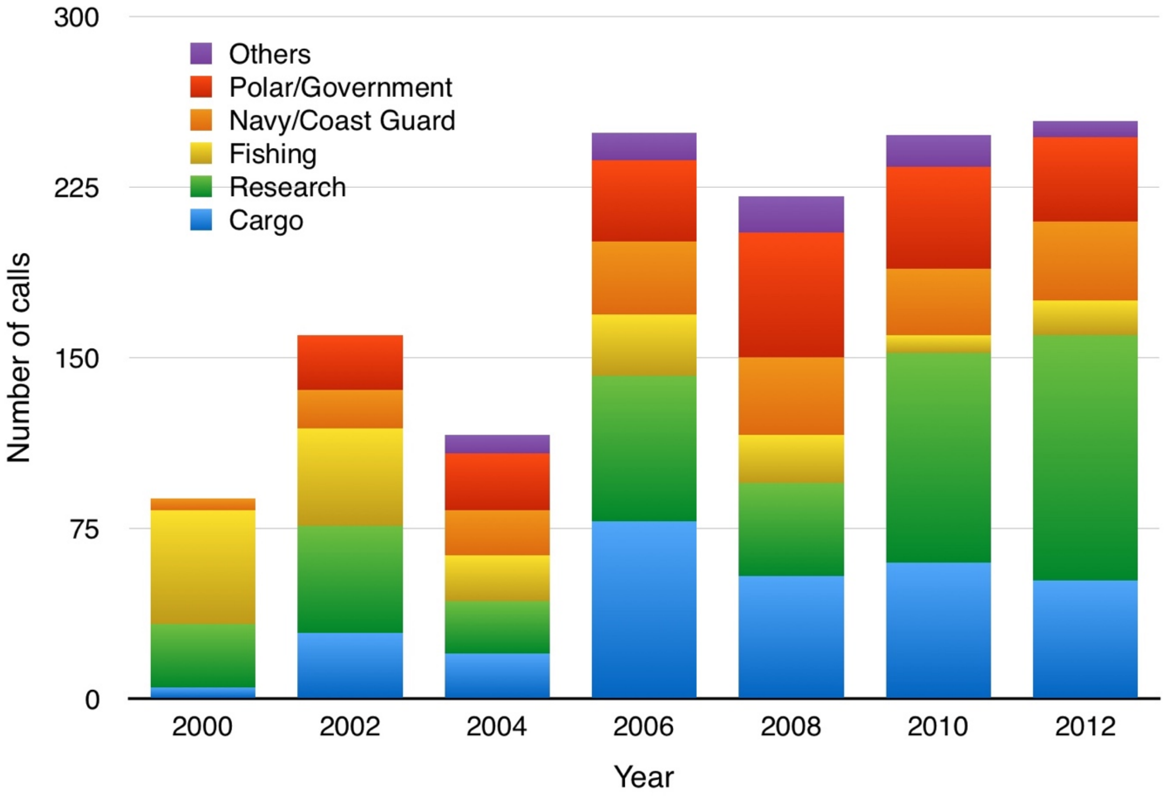


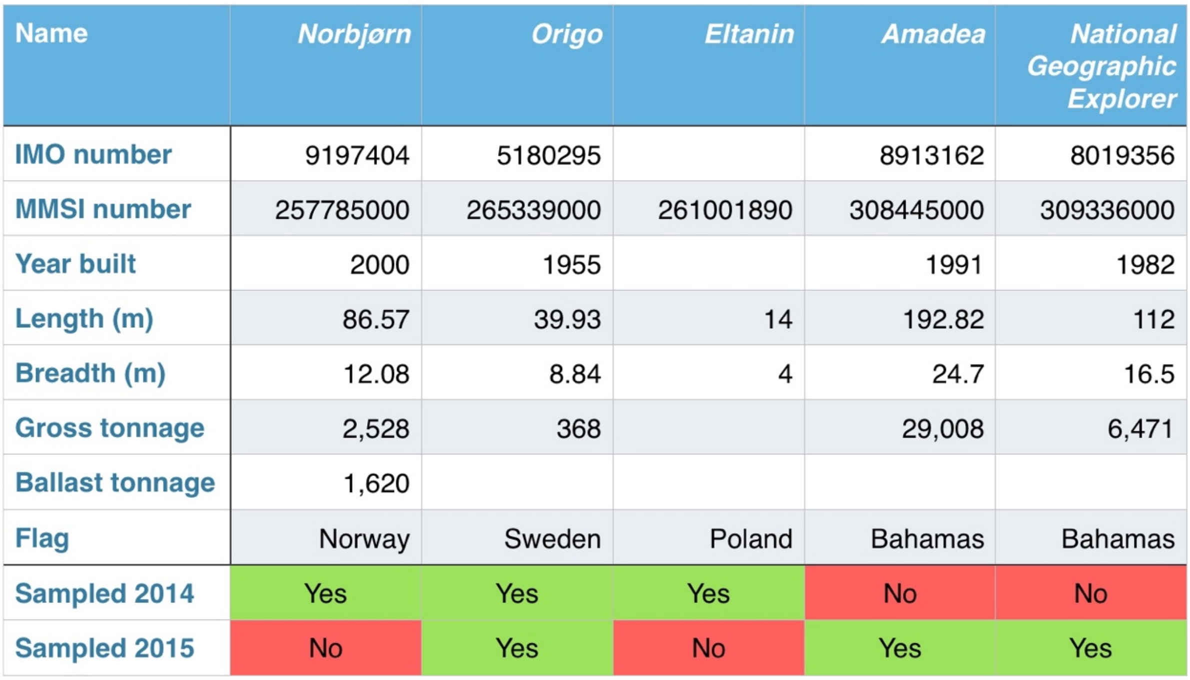
Figure 18: Port calls in Longyearbyen between 2000 and 2012, excluding passenger ships (Longyearbyen Lokalstyre, 2014).

Shipping in Svalbard is characterised by great variations and seasonality, with the most traffic occurring from July to October. Fishing is a year-round activity in Svalbard, but peaking between August and December with 50-60 vessels. Cruise ships arrive at Longyearbyen from June to September. The cruise traffic can be divided into three segments, large cruise ships that arrive from overseas, expedition cruises that go around the archipelago, and day cruises from Longyearbyen. Cargo vessels arrive regularly to Svea, Barentsburg, Ny Ålesund, and Longyearbyen. Two vessels operate on a fixed route and 5-6 additional dry cargo vessels do 15-20 tours combined annually. Svalbard also has reefer ships taking frozen fish from the trawl ships operating year-round. A couple of research vessels also operate year-round in the Svalbard zone, peaking between July and September with 5-8 vessels (Longyearbyen Lokalstyre, 2014). A new regulation on ports and navigable areas of Svalbard (Havne og Farvannsloven) entered into force 1 January 2010, with the purpose of improving security and the organisation of port activities.

4.2. Sampling sites

The detailed information about the sampled ships can be found in Table 2 below.

Table 2: Overview of ships sampled during 2014 and 2015 (MarineTraffic, 2017).



Name	*Norbjørn*	*Origo*	*Eltanin*	*Amadea*	*National Geographic Explorer*
IMO number	9197404	5180295		8913162	8019356
MMSI number	257785000	265339000	261001890	308445000	309336000
Year built	2000	1955		1991	1982
Length (m)	86.57	39.93	14	192.82	112
Breadth (m)	12.08	8.84	4	24.7	16.5
Gross tonnage	2,528	368		29,008	6,471
Ballast tonnage	1,620				
Flag	Norway	Sweden	Poland	Bahamas	Bahamas
Sampled 2014	Yes	Yes	Yes	No	No
Sampled 2015	No	Yes	No	Yes	Yes

4.2.1. Bykaia

The location for reference sampling was a position by the Bykaia berth (78°13'46.57"N and 15°35'58.54"E) in the harbour of Longyearbyen.

An initial reference dive was conducted in the port area and samples were taken from the sheet piles (Figure 19).

Figure 19: A sea urchin at Bykaia. Photo by M. Palmgren 2015.

This dive also served as a way of testing the equipment before the vessel sampling. The maximum water depth at the reference site was 12 m. Bykaia was selected as the reference location because of its accessibility and safety.

4.2.2. Norbjørn

Norbjørn is a general cargo carrier that has been in operation since 1991, trafficking the northern route from Tromsø, on the Norwegian mainland, to Longyearbyen and Ny Ålesund, in the Svalbard archipelago.

Figure 20: Norbjørn*. Photo by J. Folkunger 2014.*

The average frequency and period of operation is 3 times a month, between 1st of April to 31st of December. *Norbjørn* is trafficking the route as joint venture between Marine Supply A/S, who owns the vessel and Bring Logistics (former Norcargo). Marine Supply is a shipping company specialising in bunker and lubes trading in port and high seas for the North Atlantic region (Dark Season Blues). Marine Supply has more than 20 years of experience with high seas bunker supplies in the Barents Sea.

Norbjørn is coated with the antifouling paint Intersmooth 360 SPC, a tributyltin (TBT)-free self-polishing co-polymer (SPC) antifouling system with copper acrylate technology.

The hull of *Norbjørn* was sampled the 16th September 2014 while berthed at the harbour of Longyearbyen.

4.2.3. Origo

Origo was built in 1955 for the Swedish Maritime administration as an ice-strengthened pilot ship (Figure 21).

Figure 21: Passenger ship Origo*. Photo by J. Folkunger 2014.*

Since 1983, *Origo* has served as a school ship and still does during the winter season. In the early 1990s, the vessel was rebuilt to a passenger ship, taking 24 passengers. *Origo* now spends every summer, between May and September, cruising the Arctic waters around Svalbard for Master Mariner AB (Master Mariner AB, 2017). Scotland and the Norwegian fjords are other popular cruise destinations.

Origo is painted with the Sigma Ecofleet 290, a TBT-free and self-polishing antifouling.

The hull of *Origo* was sampled on two occasions, 16th September 2014 and 18th June 2015, while berthed at the harbour of Longyearbyen.

4.2.4. Eltanin

Eltanin is a polish sailboat, adapted for Arctic navigation (Figure 22).

Figure 22: Research sailing vessel Eltanin*. Photo J. Folkunger 2014.*

The vessel is used for both transportation and research (Arktyka, 2017). From May to September, *Eltanin* is sailed from Poland to Svalbard, where it sails from Longyearbyen to various locations on Svalbard. *Eltanin* usually sails back to Poland after September.

Information about the antifouling paint on *Eltanin* was not accessible.

The hull of *Eltanin* was sampled 12th September 2014 while berthed at the harbour of Longyearbyen.

4.2.5. Amadea

Amadea was built in 1991 and is a passenger ship that cruises the Arctic waters surrounding Svalbard each summer (**Fel! Det går inrte att hitta någon referenskälla.**).

Figure 23: Passenger cruise ship Amadea*: Photo by M. Palmgren 2015.*

The ship belongs to a German shipping company and is also cruising the Mediterranean, around South Africa, Greenland, and the Baltic Sea.

Information about the antifouling paint on *Amadea* was not accessible.

The hull of *Amadea* was sampled 16th June 2015 while berthed at the harbour of Longyearbyen.

4.2.6. National Geographic Explorer

National Geographic Explorer travels from pole to pole each year, spending summers in Antarctica and summers in the Arctic (Figure 24).

Figure 24: Passenger cruise ship National Geographic Explorer. *Photo by M. Palmgren 2015.*

As it voyages the length of the Atlantic, the ship explores the Baltic Sea, Norway, the Northwest Passage, Canada, and the wild coast of South America.

Information about the antifouling paint was not accessible.

The hull of *National Geographic Explorer* was sampled 17th of June 2015 while berthed at the harbour of Longyearbyen.

4.3. Materials and methodology

A literature review of sampling methodology regarding hull fouling was conducted. It was noted that there is a lack of standardised methodology for this type of sampling, and existing similar methodologies fail to address many practical issues. Therefore, an adaptation of existing sampling methods of Lee & Chown (2009) and Hopkins & Forrest (2010) was performed.

The sampling of the vessels was conducted in sections dividing the vessel into bow, amidships, and stern (Figure 25).

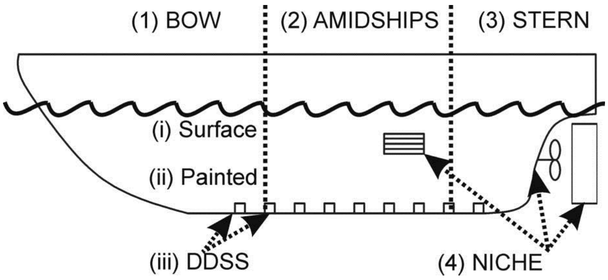


Figure 25: Illustration of a vessel hull with vertical divisions for sampling zones (Hopkins & Forrest, 2010).

The equipment used was bottles, containers, GoPro camera equipment, plankton net, zip-lock bags, scrape, salinometer, thermometer etc. Most was brought from Sweden, except the gear that could not easily be carried on the flight, and was borrowed or rented from University Centre in Svalbard (UNIS). This included drysuit, scuba gear, and alcohol for sample preservation.

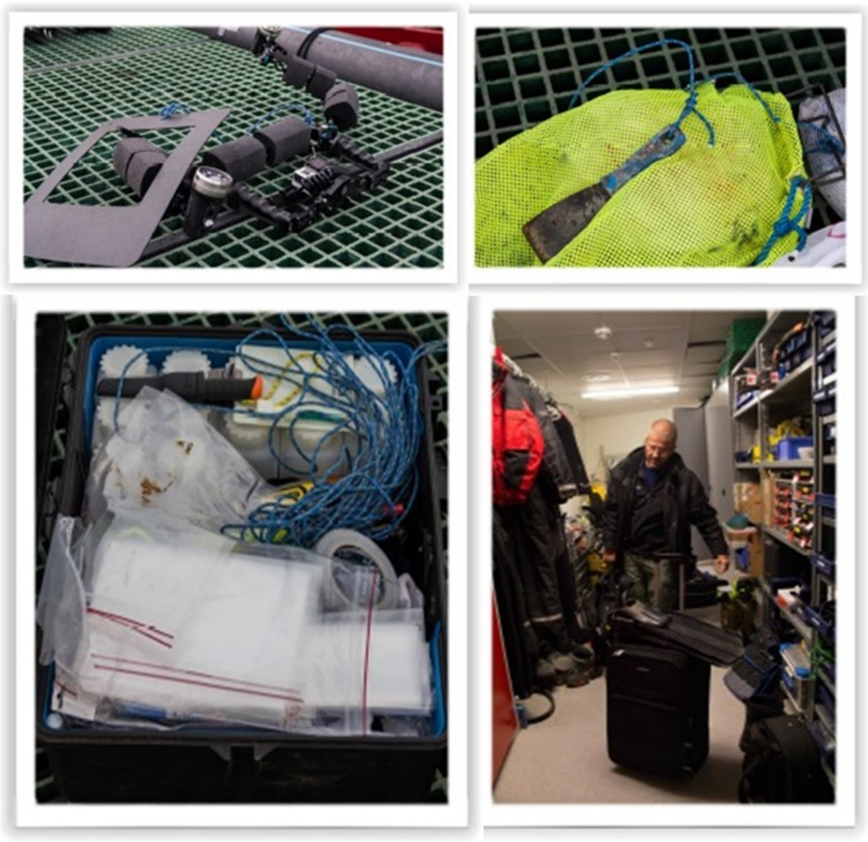


Figure 26: Equipment used during sampling. Photo J. Folkunger 2014.

The sampling of vessels was conducted on two occasions: September 2014 and June 2015.

A GoPro camera on a mount with lights was used to film and assess the level of fouling on the hulls of the vessels sampled. A 20x20 cm square had been cut out of a soft mat to allow for comparisons of level of fouling between areas of the same size.

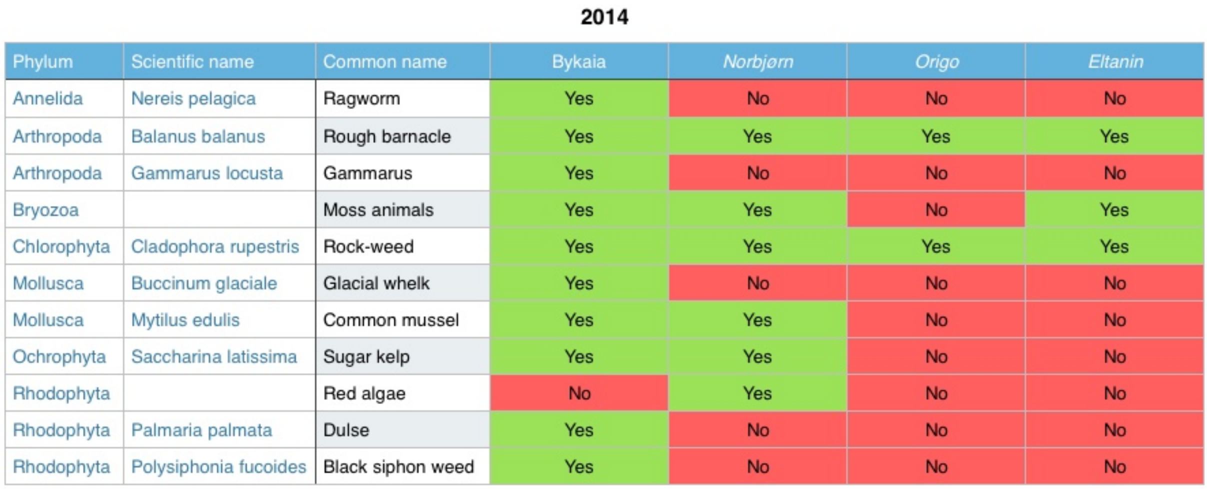
Biofouling was scraped off the hull of the vessels using a scrape. The surface that was scraped covered 20x20 cm of the hull and the biofouling was gathered into a net and put into bottles. The content of the bottles was subsequently preserved in 70% ethanol. Initial ocular analyses of the samples were performed on site with a loupe. A more comprehensive analysis was conducted in Sweden using a laboratory microscope.

During the 2015 sampling, additional complementary sampling was conducted with virtue disks. Virtue disks started as a public outreach program for a marine scientist at the Gothenburg University in Sweden, University of Bergen in Norway, and University System of Maryland in United States (Olsson, 2013). Virtue is an easy model to monitor biofouling. A number of Compact Discs (CD)s are mounted on a rack and placed in different underwater environments. The discs in this study were placed at 3 m depth under the Bykaia pier (latitude 78°13'42.79"N and longitude 15°36'22.61"E), so the rack was not disturbed by the ship movements and anchoring alongside the pier.

4.4. Results

The full list of animals found during the sampling can be found in **Fel! Det går inrte att hitta någon referenskälla.**.

Table 3: Taxa found during sampling 2014. Nothing was found during sampling 2015.



2014

Phylum	Scientific name	Common name	Bykaia	*Norbjørn*	*Origo*	*Eltanin*
Annelida	Nereis pelagica	Ragworm	Yes	No	No	No
Arthropoda	Balanus balanus	Rough barnacle	Yes	Yes	Yes	Yes
Arthropoda	Gammarus locusta	Gammarus	Yes	No	No	No
Bryozoa		Moss animals	Yes	Yes	No	Yes
Chlorophyta	Cladophora rupestris	Rock-weed	Yes	Yes	Yes	Yes
Mollusca	Buccinum glaciale	Glacial whelk	Yes	No	No	No
Mollusca	Mytilus edulis	Common mussel	Yes	Yes	No	No
Ochrophyta	Saccharina latissima	Sugar kelp	Yes	Yes	No	No
Rhodophyta		Red algae	No	Yes	No	No
Rhodophyta	Palmaria palmata	Dulse	Yes	No	No	No
Rhodophyta	Polysiphonia fucoides	Black siphon weed	Yes	No	No	No

4.4.1. 2014 sampling

The water temperature was between 5° and 7° C. No current was detected. The Secchi depth was between 0.5 and 1 m. Visibility beneath the 3-4 m halocline was around 5 m.

The vessels sampled were *Norbjørn*, *Origo*, and *Eltanin*.

Results show a higher biodiversity of benthic organisms on the reference location Bykaia, where 10 species were documented (**Fel! Det går inrte att hitta någon referenskälla.**). The sampling conducted on the hulls of the three vessels were the same as the species from the Bykaia reference location. A slightly higher abundance of species on *Norbjørn* was found as 6 species was documented (Figure 27a-b).

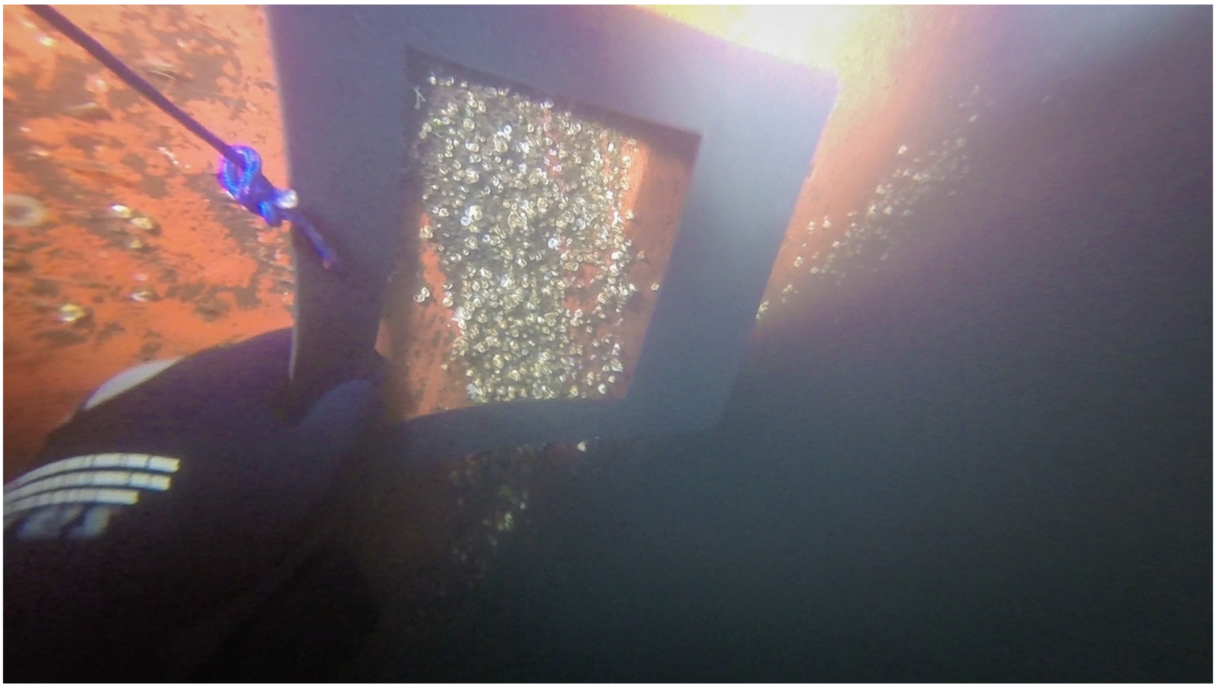


Figure 27a: Norbjørn hull with fouling. Photo M. Palmgren 2014.

Figure 27b: Norbjørn *hull with fouling. Photo M. Palmgren 2014.*

On *Origo* only two species were recorded (Figure 28a-b).

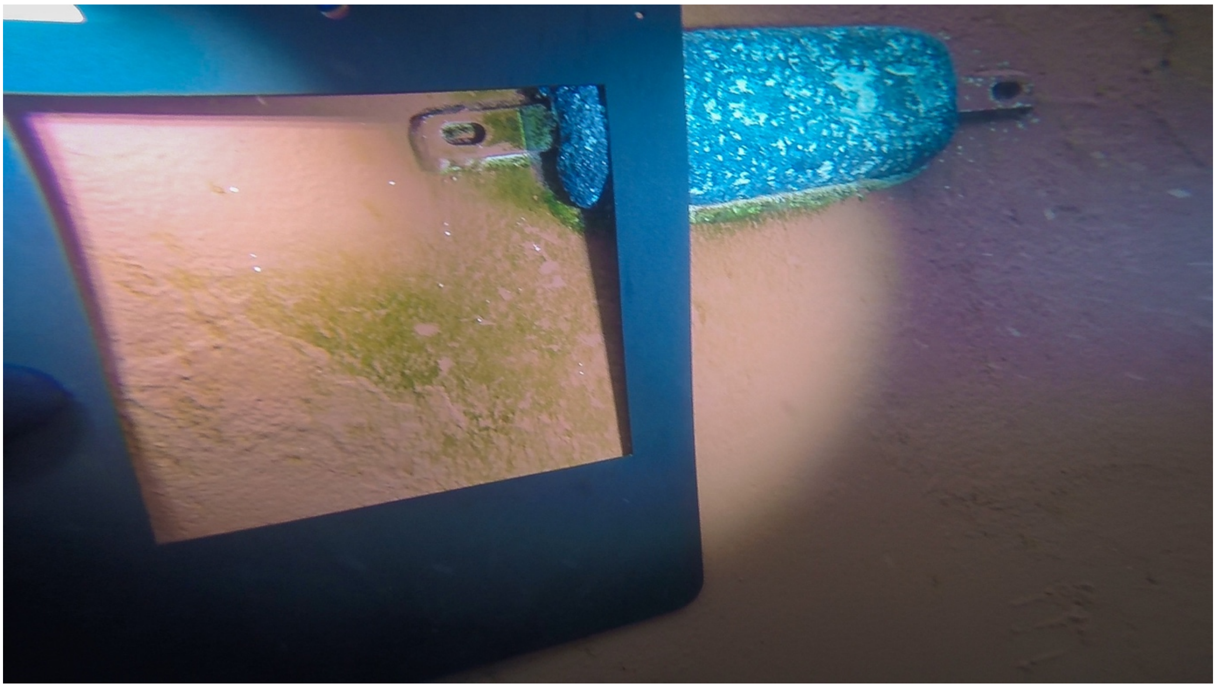


Figure 28a: Origo *hull with fouling. Photo M. Palmgren 2014.*

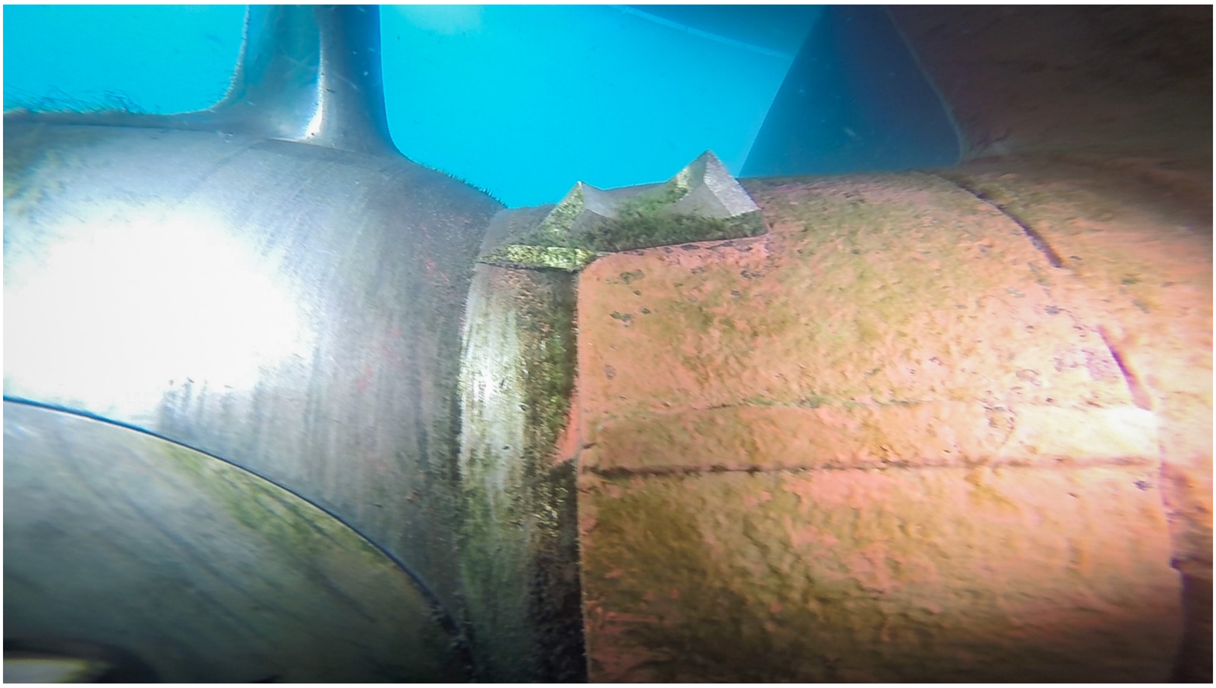


Figure 28b: Origo *propeller with fouling. Photo M. Palmgren 2014.*

On *Eltanin* only three species were recorded (Figure 29a-b).

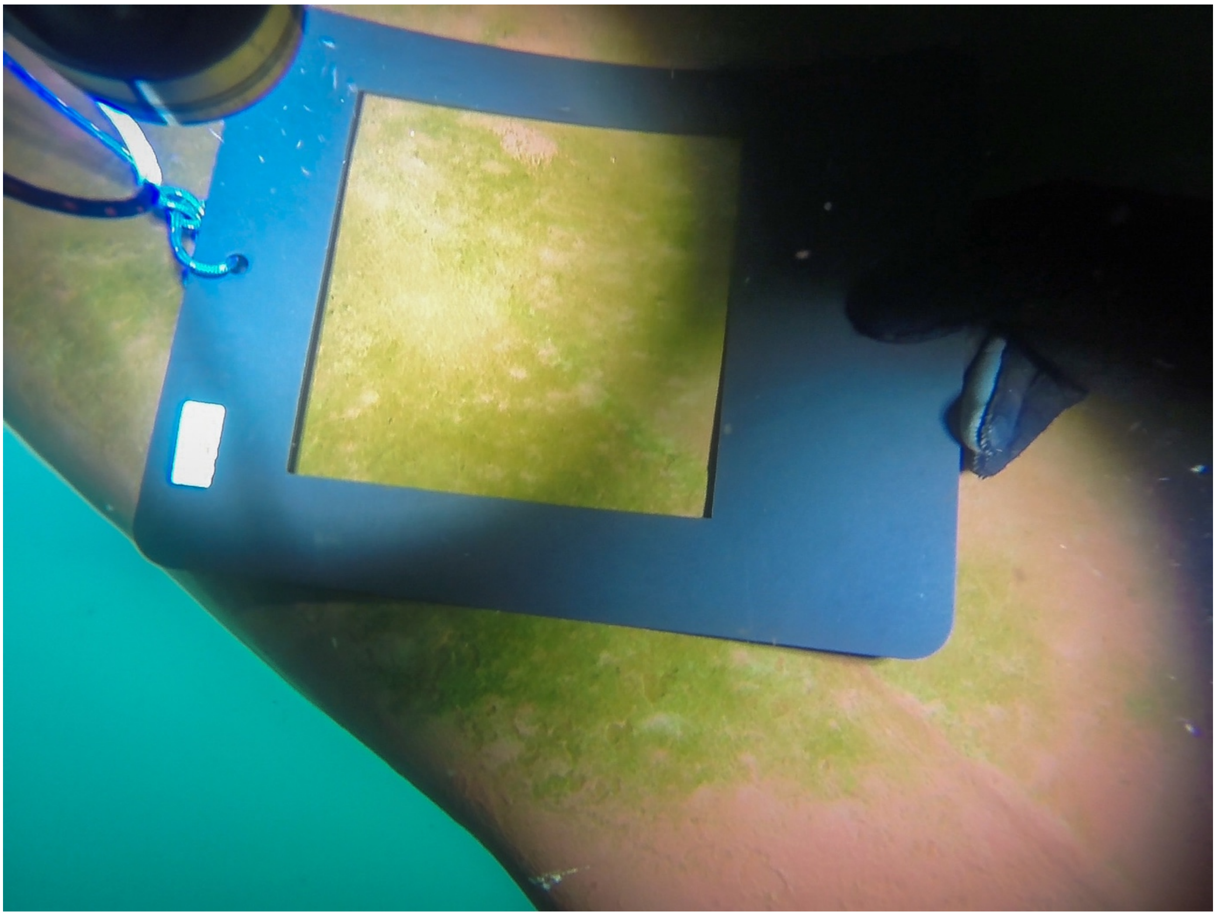


Figure 29a: Eltanin *hull with fouling. Photo M. Palmgren 2014.*

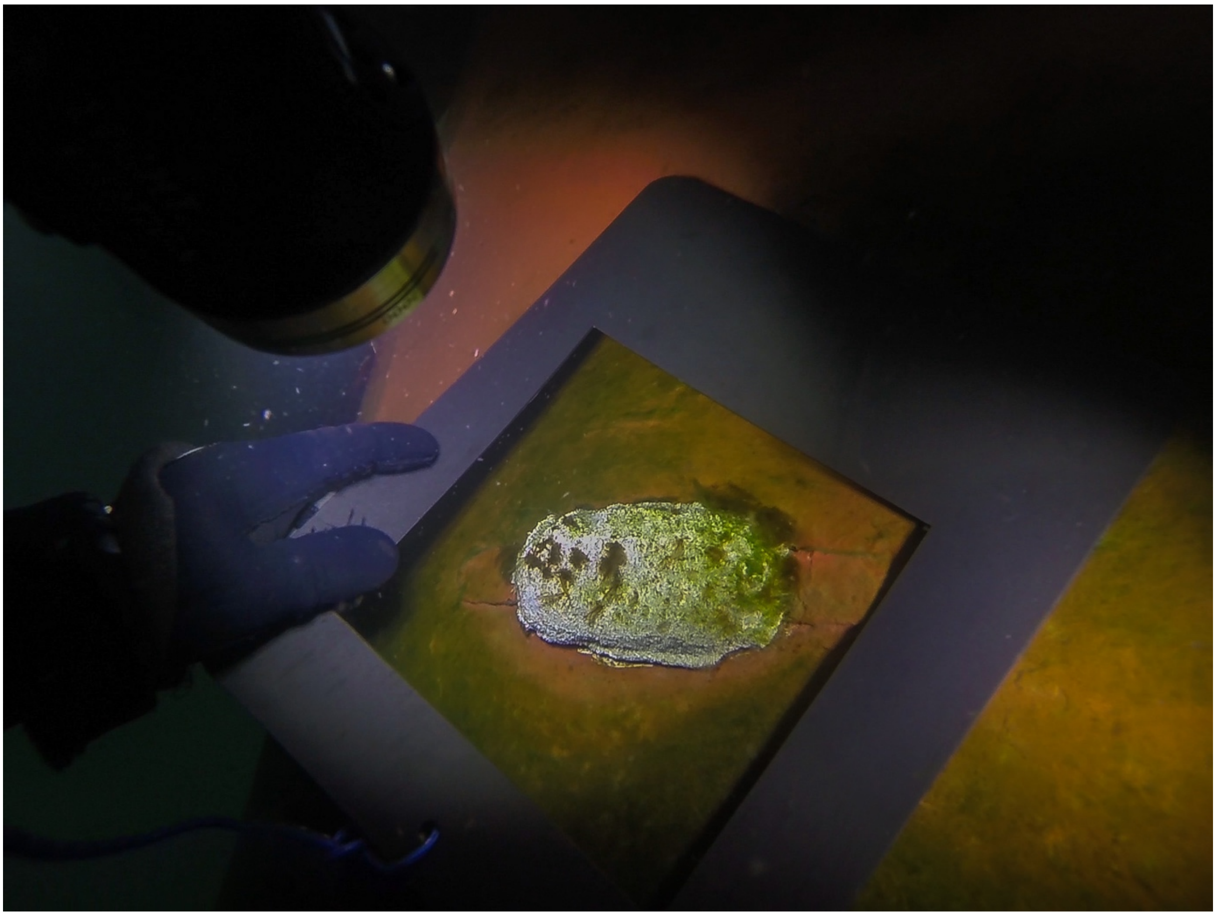


Figure 29b: Eltanin *hull with fouling. Photo M. Palmgren 2014.*

The species that were documented at all sampling sites were rough barnacle (*Balanus balanus*) and rock weed (*Cladophora rupestris*). The results of the count of each species show a significantly higher abundance of species on *Norbjørn* compared to Bykaia, *Origo* and *Eltanin* (Annex 2 – Sampling results). This is due to the high count of the rough barnacle (*Balanus balanus*).

It proved difficult to estimate the degree of coverage of organisms on the hulls of the vessels since the biofouling was so limited.

4.4.2. 2015 sampling

The water temperature was between -2° and -3° C during this sampling. No current was detected. The Secchi depth was less than 2 m. Visibility beneath the 3 m halocline was between 5 to 6 m.

The vessels sampled were *Amadea*, *National Geographic Explorer*, and *Origo*.

Amadea sailed from the Mediterranean Sea via Bremen and the Kiel Canal before arriving in Svalbard. No hullfouling was observed, except a thin biofilm (Figure 30a-c). No sampling was possible with the available equipment.

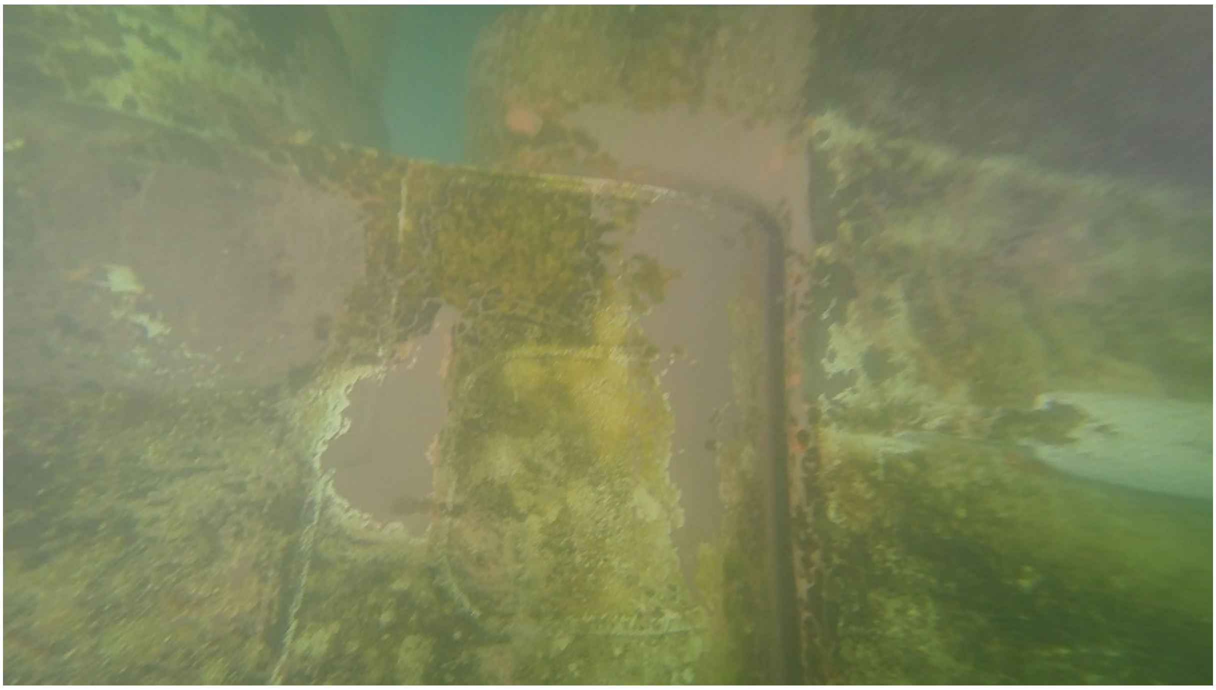


Figure 30a: Amadea *rudder with fouling. Photo M. Palmgren 2015.*

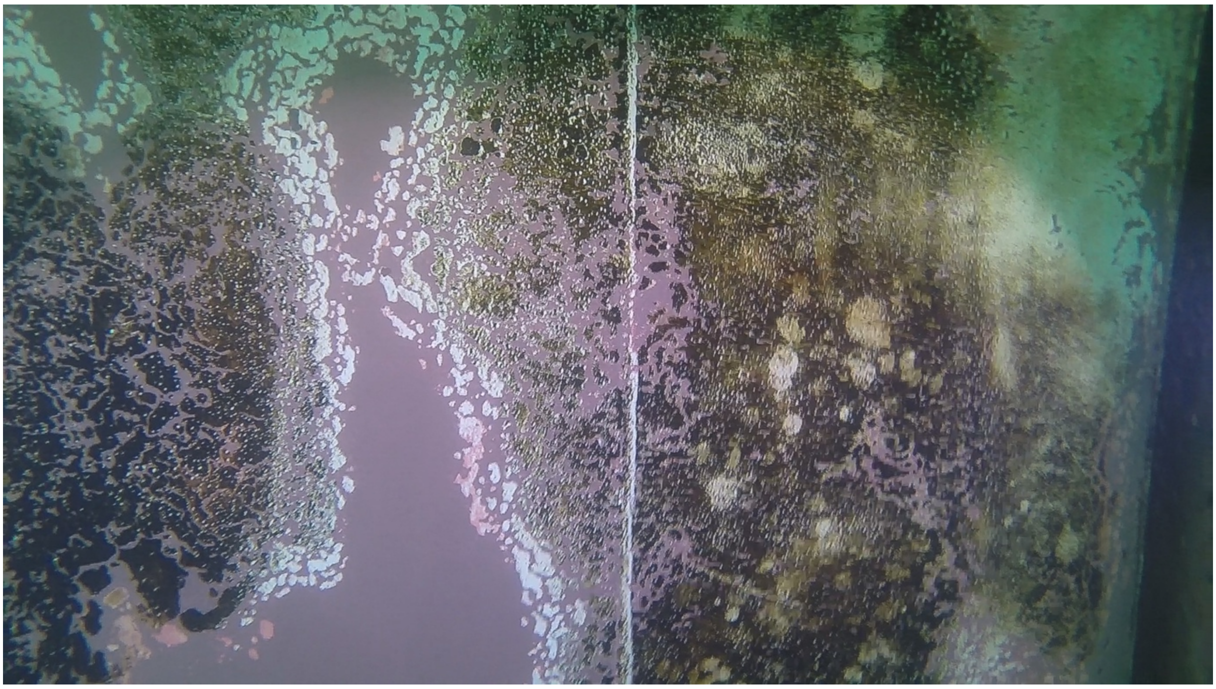


Figure 30b: Amadea *hull with fouling. Photo M. Palmgren 2015.*

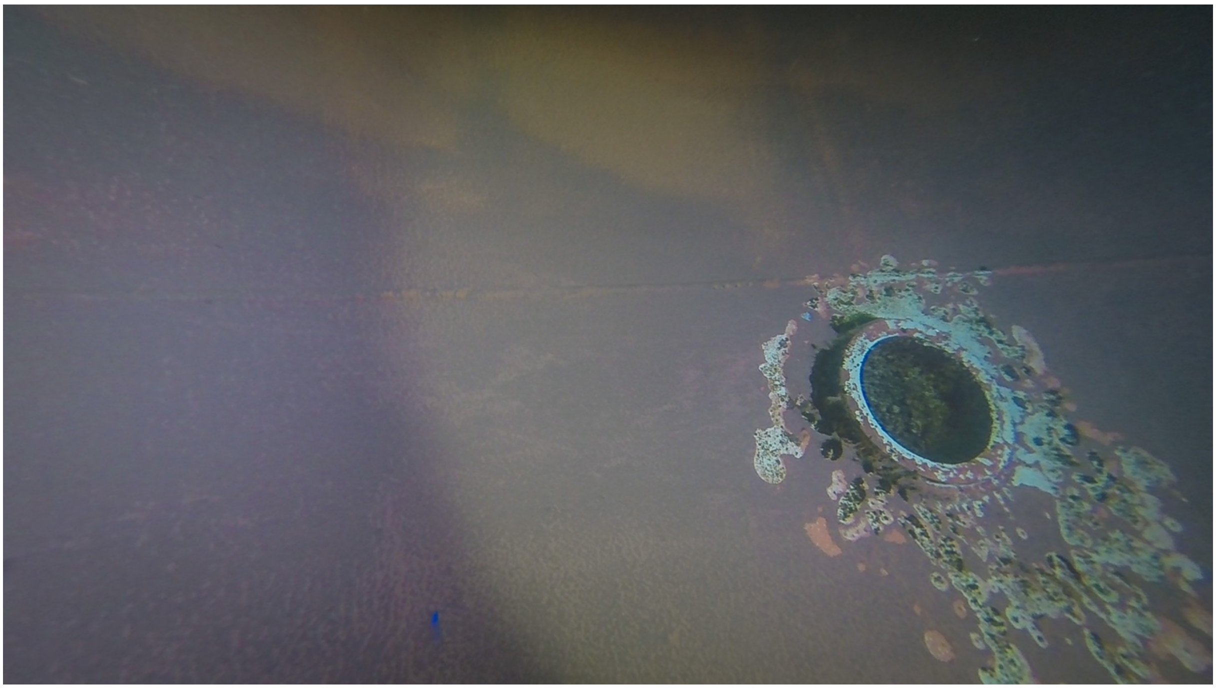


Figure 30c: Amadea *hull with fouling. Photo M. Palmgren 2015.*

National Geographic Explorer sailed from Antarctica via the West Indies before arriving in Svalbard. Again, no biofouling was detected, except a thin biofilm (Figure 31a-c). No sampling was possible with the available equipment.

Figure 31a: National Geographic Explorer *hull with fouling. Photo M. Palmgren 2015.*

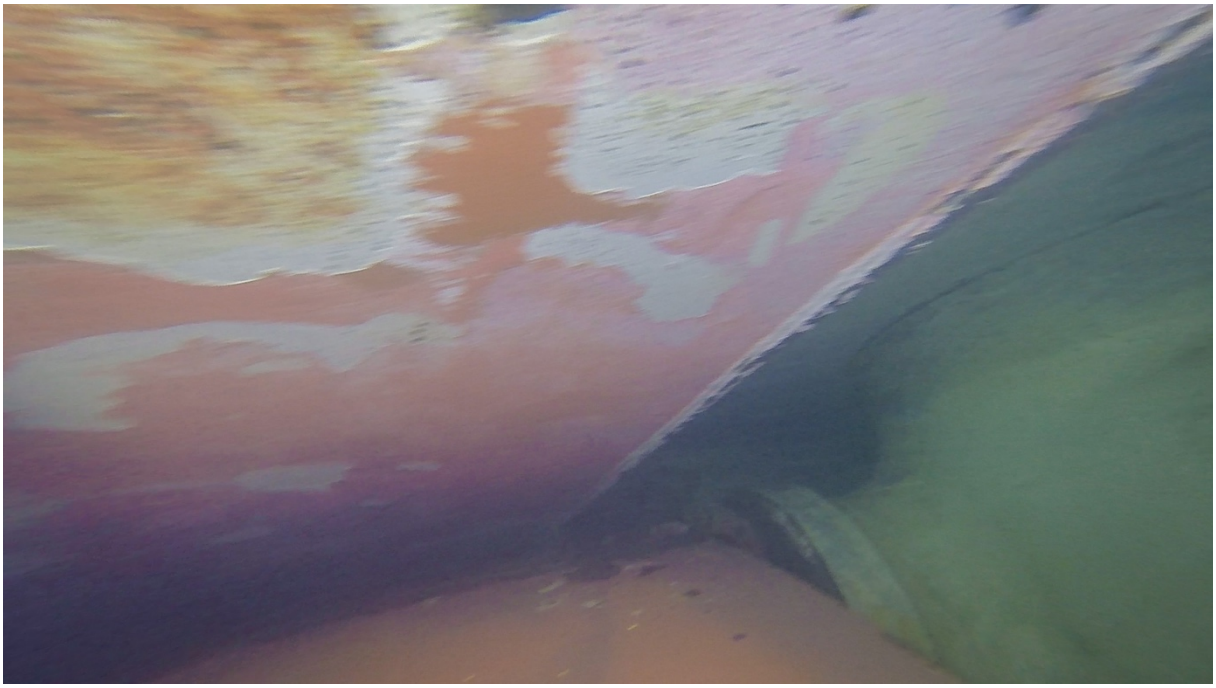


Figure 31b: National Geographic Explorer *hull with fouling. Photo M. Palmgren 2015.*

Figure 31c: National Geographic Explorer *rudder with fouling. Photo M. Palmgren 2015.*

Origo is the only vessel that was sampled in both 2014 and 2015. In 2015, it had just arrived from Sweden and was free from biofouling, except for smaller areas of a thin biofilm (Figure 32a-b). No sampling was possible with the available equipment.

Figure 32a: Origo *hull with fouling. Photo M. Palmgren 2015.*

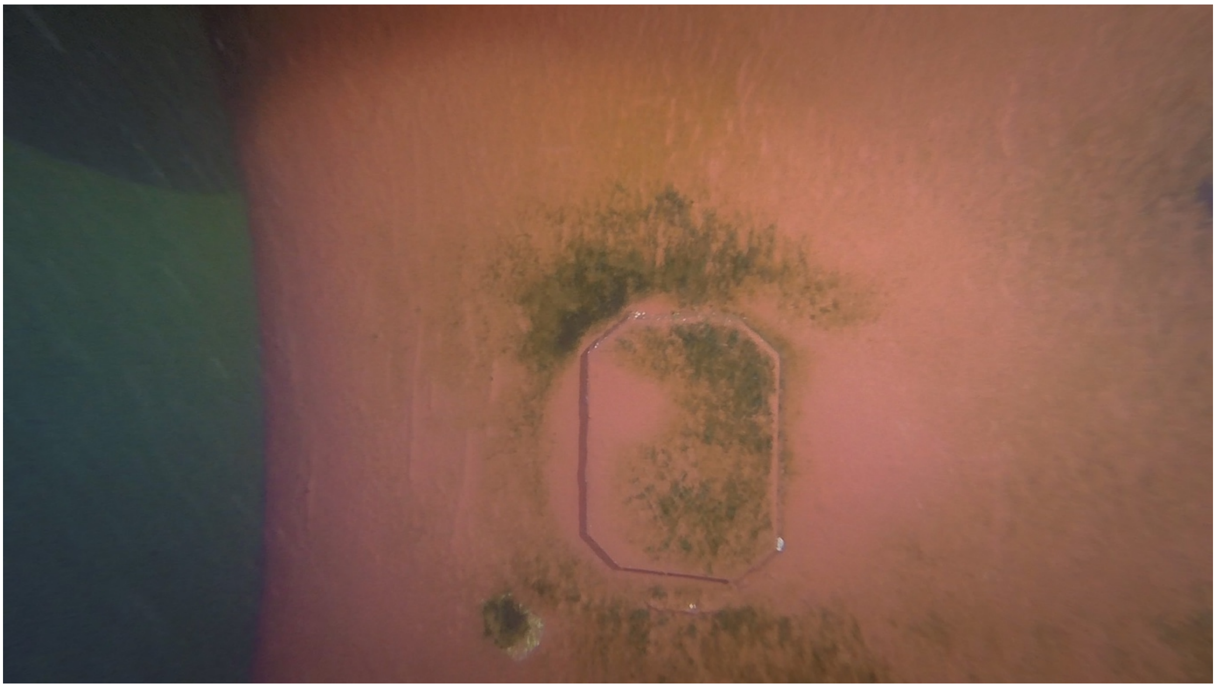


Figure 32b: Origo *hull with fouling. Photo M. Palmgren 2015.*

4.4.2.1. Virtue disc

During the Virtue disk study, the CD rack laid submerged from June to October 2015 (Figure 33).

Figure 33: Virtue disk placement. Photo by M. Palmgren 2015.

Researchers from UNIS assisted in retrieving the rack from Bykaia and ship it back to Sweden for further analysis. The analysis showed that there was no organic material on the disks and only sediment was found. Therefore, no conclusion about biofouling over summertime could be made.

4.5. Discussion

The analysis showed no significant difference in the fouling on different ships during the two sampling occasions. However, there were differences in the extent of fouling between the two sampling periods: the fouling was higher in September than in June, reflected in the denser growth of organisms. The likely explanation is that the growth period for most organisms (plants and invertebrates) is the summer period and the three months between the sampling periods meant that the fauna and flora had longer time to develop. The ships examined in June had not spent more than a few weeks in the waters of Svalbard and during the voyage to the Arctic the ships had passed through ice and ice slush, scraping off most of the biofouling attached to the hull of the ship. This was a known phenomenon among the skippers who all confirmed that the ice acts like sand paper, grinding away any biofouling attached to the ships hulls.

Virtue disks were used to record biofouling and were placed at one sampling site during the period June to October. No fouling was found on the disks. The likely explanation to this is the high volume of suspended sediments in the water during the period of deployment. This meant that any surface was covered with sediment which prevented algal growth and/or the settlement.

All species documented during sampling in the port of Longyearbyen in this study have been recorded previously during surveys of benthic flora and fauna on Svalbard, Bjørnøya, and Jan Mayen during the 1990s (Gruszczynski & Rózycki, 1994; Gulliksen, Palerud, Brattegard, & Sneli, 1999; Weslawski et al., 1993; 1997).

It is however interesting to follow the recent recolonisation of the common mussel (*Mytilus edulis*) on Svalbard. From research and studies of fossil records, it is concluded that the common mussel has not been present at Svalbard for the last 1,000 years (Lønne & Nemec, 2004; Salvigsen, 2002). During surveys in the 1990s, the first record of the common mussel was made on Bjørnøya, the island between Norway and Svalbard (Weslawski et al., 1997). In 2004, a scattered but viable population of common mussel was first discovered at the mouth of Isfjorden on Svalbard (Berge, Johnsen, Nilsen, Gulliksen, & Slagstad, 2005). Possible explanations for the reoccurrence are transportation by attachment to floating and drifting substrate, ship ballast water, or larvae drifting with ocean currents. It was concluded that the most likely way of transfer was mussel larvae originating from the coast of Norway and transported to the west coast of Svalbard with the relatively warm West Spitsbergen Current. However, this study found the common mussel in the port of Longyearbyen, on both the reference location Bykaia and on the hull of Norbjørn. The mussels may have transferred from the hull of ships docked to the berth to the sheet piles of the port. It can therefore not be excluded that common mussel can be introduced to the waters of Svalbard as biofouling on ship hulls. Further studies are needed to estimate the likelihood of larvae spreading to other coastal areas outside the port of Longyearbyen.

Several factors have to be considered when analysing the risks for an alien species spreading to new geographic areas, establishing, and expanding its population there, and becoming "invasive". For example, the number of individuals and the physiological condition of the species is critical. The geographical distances and the means by which the organisms are transported are also important parameters. If ships are the vectors, the effect of voyage length on the organism survival, the shipping network between ports, and how favourable the new environment is to the introduced species are important. However, the contribution of different variables and their interactions are poorly known (Fofonoff, Ruia, Stewens, & Carlton, 2003; Ruiz & Reid, 2007). A suggested method to estimate the risk of specific ships to be potential carriers of invasive species into areas or ports of interest, is to compare environmental conditions between the source and recipient ecosystems, as well as mapping the environmental conditions in ports and along shipping routes (Hayes & Barry, 2008; Keller et al., 2011). As the risk of harm from alien species is correlated to their ability to thrive in the new ecosystem, it is of importance to compare, environmental conditions in the port of arrival to conditions in origin and visited ports (Barry et al., 2008; Endresen et al., 2004). Salinity and temperature variations are suggested as environmental variables to examine, since salinity and temperature tolerance are known to be strong determinants of aquatic species range (Barry et al., 2008; Berezina, 2003; Hoek, 1982). Previous studies conclude that this mapping of environmental conditions and shipping networks between areas of interest give an opportunity to assess and categorize the risk of ships transporting potentially invasive species and based on such information be able to design a more efficient management strategy.

5. Conclusions of literature review and fouling study

The predictions of the changes in the Arctic due to invasions of new species and as an effect of climate change are highly variable and site specific. For invasions of alien species, human activities such as shipping are of critical importance. The present study has shown clear evidence of North Atlantic species spreading in the Svalbard area and shipping as the vector is a clear possibility although natural spreading due to warming may explain some of the recent observations. The impacts of climate change are obviously affected by currents, the depth conditions, and the influence from land runoff. In summary, the biological impacts of the changes in the Arctic Ocean are related to the warming and reduction of the sea ice as well as the northward spreading of Atlantic and Pacific Ocean species:

- The Arctic basins are likely to become more productive due to a shift from light limitation to nutrient limitation;
- From an anthropogenic perspective the fisheries productivity in the Arctic Ocean is likely to increase in the short to medium term;
- Changing sea ice and snow patterns will shift the primary production from ice algae to phytoplankton;
- As the sea ice withdraws, the availability of ice-associated zooplankton and other invertebrates will be affected, which will have an impact on the Arctic food chains where the polar cod is an essential link, providing critical feed for seabirds and marine mammals, as well as for the invasive Atlantic cod;
- Sub-Arctic species such as the common mussel, Atlantic cod, and herring will expand northward and compete with Arctic species. The decline in ice-associated species can already be observed.

Further, it can be concluded that the current trends of reductions of the sea ice is likely to result in extinction of Arctic endemic species, a loss that will represent biodiversity losses of global significance, and reverse millions of years of evolutionary change. The expansion of the northward range of sub-Arctic species in combination with the reduction of the sea ice is likely to fundamentally impact Arctic Ocean productivity and food webs:

- Due to the reduction in sea ice it is highly likely that reductions in the distribution and abundance will take place among seals and walrus;
- Pack-ice breeding seals will experience reproductive failures more frequently as their late winter/early spring breeding becomes affected, impacts that are already observed in the Atlantic sector of the Arctic;
- Polar bears are likely to become extirpated within 50 to 70 years over most of their present range.

- Arctic endemic whales will suffer from the change in the food webs, from competition with non-endemic migrant whales, and in some regions from the potential for increased predation from killer whales.

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7. Annex 1 – National experts

Dr. Colin Henein, Policy Adviser, Seaway and Domestic Shipping Policy, Marine Policy, Transport Canada

Mr. Jeffrey G. Lantz, United States Coast Guard, Director Commercial Regulations and Standards

Dr. Richard Everett, environmental protection specialist in the Environmental Standards Division, United States Coast Guard

Mrs. Karin Vedø, Senior Legal Advisor, Legislation and international relations, The Norwegian Maritime Directorate

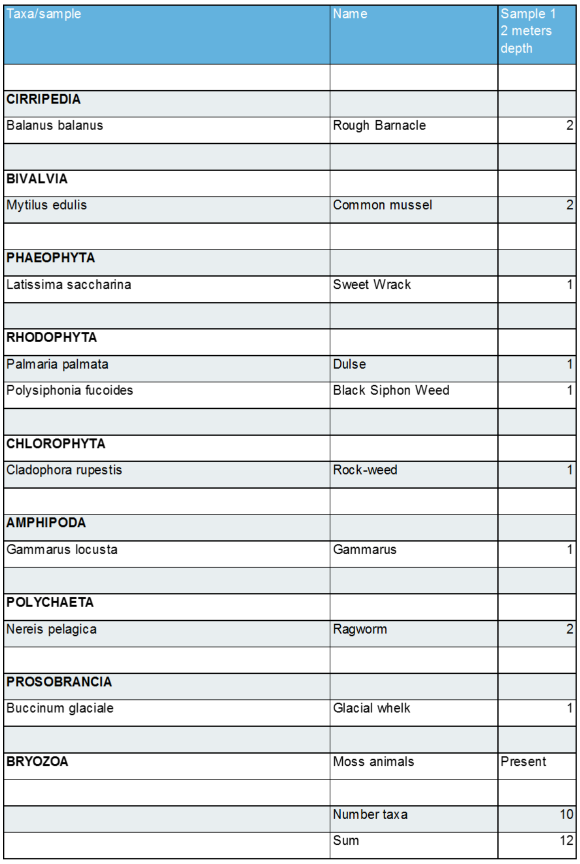
Mr. Turid Stemre, Senior Advisor, Norwegian Maritime Authority

Mr. Jens Olav Sæther, Vice Governor of Svalbard

Mrs. Anne Skov Strüver, Director, Maritime Regulation, Danish Maritime Authority

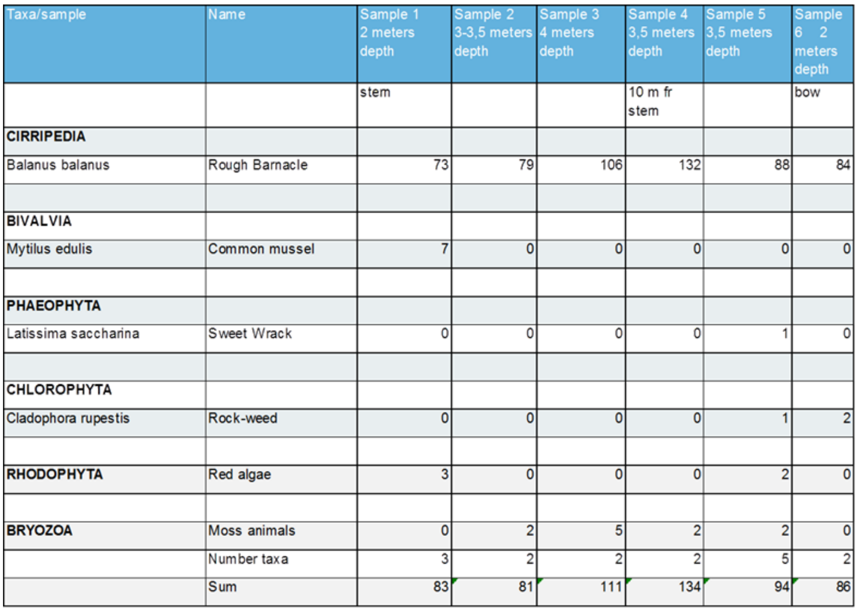
8. Annex 2 – Sampling results

Bykaia 14/9 -2014



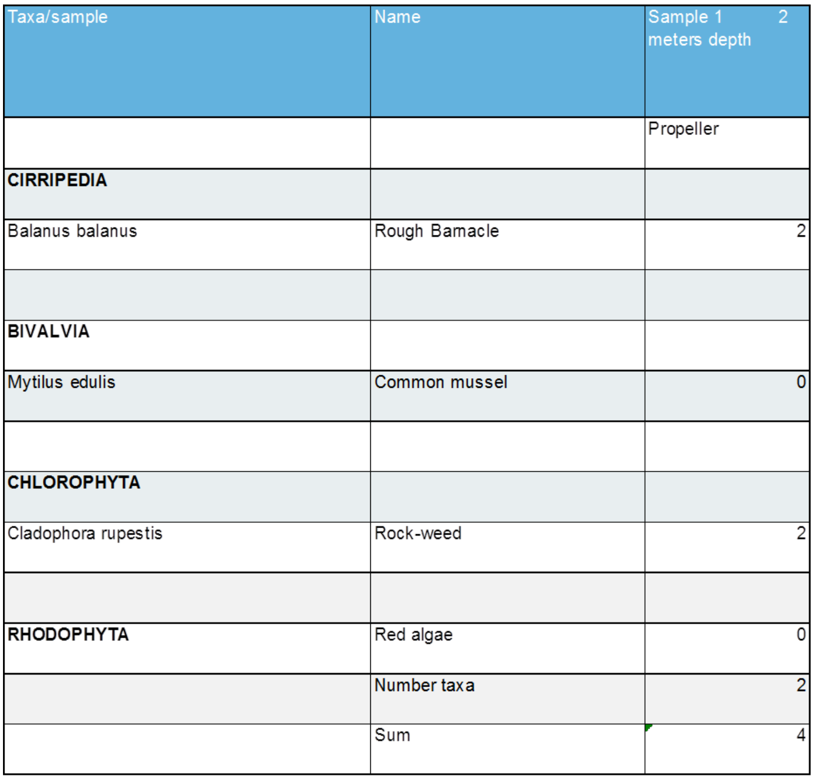
Taxa/sample	Name	Sample 1 2 meters depth
CIRRIPEDIA		
Balanus balanus	Rough Barnacle	2
BIVALVIA		
Mytilus edulis	Common mussel	2
PHAEOPHYTA		
Latissima saccharina	Sweet Wrack	1
RHODOPHYTA		
Palmaria palmata	Dulse	1
Polysiphonia fucoides	Black Siphon Weed	1
CHLOROPHYTA		
Cladophora rupestis	Rock-weed	1
AMPHIPODA		
Gammarus locusta	Gammarus	1
POLYCHAETA		
Nereis pelagica	Ragworm	2
PROSOBRANCIA		
Buccinum glaciale	Glacial whelk	1
BRYOZOA	Moss animals	Present
	Number taxa	10
	Sum	12

Norbjørn 16/9 -2014



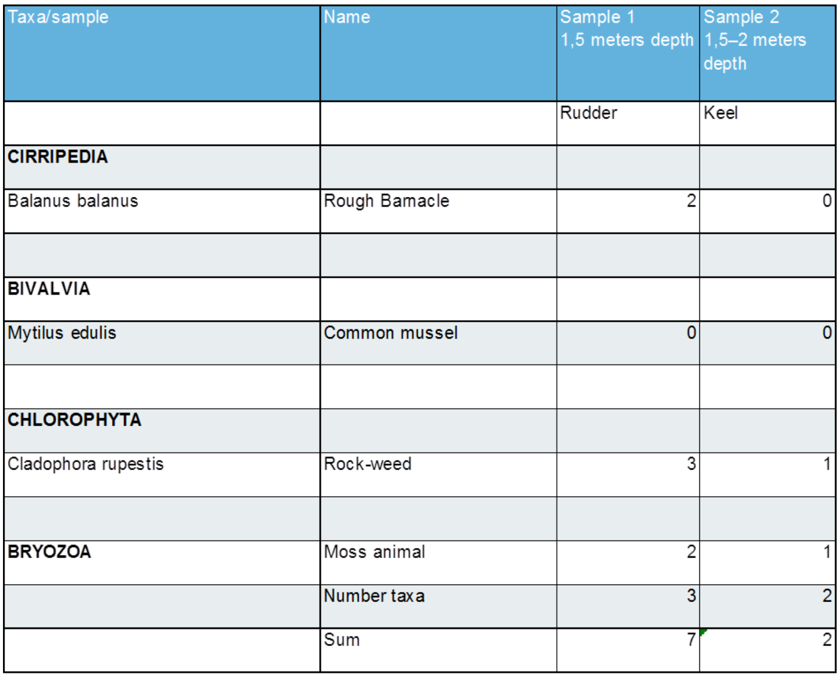
Taxa/sample	Name	Sample 1 2 meters depth	Sample 2 3-3,5 meters depth	Sample 3 4 meters depth	Sample 4 3,5 meters depth	Sample 5 3,5 meters depth	Sample 6 2 meters depth
		stem			10 m fr stem		bow
CIRRIPEDIA							
Balanus balanus	Rough Barnacle	73	79	106	132	88	84
BIVALVIA							
Mytilus edulis	Common mussel	7	0	0	0	0	0
PHAEOPHYTA							
Latissima saccharina	Sweet Wrack	0	0	0	0	1	0
CHLOROPHYTA							
Cladophora rupestis	Rock-weed	0	0	0	0	1	2
RHODOPHYTA	Red algae	3	0	0	0	2	0
BRYOZOA	Moss animals	0	2	5	2	2	0
	Number taxa	3	2	2	2	5	2
	Sum	83	81	111	134	94	86

Origo 12/9 - 2014



Taxa/sample	Name	Sample 1 2 meters depth
		Propeller
CIRRIPEDIA		
Balanus balanus	Rough Barnacle	2
BIVALVIA		
Mytilus edulis	Common mussel	0
CHLOROPHYTA		
Cladophora rupestis	Rock-weed	2
RHODOPHYTA	Red algae	0
	Number taxa	2
	Sum	4

Eltanin 12/9- 2014



Taxa/sample	Name	Sample 1 1,5 meters depth	Sample 2 1,5–2 meters depth
		Rudder	Keel
CIRRIPEDIA			
Balanus balanus	Rough Barnacle	2	0
BIVALVIA			
Mytilus edulis	Common mussel	0	0
CHLOROPHYTA			
Cladophora rupestis	Rock-weed	3	1
BRYOZOA	Moss animal	2	1
	Number taxa	3	2
	Sum	7	2