

Chapter 2

The Arctic Marine Environment

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Abstract The following sets the scene for subsequent chapters of this book: It presents a descriptive overview of the Arctic environment, demonstrating the scope of this term and highlighting unique environmental features of the circumpolar region, while focusing on the marine environment in general and the transatlantic region in particular. The global and regional threats for the Arctic environment are presented to establish a basic understanding of the evolving and increasing risks that this relatively pristine area encounters already, and those yet to come. Next to the primary global threat of climate change—bringing with it increasing sea ice loss, ocean acidification, thawing permafrost, and melting glaciers—developments in the areas of pollutants and chemicals, natural resources, shipping, fisheries, tourism, and military activities show increasing impacts on the Arctic environment.

2.1 Introduction

The Arctic is a vast, ice-covered ocean, surrounded by tree-less, frozen ground, that teems with life, including organisms living in the ice, fish and marine mammals, birds, land animals and human societies (NOAA 2012).

This quote by the United States (US) National Administration for Oceanic and Atmospheric Research (NOAA), describes the Arctic environment succinctly: The Arctic environment is unique. Additionally, distinctive and fragile Arctic ecosystems are increasingly threatened, but what exactly is at risk? What are these risks? And why does it matter?

This chapter is based on previous publications by Ecologic Institute within the Arctic TRANSFORM project and EU Arctic Footprint and Policy Assessment (Cavalieri et al. [2010](#)).

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The Arctic marine area is a place where local communities fight to maintain traditional livelihoods, as well as where the adjacent circumpolar states—and now others—have vested interests. Although the environmental conditions of the Arctic still exhibit extreme, and often challenging, variations in light and temperature, the quickly diminishing ice cover in the polar region is opening up new and increased opportunities for economic activities, particularly during extended periods of daylight in the long northern summers. This includes activities such as hydrocarbon exploration and development, shipping across the (at this time) two possible shipping transport routes (the Northern Sea Route and Northwest Passage), and the possibility of increased fisheries activity. As considered throughout this book, these developments should be tackled with governance approaches tailored to the region's particular requirements and environmental conditions.

Recent scientific assessments describing the regional Arctic landscapes and Arctic ecosystems¹ cover a level of detail that can be summarized only briefly within the limited scope of this chapter. Instead, the chapter's main focus is on setting the scene for the following discussions on governance by providing an overview of aspects to be taken into consideration when considering specific measures and programs in the Arctic. This includes a presentation of the Arctic environment that highlights circumpolar environmental features and the threats they are facing today, focusing on the marine environment, with its links to coastal areas and the mainland where relevant. The impacts on indigenous and other local communities are elaborated on in detail in [Chap. 4](#).

This chapter first gives a brief overview of relevant environmental aspects, with a focus on marine habitats, and highlights distinct geographical particularities within the Arctic region where appropriate ([Sect. 2.2](#)). It then turns towards the environmental challenges and threats the region face ([Sect. 2.3](#)). Finally, the conclusion ([Sect. 2.4](#)) stresses the most critical aspects presented.

2.2 The Arctic Environment

The marine and terrestrial area covered by the term 'Arctic' has been defined in several different ways. The Arctic Monitoring and Assessment Programme (AMAP) working group of the Arctic Council has conducted elaborate studies in the Arctic region and listed existing definitions of the Arctic using geographical, geophysical, and political definitions (AMAP 1998; see also [Chap. 1, Sect. 1.2](#)). AMAP's definition of the Arctic is based on the terrestrial and marine areas north of the Arctic Circle (at 66°32'N), with certain exceptions, namely the widening

¹ Including, *inter alia*, AOR 2011, summarizing existing Arctic Council assessments. See also AMAP 2011b and IASC et al. 2011. The most comprehensive overview yet will be provided in the upcoming Arctic Biodiversity Assessment (ABA) scientific report, to be completed in 2013, online at <<http://www.caff.is/aba>> . Accessed 31 Jan 2013.

of the area to 62°N in Asia and to 60°N in North America, thereby including the marine areas north of the Aleutian islands between Russia and the US, and the Canadian Hudson Bay, as well as parts of the North Atlantic Ocean, including the Labrador Sea.

The Arctic region therefore includes the Arctic Ocean basin, which is surrounded almost entirely by land masses, with straits towards the Atlantic and Pacific Oceans. Arctic coastal land is split within five states' jurisdictions. The largest Arctic Ocean coastal states are Russia and Canada, covering together around 9.5 million km² (about 70 %) of the Arctic land mass (AMAP 1998). The other regions, from east to west, are the Euro-Barents region (Norway), Greenland, Northern Canada, and the Bering region, including Alaska and the Pacific coast of Russia.

Biodiversity in the Arctic experiences threats from both inside and outside the region. Bird species, fish stocks, and marine mammals in the Arctic environment are not only linked with external systems by their migration patterns, but Arctic habitats are also affected by global ocean currents and pollution transport into the region (CAFF 2010; see also below Sect. 2.3.2). In return, the Arctic environment plays an important part in the biological, chemical, and physical balance of the planet (CAFF 2010, see also below Sect. 2.3.1).

2.2.1 Marine Environment

Nearly two thirds of the Arctic region is covered by ocean waters. These waters are an important part of the global climate system, due to their influence on deep ocean currents and global circulation of the oceans (ACIA 2005). Winds and precipitation also play an important role in mixing warmer waters from the south with colder Arctic waters; this may be subject to change in a warming climate. Arctic ecosystems depend on these interactions and can be highly vulnerable, although it has not been determined with full certainty how potential climatic changes will affect the Arctic environment or if they will lead to a net warming or cooling (ACIA 2005).

The Arctic Ocean provides for diverse habitats, on the surface as well as in the water column, and in open waters as well as in coastal areas. The last ice age and its glacier formations led to a loss in biodiversity that—in combination with extreme climate variability between seasons, sea ice coverage, little solar radiation, and constantly low water temperatures—has resulted in a unique and varied maritime ecosystem. The Arctic Council's PAME (Protection of the Arctic Marine Environment) working group has identified as many as 17 Large Marine Ecosystems (LMEs), described as large ocean areas sharing fundamental oceanographic characteristics (AOR 2011). From a geological point of view, marine ecosystems in the Arctic are rather young, and Arctic food webs can be characterized in a relatively simple structure: The marine food web in the Arctic is based on primary production of algae that is consumed by zooplankton, which is in turn eaten

by fish, which are consumed by seabirds and mammals, including humans (ACIA 2005). Despite its simplicity, the functioning of the food web is critically linked to timing. For instance, algal blooms are sensitive to temperature and sea ice retreat, with implications for the entire food web (ACIA 2005).

Box 2.1 The Arctic Ocean and global oceanic currents

The Arctic marine region includes the Arctic Ocean and the surrounding regional and shelf seas, thereby representing an area of approximately 20 million km² (AMAP 1998). The Arctic Ocean consists of two basins—Eurasian and Canadian, divided by the transpolar Lomonosov Ridge. The Arctic Ocean is connected to the Pacific Ocean via the Bering Strait between the US and Russia, and to the Atlantic Ocean via the Nordic Seas (Greenlandic Sea, Icelandic Sea, Norwegian Sea) to the East of Greenland and through Davis Strait and Hudson Strait to the West of Greenland.

Currents from both the Atlantic and Pacific Ocean bring water into Arctic waters—warmer waters from the North Atlantic Current via the Fram Strait and the Barents Sea, and comparatively cooler water via the Bering Strait. Due to the narrow and shallow access of the Pacific through the Bering Strait, most of the water in the Arctic ocean originates from the Atlantic, in a ratio of about 80:20 (AMAP 1998).

The Arctic Ocean's vertical water structure is also influenced by these different influxes: Its cold surface waters are divided into a Polar Mixed Layer with low salinity (down to 30–50 m of depth) and a water column of increasing temperature and rising salinity (halocline, down to 200 m of depth) which differs for the incoming Pacific and Atlantic waters. The halocline generally insulates the upper layers from the warmth stored in Atlantic waters in intermediate depths (200–900 m) and thereby also influences the sea ice cover. When the density of the incoming water masses increases (by temperature cooling and rising salinity), water sinks and flows back via the East Greenland Current and the Canadian Straits, in a ratio of about 75:25 (AMAP 1998).

On the ocean surface, sea ice is a dominant feature in the Arctic marine area (CAFF 2001). Almost half of the Arctic Ocean is covered by a permanent ice cap, which grows and shrinks seasonally with maximum cover in March and minimum cover in September (on changes and threats, see Sect. 2.3.1.1). Sea ice determines physical properties, such as exchange of heat between the atmosphere and ocean and light availability, and provides a unique habitat for Arctic species (ACIA 2005). Sympagic organisms live on or immediately below the sea ice and include primary and secondary species dependent on sea ice, with thicker sea ice supporting more complex sympagic communities. They support pelagic ecosystems in the water column in the open ocean, as well as benthic ecosystems on the ocean floor (Molenaar et al. 2008).

Ice algae develop during spring and throughout summer as light becomes available in the polar region. Polar cod, which provide a key link between zooplankton and marine mammals, live in both sea ice and pelagic environments. Nesting seabirds, such as ivory gulls, feed on polar cod and other small fish and zooplankton at the ice edge. Marine mammals, such as the polar bear, walrus, ringed and bearded seals among others, and also whales, such as narwhales, belugas, and bowhead whales, depend on the sea ice for food and survival (CAFF 2010).² In the water column and on the seabed, fish, crustaceans and—again—marine mammals also find their habitats, including Atlantic cod, haddock, Alaska pollock, Pacific cod, and the Arctic spider crab (ACIA 2005).

A variety of ocean depth levels adds regional diversification. In the Arctic region, extended continental shelves, particularly along the Russian coastline (see also Chap. 1 for the ongoing claims by circumpolar states) result in rather shallow coastal waters. Across the North Pole, on the other hand, deep sea plateaus are cut by oceanic rims, providing for an entirely different environment. Biodiversity is clustered in areas of higher productivity with warmer waters, especially in the Barents and Chukchi Seas and the Bering Shelf, which host migratory seabirds, marine mammals, and some of the most important fisheries in the world (ACIA 2005).

Within coastal seas, pelagic and benthic organisms together provide for a wealth of ecosystems. Coastal regions also provide shelter, food, and breeding grounds for birds and mammals alike. Some species, such as the common eider, are dependent on benthic organisms in shallow waters. As this seabird also breeds along a vast range of Arctic coastlines, including among others the Barents region, Iceland, both of Greenland's coasts, wide stretches of the Hudson Bay, the Canadian and US Beaufort sea's coasts, and the Bering strait region with the Aleutian islands—it has been used as an indicator of the health of marine of marine environments (CAFF 2010).

2.2.2 Land-Based Impacts on the Marine Environment

Arctic landscapes cover a wide range of topography from bare rock, mountains and glaciers to swamps, meadows, and lowland plains (CAFF 2010). Wetlands cover almost 70 % of land masses in the Arctic region, contribute significantly to freshwater cycles and the exchange of atmospheric gases, including climate forcers, and provide a habitat for many bird species on their migratory routes (CAFF 2010).

Freshwater ecosystems form an important part of Arctic geography and are directly linked with the marine, saltwater ecosystems of the Arctic Ocean. They also span a range of diverse environments. Even in areas with rather low precipitation, freshwater ecosystems can be found, for instance in Arctic lakes, and include

² See also indicator Number 10 of CAFF 2010 for more details on each of the mentioned species of "Arctic sea-ice ecosystems".

one of the largest freshwater reserves in the world, the Greenlandic ice shield (see below, [Sect. 2.3.1.2](#), for climate impacts on glaciers).

The Arctic region includes some of the largest rivers on the planet, leading an estimated 4,200 km³ of freshwater together with about 221 million tons of sediment into the Arctic Ocean (AMAP 1998). Inflow from rivers into the Arctic Ocean represents about 2 % of the overall inflow, which is comparatively more than in other oceans (AMAP 1998).

Inputs by several large river systems, such as the Lena, Ob, and Yenisei in the Russian Arctic also provide pathways for pollutants to enter the Arctic Ocean (see [Sect. 2.3.2](#)).

Box 2.2 Biodiversity links between Arctic marine and land environments

Biodiversity thrives in the delta regions of these rivers, as they offer a range of various specific habitats. It is important to note that the marine environment is not entirely distinct from the terrestrial environment, as marine mammals, seabirds, and humans are dependent on both for their survival (ACIA 2005). Several species, including Atlantic salmon and some populations of polar bears (CAFF 2001), are specialized in migration between land/freshwater and oceanic habitats, for breeding and hunting grounds respectively, thereby linking the Arctic marine environment to land-based impacts, such as pollution.

2.3 Specific Threats

The Arctic environment suffers from a range of developments and human activities with increasingly adverse impacts. From a perspective directed towards managing these activities, it is beneficial to identify their respective origins and to classify them accordingly.

- From a global perspective (external), there are two broad areas in particular that exhibit Arctic-specific outcomes: climate change and chemical pollution.
- Focusing on the Arctic region itself (internal), there are five areas and activities that show prospects of rising impacts on the Arctic (marine) environment: natural resources, shipping, fisheries, tourism, and military activities.

2.3.1 Climate Change

The most overarching development with severe impacts on the Arctic environment is global climate change. The direct effects of climate change, as well as secondary effects from the increased use of Arctic marine resources, will significantly

impact marine systems. Of the numerous risks to the Arctic environment that climate change presents, four particular environmental changes are highlighted here:

- Reduction of sea ice extent, thickness, and distribution,
- Melting of glaciers,
- Thawing of permafrost soil, and
- Ocean acidification

Warming in the Arctic is linked to global increases of greenhouse gas emissions from anthropogenic sources, which increased by 70 % between 1970 and 2004. Atmospheric carbon dioxide (CO₂) concentrations showed an increase of 35 % since the industrial revolution, while atmospheric methane concentrations more than doubled over that time (IPCC 2007a). Hence, anthropogenic sources account for greenhouse gas levels that by 2005 already exceeded the natural range of the past 650,000 years (IPCC 2007b).

As stated in the 2007 IPCC (Intergovernmental Panel on Climate Change) Fourth Assessment Report (AR4), climate change impacts in the polar regions over the next 100 years “will exceed the impacts for many other regions and will produce feedbacks that will have globally significant consequences”. However, precise estimates and detailed understanding of the nature and extent of these impacts are still difficult to predict (IPCC 2007b). Models predict general warming in the Arctic with temperature increases ranging from about 3 °C to 6 °C by 2080, even using scenarios in which greenhouse gas emissions are projected to be lower than they have been for the past ten years (AMAP 2011a).

Box 2.3 Climate change and biodiversity

Species which are specially adapted to the harsh conditions of the Arctic region may suddenly find themselves competing with invasive species, where newly warmed Arctic waters create more widely habitable ecosystems. Changes in migration times and routes of birds and ocean mammals may occur, due both to warming and anthropogenic interference. Invasive parasites and pests can threaten both plant and animal populations (ACIA 2005). Such secondary effects of climate change will add stress on Arctic marine biodiversity.

Sea Ice Reduction

September sea ice extent has been declining during the period of 1979–2010 by an average of 11.5 % per decade (NSIDC 2010). Reduced Arctic sea ice extent, especially during the summer months, will rapidly alter the quality of the entire sea ice ecosystem and is expected to impact the entire Arctic marine food web. Sea ice is an important habitat for many Arctic species, including marine mammals such as polar bears, ringed seals, bowhead whales, belugas, and narwhals (AMAP 2011a; see also Sect. 2.2.1).

Ice-dependent species—both land and sea species—are expected to follow the ice edge as it melts and moves further north; however, the abundance of these species is expected to decline due to the rapid shifts in marine conditions (AMAP 2011a). Walrus are also directly threatened by sea ice loss, as the ice provides additional breeding grounds which are reduced and crowded spaces on the coast provide neither a place to raise young, nor sufficient food sources (Reimnitz et al. 1994).

However, it is important to note that some species, especially commercial fish (e.g., cod and herring in the North Atlantic and walleye pollock in the Bering Sea), are expected to benefit from increases of open water leading to increased productivity (Molenaar et al. 2008).

Seasonally occurring changes in the ice coverage of the Arctic region have become increasingly extreme in recent years as compared to available data in the earlier 20th century. The past decade is the warmest on record for global surface air temperature with some Arctic regions growing warmer at an even faster pace (IASC et al. 2011).

Shortly after the IPCC stated in its 2007 report that the Arctic could become ice-free in a business-as-usual scenario around the year 2100, Arctic sea ice extent fell far below these modelled estimates. The summer of 2012 brought the latest record of minimal sea ice extent (and thickness) in the Arctic after an already all-time low in recorded history in 2007: On 26 August 2012, the 5-day running average for Arctic sea ice extent was measured with 4.1 million km², almost 1.7 % (or 70,000 km²) less than in September 2007, with the monthly average of 4.72 million km² about 38 % (or 2.94 million km²) less compared to the 1979–2000 average (NSIDC 2012). The extent remained below the 2007 minimum for a total of 40 days (Fig. 2.1).

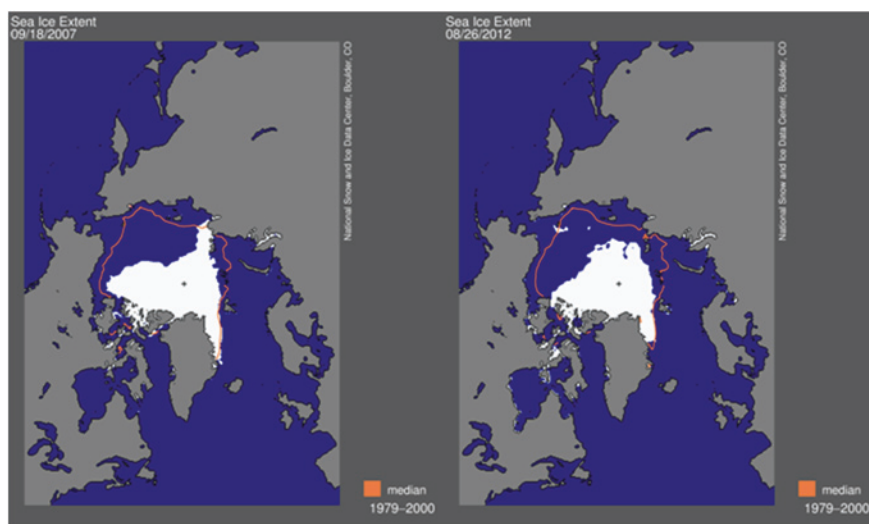


Fig. 2.1 Arctic sea ice extent minima 2007 and 2012 (NSIDC 2012)

Box 2.3 Local warming—the albedo effect

One of the feedback loops identified in relation to Arctic sea ice is the so called albedo effect. It is rooted in the principle that darker surfaces absorb more energy than brighter ones. As sea ice melts, reduction in albedo will likely create a positive feedback effect leading to further global warming (IPCC 2007b): With the opening up of areas in the Arctic Ocean through loss of sea ice cover, the amount of solar radiation absorbed rises, heating up the ocean even more. The higher surface temperatures contribute to further ice melt and slow the growth of new sea ice.

Another albedo-related threat is black carbon. Formed by the incomplete combustion of fossil fuels, biofuels, and biomass—mostly originating outside of the Arctic region—black carbon is a particulate matter with an extent less than 2.5 μm (micrometer) that is emitted into the atmosphere. Its consistency allows it to absorb light, darken surfaces, and thereby increase radiative forcing up to 0.9 W/m^2 , second only to CO_2 with an estimated 1.66 W/m^2 (IPCC 2007b; SLCF Task Force 2011). Together with other pollutants that similarly have a powerful, but short-lived climate warming influence, such as tropospheric ozone and the powerful greenhouse gas methane, black carbon is defined as a ‘short-lived climate pollutant’ (SLCP).

In addition to effects from ice melt and increasing heat absorption, the above-average warming of the atmosphere over the Arctic region can be traced back to other particularities. In contrast to the tropics, for instance, a greater proportion of radiant energy warms the atmosphere above the Arctic, and the Arctic atmospheric layer is shallower (ACIA 2005).

Shrinking sea ice extent also coincides with the loss of ice volume and the loss of multi-year ice (NSIDC 2012). Thin ice melts more rapidly, indicating that the rate of sea ice melt is likely to continue to increase as sea ice continues to become thinner and thicker multi-year ice vanishes (AMAP 2011a). In addition to altering sea ice ecosystems, this ongoing ice loss has the potential to bring dramatic changes to coastal areas. As closed ice cover leads to a degree of protection of coastal lines, these areas will become vulnerable to increasing erosion by waves and storms from open water. A recent study found an average erosion rate of 0.5 m per year for over 60,000 km of sampled coast lines along the Arctic Ocean (Lantuit et al. 2012), with most segments from the Laptev Sea and the Eastern Siberian Sea, followed by the US and Canadian Beaufort Sea. While 89.2 % of the sampled segments (regardless of length) showed erosion rates between 0 and 2 m per year, about 3 % of the length coast lines were found to have a coastal erosion of over 3 m per year. (Lantuit et al. 2012).

Melting Glaciers and Rising Sea Levels

Another impact of climate change observed in recent years is the increasing melt of glaciers, particularly in Greenland. In contrast to sea ice melt, the melt of

glacier-bound ice masses contributes to rising sea levels and impacts marine environments by altering the salinity of Arctic waters.

Over 80 % of Greenland's land mass is covered by enormous glaciers with ice sheets as thick as 2–3 km (AMAP 2011a). Average annual ice net mass loss was recently estimated for the years 2005 to 2006 to amount to around 200 (± 50) billion tons (AMAP 2011a). In the summer of 2012, satellite imagery showed that more than 97 % of Greenlandic glacier surfaces had begun melting, the largest extent of surface melting observed in three decades of satellite observations.³ Continued warming will lead to even further melt, although it is as yet unclear to what extent and how fast this will occur. Estimates suggests that total melt of the Greenlandic ice sheet would lead to a potential global sea level rise of 7.5 m (AMAP 2011a).

Rising sea levels can have severe impacts on coastlines and their inhabitants. For land-based species, such as sea birds and marine mammals that rely on bordering marine environments, coastal abrasion by increased erosive forces can lead to the loss of unique breeding spots and feeding grounds (IASC et al. 2011).

There is also concern that significant freshening could impact the thermohaline circulation of the world's oceans, which is a major driver of global weather patterns (IPCC 2007c). With regard to more immediate threats, the freshening of surface layers of the Arctic Ocean could lead to significant changes in the delivery and cycling of nutrients of surface waters, thereby influencing the amount and type of primary production (AMAP 2011a). Sensitive species, such as Greenland Halibut, react to changing salinity conditions in the water by moving their habitat to shelf areas (AMAP 2011a).

Greenhouse Gas Release by Melting Permafrost

In addition to the effects of global warming on oceanic conditions and marine environments, a major feedback loop could be triggered by climate change in land and marine environments. Apart from large areas of land being covered by glaciers (primarily in Greenland and Canada), the upper layer of most land masses of the circumpolar Arctic consists of permafrost—in existing climate conditions, this permanently frozen ground⁴ can go as deep as 1,000 m. Permafrost soils provide a generally stable surface that is being used by land animals and birds (as breeding grounds) alike, and have enabled local communities to build necessary infrastructure and housing. It is not limited to upper layers of land but also exists in seabed formations, with the largest hydrate formation under the surface deemed to be on the East Siberian Shelf (AMAP 2011a).

The total coastline affected by permafrost in the northern hemisphere amounts to 407,680 km, thereby representing about 34 % of the world's coastline (Lantuit

³ For images, see NASA Earth Observatory 2012a. Also, in July 2012, a piece of an estimated 120 ± 5 km² broke off the Petermann glacier in North-West Greenland that connects the Greenland ice shield with the Arctic Ocean (NASA Earth Observatory 2012b).

⁴ The Permafrost Subcommittee of the National Research Council of Canada has established a definition that includes “ground (soil or rock and included ice and organic material) that remains at or below 0°C for at least two consecutive years” (National Research Council of Canada 1988).

et al. 2012). About two thirds of Arctic coastlines consist of permafrost grounds (IASC et al. 2011). These are particularly vulnerable to coastal erosion which is of growing concern due to the decreasing ice coverage of Arctic waters, as highlighted above. In addition, climate change has already brought temperatures at the top of the permafrost layer up by approximately 3 °C since 1980, decreasing the maximum area of frozen ground in the Northern Hemisphere by 7 % since 1900 (IPCC 2007a). The remaining total area in the Northern hemisphere covered by permafrost is estimated to amount to 18.8 million km² (Schuur and Abbott 2011).

These increasing temperatures on Arctic land masses have already had severe impacts on living conditions for fauna and flora: Warmer temperatures generally resulted in more greening of land and a shift of habitats of flora towards northern environments, including shrubs and other plants. Reduced permafrost also results in more Arctic wetlands, which release carbon and methane previously contained in the frozen soil into the atmosphere. As regional studies found, the effect of greening Arctic landscapes with greater photosynthetic activity and carbon uptake can offset these releases temporarily, but not completely (AMAP 2011a). Thawing permafrost can also cause an initial expansion of surrounding lakes and groundwater, followed by drainage and disappearance of lakes, which has been detected in Alaska and Siberia (IPCC 2007a).

With regard to the human dimension, thawing permafrost with its consequences for the consistency of the grounds can ultimately lead to the destabilization of building sites and have significant impacts on the coastal lines along the circumpolar shores as well as for indigenous and other local communities (see Chap. 4 for further detail). Permafrost has also sometimes been used as a natural insulation for landfills and containment holding facilities; thawing could now lead to a contamination of ground water and large clean-up costs (IPCC 2007c).

However, the impact of global warming on these frozen grounds goes even beyond the necessity of climate adaptation for communities, as it also releases previously bound carbon compounds, such as carbon dioxide and methane into the air. To stress the importance and possible impact of this reaction: Due to the vast amount of permafrost coverage (see numbers above), it is estimated that worldwide about 1,700 gigatons of carbon are bound in permafrost deposits (Schuur and Abbott 2011)—a number put into perspective by the world's largest emitter's (China's) numbers from 2010, about 7.285 gigatons of CO₂ emitted from fuel combustion (IEA 2012). While current annual emissions from the ice complex along the Siberian coastline, for instance, are estimated at 44 (±10) megatons of carbon (Vonk et al. 2012), the ever faster cycle of permafrost thawing and subsequent release of stored greenhouse gases is feared to potentially lead towards a climate change 'tipping point', greatly accelerating planetary warming.

Ocean Acidification

The most direct impact of climate change on the Arctic marine environment is caused by acidification. Ocean acidification results from a gas exchange between

the oceans and atmosphere, whereby CO₂ dissolves in the water and decreases its pH level. Generally, oceans serve as a sink for CO₂, but increased anthropogenic atmospheric CO₂ concentrations have already led to a higher rate and scope of ocean acidification. This is of particular importance to the Arctic Ocean, since CO₂ is more soluble in cold water. Thus, due to its low water temperature, the Arctic Ocean faces more rapid rates of increasing acidification by absorbing more carbon dioxide than other oceans do (Robbins 2012).

Ocean acidification can lead to a reduction in the diversity and abundance of calcareous organisms, an important marine food source, and thereby affect the rest of the Arctic food chain (CAFF 2010). A combination of the aforementioned effects of climate change further increases the acidification process: The melting of sea ice exposes greater areas of the Arctic Ocean to the atmosphere, and fresh-water entering the Arctic Ocean from melting glaciers increases the ocean's potential for CO₂ dissolution, while decreasing its buffering ability.

2.3.2 Chemicals and Air Pollution

Another global threat to the Arctic environment stems from a complex system of interdependencies within air and ocean currents as well as meteorological particularities. The Arctic region has proven to be a sink for pollutants from around the globe, due to its atmospheric conditions: Low air, ground, and water temperatures have a severe impact on the reactivity of chemicals. Once transported into the region—be it via pathways in the air or the ocean, or by riverine discharge—chemicals remain largely in place. The breakdown of chemicals in the Arctic region is slowed down by low temperatures and limited solar radiant. This poses a threat for animals and human beings alike. Accumulation of chemicals over time and rising through the food chain can increase to toxic levels, threatening large predators such as polar bears as well as local communities living on a subsistence lifestyle.

Several kinds of contaminants arrive in the Arctic environment from around the globe. For instance, persistent organic pollutants (POPs) and heavy metals (e.g., mercury) are mainly produced in warmer climates, volatilise, and then spread to the Arctic region through wind, water, and migratory species.

Box 2.4 Transport of contaminants into the Arctic

Air transport is a fast pathway for volatile contaminants and for contaminants that attach to particles. Patterns tend to favour transport of air masses from polluted regions in Europe and Asia during winter months.

Ocean currents continuously exchange water masses from the Arctic Ocean with Atlantic and Pacific waters. Declining ice coverage is likely to

cause the Arctic Ocean to emit trapped contaminants back to the atmosphere and increases chemical exchange with the air.

Riverine inputs can also contribute significantly to the flow of pollutants into the Arctic Ocean. Russian rivers lead into Arctic regional seas, including 500,000 t of oil/oily substances every year. The Russian rivers Lena and Ob have carried higher amounts of mercury into the marine environment than atmospheric fluxes (Fisher et al. 2012).

Some non-volatile POPs, including brominated flame retardants (BFRs) for instance, are transported on other particles and thus rely on their transport processes to reach the Arctic. Once in the region, POPs then bio-accumulate in the Arctic marine food web, including humans, and can be stored in layers of ice and permafrost. The latter can lead to so-called secondary emissions, as further melting or thawing could release the POPs now locked in sea ice directly into the food chain (ACIA 2005). For some compounds, such as PCBs and mercury, the levels in some groups of people and wildlife populations are high enough to cause concern about health effects (AMAP 2011b).

Impacts on the environment from contaminants can be severe, as POPs and heavy metals include a number of anthropogenic and natural substances that are toxic to humans and animals under certain circumstances. Populations and ecosystems often experience the impact of several stressors at the same time, which can increase their vulnerability towards them (AMAP 2009).

Climate change is likely to affect both sources and pathways of POPs and mercury through changes in wind patterns or ocean currents and precipitation. Permafrost and glacier melt may also result in higher re-emissions of mercury and other contaminants. However, it is difficult to predict whether long-term climate change will lead to generally increased or decreased loads, as there are processes working in both directions. In terms of affecting long-term levels of and impacts from contaminants in the Arctic, anthropogenic emissions of greenhouse gases may become as important as emissions of the contaminants themselves (AMAP 2004).

Other forms of transboundary air pollution contribute to Arctic haze, a reddish-brown fog in the lower atmosphere at high northern latitudes. It is caused by a mixture of sulphate, black carbon, nitrogen oxides (NO_x), sulphur dioxide (SO₂) and other contaminants. These aerosol particles provide a transport pathway for pollution into the Arctic and can also contribute to climate change (ACIA 2005). Black carbon, for example, reduces the albedo of Arctic snow and ice and accelerates warming (see also Sect. 2.3.1 on black carbon).

Industry in and around the Arctic also contributes to acidification and contamination, especially locally. This includes severely contaminated areas with major forest damage around the copper-nickel smelters on the Kola Peninsula and at Norilsk in Siberia (EEA 2007). Highly acidified soils are not able to support plant life.

Box 2.5 Origins of contaminants

Many POPs have been produced for technical applications (e.g., PCBs, BFRs, organic pesticides, PFOs) or are created when the technical products break down (e.g., DDE from DDT). Others are by-products in production of technical products or in various combustion processes (e.g., dioxins and furans).

Mercury and other heavy metals are released via mining, metal processing, or through the respective products. Mercury is also mobilized through coal combustion and also occurs naturally. Re-emissions account for about one third of emissions to the atmosphere and are hard to distinguish from natural sources (e.g., mercury released in forest fires).

2.3.3 Fisheries

The increasing relevance of fisheries activities for the Arctic environment is an indirect impact that can be attributed to climate change. It can be broken down into two aspects:

- Following declining sea ice coverage, Arctic waters provide larger areas for fishing vessels that can also be accessed during longer periods of the season.
- Increasing water temperatures shift inherent temperature gradients for certain species, allowing some to move their habitats further north,⁵ but forcing other species to migrate into colder regions or threaten them to become extinct.

These shifts over time add urgency to existing problems in the Arctic marine environment, such as overfishing. Albeit providing only a mere 2.6 % of global fish catches (Rudloff 2012), Arctic fish stocks provide for a substantial part of the European Union (EU)'s supply: For instance, for Norwegian and Icelandic fisheries, the EU was by far the major export destination with 80 and 60 % of fish catches respectively (Rudloff 2012).

The negative impacts of overfishing are numerous. Overfishing can reduce the size of the stock not only temporarily, but can also distort its age structure, for instance by reducing the number of adult fish to an extent which threatens the longer term viability of a stock. As a result of continuously unsustainable quotas or non-compliance with existing quotas by illegal, unregulated, and unreported (IUU) fisheries, stocks of North American cod and Alaska pollock in the Central Bering Sea faced depletion already in the early 1990s (Burnett et al. 2008). More recent data shows that more than half of the Northeast Atlantic regional stocks of cod, haddock, whiting, and saithe are threatened with collapse (UNEP 2005).

⁵ See, for instance, how the increase in mackerel stocks' abundance rapidly increased Icelandic catches of this species from 2005 on (European Commission 2012). Following the increase of Icelandic quotas, the EU is considering sanctions on Icelandic fishing boats (so called "Mackerel Wars"). See recently Davies 2013.

Apart from impacts to respective fisheries industries, collapsing fish stocks may also have enormous consequences for the Arctic marine environment, the species and ecosystems of which are delicately balanced. Food chains in Arctic ecosystems are usually very simple. Hence, a disruption of a single link in the food chain—for instance, by over-exploitation of stocks—could severely affect the rest of the system. The aforementioned impacts on water temperatures could, however, also lead to beneficial results: Moderate temperature increases are likely to benefit some commercial fish stocks that are currently threatened as well as increase habitat for some species such as cod and herring (IPCC 2007c).

The overall net effect on Arctic fish stocks and commercial fisheries is still uncertain. For one thing, practical approaches for the integrated management of fisheries and the adaptation of management structures will play a role as the effects of climate change continue to emerge (ACIA 2005). Possible conflicts with regional fisheries in the Arctic could arise from the mere physical interference with or from environmental contaminants caused by economic activities, such as transportation and the exploration and exploitation of natural (offshore) resources.

2.3.4 Shipping

The risks from increased shipping in the Arctic region may be considered as indirect effects of climate change. Traditionally, shipping in harsh Arctic conditions and weather (including limited visibility and navigation, sea ice coverage, and a lack of natural light), has been limited to supply vessels for regional settlements, as well as research and fishing vessels in some areas.

Recent developments, however, show several factors that already lead to increased shipping activities in the circumpolar region:

- Sea ice loss (making routes open longer/shipping safer) makes transports economically more viable
- Exploration and development of (offshore) natural resources entails an increase in traffic to support build up and continuing supply
- Fish stocks migrating north (see above) requires more fishing vessels in the Arctic

The economic implications of these developments are of interest to all Arctic coastal states (AMSA 2009). Reductions in sea ice already allow increased shipping within the Arctic marine area, opening up potential routes and widening the time frame available for shipping along them. The historically inaccessible Northwest Passage, for instance, was for the first time in history navigable in 2007 (ESA 2007), and the seasonally accessible Northern Sea Route, was open for five months in 2011 (Corell et al. 2012). After 34 vessels along the Northern Sea Route in 2011, 2012 saw the highest number of 46 vessels—with over 1.25 million tons

of cargo transported a more than 50 % increase compared to the previous year (Barents Observer 2012).

With ongoing exploration and exploitation activities in the sector of offshore hydrocarbon resources (see also Sect. 2.3.5), the supply of drilling wells and their maintenance goes hand-in-hand with increased shipping activities by drilling vessels and support barges.

Finally, increasing water temperatures lead to a shift in natural barriers for migratory fish stocks (see Sect. 2.3.3). Following these stocks, fishing vessels will also need to use Arctic waters more frequently and/or for extended periods of time—due to increasing accessibility.

The expected future impacts of increased shipping activities on the Arctic marine environment can be narrowed down to three major influences:

- Operational spills and discharges,
- Accidental spills and discharges, and
- Impacts on marine mammals (including noise)

Increased use of Arctic sea routes is most likely to have positive impacts on shipping, but is yet limited by high operational costs (e.g., due to the need for ice-breakers) and other hurdles mentioned above. However, the shipbuilding industry in participating countries could benefit from an increase in demand. On the other hand, the overall increase in traffic holds significant risks for the environment, not only during general operations, but also in the case of accidents or other emergencies (Brigham 2011).

Emergencies can quickly occur in the extreme environments of most Arctic regions throughout the year. The weather and oceanic conditions in the Arctic are generally harsh and difficult to account for. Depending on the season, few hours of daylight may be available—if any—and in areas of broken sea ice coverage larger pieces of floating ice can pose a threat to ships with low or no polar class level constructions. In addition to darkness and climatic conditions, the distances from coastal installations not only make search and rescue operations much more difficult to conduct, but also make clean-up challenging in the case of a spill (AMSA 2009).

Similar conditions, however, can result in different viabilities for shipping routes in Arctic waters: For instance, the scattered Canadian Arctic Archipelago covers a distance of about 2,400 km and leads to several possible “Northwest Passages”, the use of which is heavily dependent not only on weather and ice conditions, but also on the respective ship’s draft.⁶ The Russian regional shelf seas—from the Russian border with the US to Norwegian territory—the Chukchi Sea, the East Siberian Sea, the Laptev Sea, the Kara Sea, and the Barents Sea are characterized in their respective coastal areas by rather shallow water depths, being in between 58 m (East Siberian Sea) and 578 m (Laptev Sea at its northern limit)

⁶ PAME (2009).

only (AMSA 2009), which influences biodiversity as well as use for shipping activities along the Northern Sea Route.

Recent findings suggest that in the near future (up to 2020), only the Northern Sea Route is expected to become a viable trans-Arctic route, influencing the Bering Strait Region as well. However, an increase in supply traffic is also expected in Canadian Northern Communities (AMSA 2009).

Shipping along these routes has impacts on Arctic marine, air, and coastal environments. It is expected to negatively impact migratory marine mammals that use these routes, as well as increase the risk of oil spills (ACIA 2005). Shipping also contributes to the degradation of air quality from the release of carbon monoxide, nitric oxide, and other chemical substances from ships' combustion engines (Granier et al. 2006). During summer months, surface ozone concentrations in the Arctic could be enhanced by two or three times in the next decades as a result of ship operations through the northern passages (Granier et al. 2006).

2.3.5 Oil and Gas Extraction

Parts of the Arctic environment also face threats from future exploratory drilling for and exploitation of oil and gas resources. According to a much cited US Geological Survey study, approximately 13 % of the world's undiscovered oil resources, 30 % of the world's undiscovered gas resources, and 20 % of undiscovered natural gas liquids are estimated to be located in Arctic region, about 84 % of which are located offshore (Gautier et al. 2008). Direct environmental impacts in the Arctic from energy extraction, including drilling, infrastructure development, and possible accidents, pose a number of threats to ecosystems and communities. Oil pollution poses a particular threat to the fragile Arctic marine environment, which recovers slowly due to low temperatures. Natural recovery from spills is slower due to shorter growing seasons and slower growth rates.

Generally, risks can be grouped into:

- Operational risks, such as discharges and emissions from drilling platforms and transport vessels alike, and
- Accidental risks, such as oil spills

Although many remote onshore sites in Arctic regions are—just like offshore sites—dependent on sea routes for supply and transportation, (exploratory and production) offshore drilling itself can have a much bigger impact on marine habitats. The biggest threats from offshore hydrocarbon exploitation to the Arctic marine area are related primarily to accidental risks such as oil spills.

Oil spills can occur during oil extraction, storage, or transportation from sub-sea exploration or production and poorly maintained infrastructure in sub-sea pipelines. So far, there have been no major oil spills in the Arctic. However, should this happen—especially during winter months—rescue and clean-up actions

in case of accidents are difficult to impossible, due to harsh climate conditions, usually isolated drilling locations, and a lack of effective removal methods in remote icy areas.

Although some climatic conditions might assist with clean up—for instance, ice contains oil, making it easier to prevent further spreading and make the removal more effective—limited experience to date with clean-up measures under Arctic conditions has led to a shortage of best practices.⁷ There is also concern that if a spill from an uncontrolled well in an ice-free area occurs late in the Arctic summer, ice conditions could change so quickly as to prevent drilling a relief well until the following year (Schmidt 2012).

Operational risks are also of concern. Possible discharges of produced waters, drilling liquids, or chemicals from drilling and extracting facilities and building new infrastructure to support operations would have all environmental impacts. Oil and gas flaring releases black carbon emissions, which can reduce albedo and thus increase the rate of regional warming within the Arctic (see Sect. 2.3.1). Air pollutants, such as NO_x, SO₂, VOCs, CO₂, methane, and particulate matter (PM), are released into the atmosphere by fuel combustion for onsite power generation, well testing, gas flaring, and other operational leaks. These substances contribute to Arctic haze and have the potential to fasten ice melt (see above Sect. 2.3.2).

In addition, noise from oil and gas activities can interfere with marine animals and temporarily displace them from their habitats. Seismic exploration has affected the migration patterns of bowhead whales and reduces the accessibility of indigenous hunters to their game (CAFF 2001). It may also cause polar bears to abandon their dens and thereby increase cub mortality (CAFF 2001). The effects of drilling activity, pipelines, and subsurface installations on marine communities and seafloors vary and depend on the communities present and their level of sensitivity to disturbances. The geological composition of the sea floor appears to recover from exploratory drilling within a year in some cases (Corrêa et al. 2009).

2.3.6 Tourism

Despite all aforementioned changes in and impacts on the Arctic environment, the circumpolar region is still overall regarded as pristine. As a consequence, and following increased interest in ‘adventure tourism’, the popularity of Arctic tourism has increased greatly over the past two decades. Marine tourism in the Arctic is highly diversified and *inter alia* driven by tourists looking for sightseeing and observing wildlife species in their natural habitats (AMSA 2009). Concerns over the impacts of climate change and the perception that the Arctic environment’s

⁷ See, for instance, the EPPR working group’s presentation at the SAO meeting in Haparanda (Bjerkemo 2012).

landscapes and wildlife are endangered are further driving demand for tourism services in these areas.

Tourism activities have increased in land-based hotels as well as on ship cruises. The number of nights spent at hotels in Greenland increased from about 180,000 in 2002 to more than 235,000 in 2008. Svalbard—an Arctic archipelago off Norway’s coast—saw numbers rising from around 30,000 in 1995 to 89,000 in 2008 (Emmerson and Lahn 2012). Cruise passengers landing onshore increased in Svalbard from about 37,000 in 1996 to nearly 70,000 in 2003, while the number of cruise ship landing sites nearly tripled between 1996 and 2010 (Evenset and Christensen 2011).

Tourism activities have the potential to impact both land and marine environments in the Arctic region. For example, tourists can cause significant disturbances for nesting or breeding birds and haul-out sites of marine mammals such as ringed seals or walruses. Pathways of tourist groups to ‘points of interest’ (viewing points on colonies of birds, for instance) can leave Arctic flora trampled down; in addition, litter on the visited sites remains long after the temporary disturbances are gone.

Marine-based tourism accounts for the largest segment of the Arctic tourism industry in terms of numbers of persons, geographic range, and types of recreational activities (AMSA 2009). Due to limited housing capabilities in the high North, as well as the focus on ships being the main means of transport in the Arctic area, the vast majority of tourists visit Arctic regions on cruise vessels. Cruise ship tourism mostly takes place in areas around Greenland, Iceland, Norway (including Svalbard), and Alaska. The impacts on the marine environment mostly pertain to the aforementioned section on shipping. Particular risks arise where vessels used for tourist operations in Arctic waters do not meet needs for protection against floating ice, equipment for confinement of oil, or waste storage capacities.

2.3.7 Nuclear and Radioactive Waste (Including Military Use)

In general, the Arctic is considered a region of “particular vulnerability” to radioactive contamination (AMAP 2010). Despite radioactive particles from nuclear explosions having decreased since the end of atmospheric nuclear testing in 1963, there has been concern that without a nuclear-weapons-free zone agreement, the Arctic could be threatened by nuclear dumping and the expansion of nuclear activities in the Barents Sea region (ADHR 2004).

A large portion of the dumping, from waste and reactors, can be attributed to the Russian Federation—partially inherited from the former Soviet Union—while both the former Soviet Union and the US are largely responsible for pollution from nuclear testing, with France, China, and the United Kingdom also contributing (Bøhmer et al. 2001).

The specific environmental impacts and risks of military and nuclear waste in the Arctic marine environment depend upon the type of waste and containment.

Contamination from radioactive materials can persist for long periods in soils and plants, and may be revealed in higher concentrations further up the food chain. Radioactive contamination poses particular threats to marine ecology and fisheries with risks increasing where waste settles, rather than diluting and dispersing (Nuclear Threat Initiative 2010). Arctic indigenous peoples are also at risk from exposure from radioactive contaminants. Climate change and its impacts on temperature, permafrost, erosion, precipitation, weather events, sea ice, and oceanic circulation could alter radioactive uptake and distribution in the Arctic (AMAP 2010).

Still, studies have demonstrated that no significant amounts of radioactive materials have migrated from dumping sites and that releases from solid radioactive waste have been small and localized (AMAP 2010). Long-term monitoring has demonstrated that radioactivity is declining, but also stressed the need for significant hazardous operations in relation to the management of spent nuclear fuel (AMAP 2010).

In addition, Russian plans for expanding the use of mobile floating nuclear power plants in the Barents region are ongoing—despite safety concerns from environmental groups (Nikitin and Andreyev 2011). This will ensure ongoing discussions about the use of radioactive materials in, and their impacts on the Arctic environment. For instance, an assessment of whether the current international legal framework and safety standards are applicable and appropriate for transportable nuclear power plants (with particular attention given to floating reactors) was recently conducted by the IAEA (IAEA 2012).

2.4 Conclusion

The Arctic environment is indeed unique and at a point in time that requires international attention and continued efforts to address the many challenges it faces.

The continuing loss of sea ice coverage proves to be not only an imminent threat to species' habitats, but may also trigger climate feedback loops that will hasten the change in the region even further. Climatic changes in the Arctic are linked to global changes such as sea level rise and oceanic circulation, with potentially severely adverse affects. Warming water temperatures could shift species' distribution and confront highly specialized Arctic species with competition from invasive species. Pollutants that enter the region via air, ocean, or river pathways have a disproportionate impact on the Arctic and are now being released from decades of deposits in ice and permafrost. Increasing human activities in fisheries, shipping, and the exploration and exploitation of hydrocarbons add even more pressure to Arctic marine ecosystems. Growing numbers of tourists visit the Arctic to see one of the last pristine environments.

This chapter has sought to provide an overview of answers to the questions: What exactly is at risk in the Arctic environment, why is it at risk, and why does it matter? Once familiar with the urgency that lies in protecting the Arctic marine environment, a logical follow up question comes to mind: What do we do about it?

In the following chapters, specific threats will not only be further elaborated upon, but opportunities, instruments, and approaches will be identified and analyzed to begin answering this question. Particular attention is needed to describe both the influence of global and regional environmental developments and possible gaps in the legal and policy framework for the marine Arctic.

While complex questions are often used as excuses to postpone solutions, the Arctic region's complexity and uniqueness should not be invoked at its expense: There is an urgency and need to act. The diversity of habitats and need to adapt to ongoing changes demand quick responses in governance, however, the existing Arctic patchwork of differing national interests, environmental threats, regulatory approaches, and international fora, implies that there are no simple answers.

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