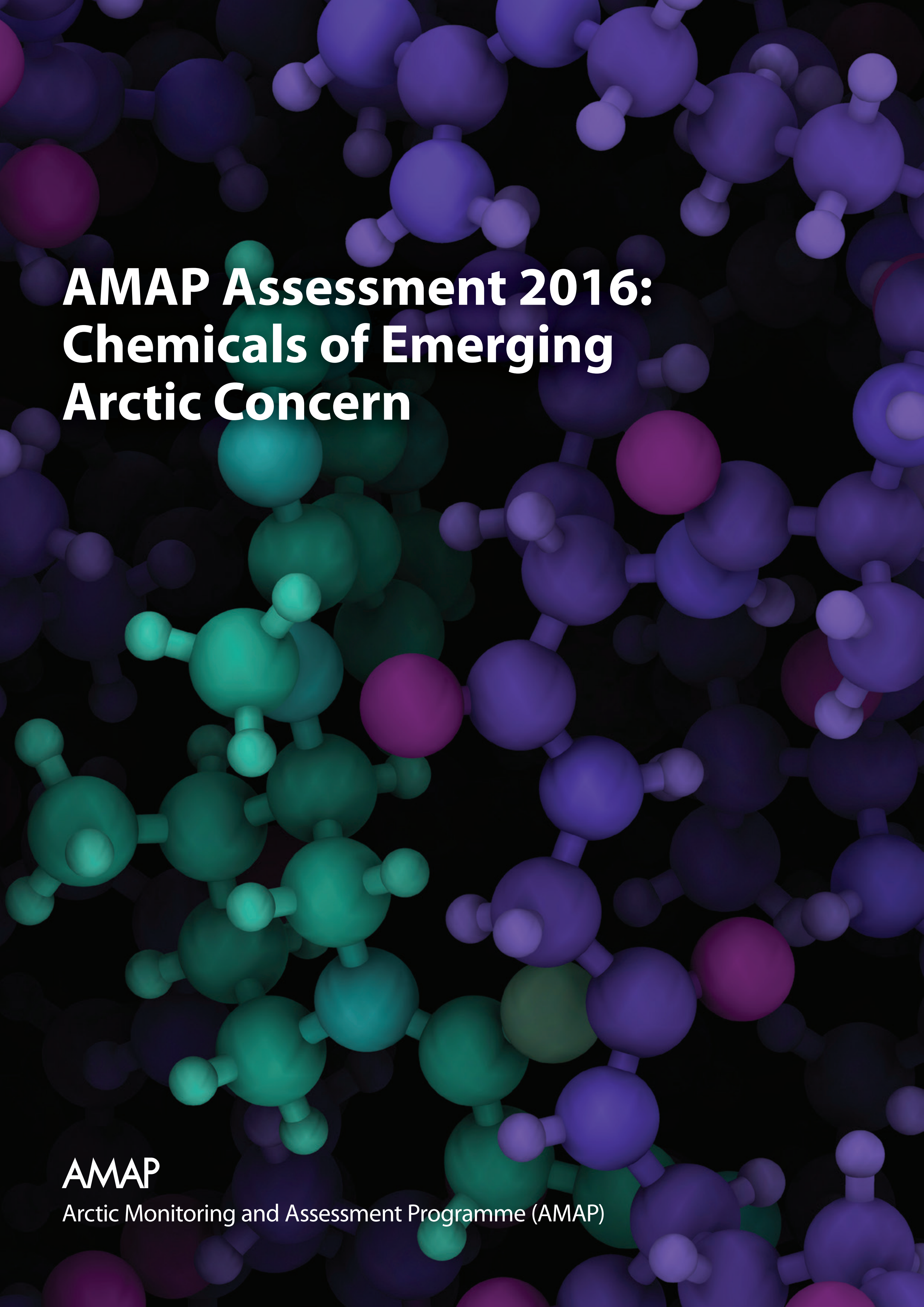

AMAP Assessment 2016: Chemicals of Emerging Arctic Concern

AMAP

Arctic Monitoring and Assessment Programme (AMAP)

2.17 Marine plastics and microplastics

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2.17.1 Introduction

This section reviews the state of knowledge to late-2015 concerning microplastic in the Arctic. Marine litter and especially plastic debris in the oceans has emerged as a major environmental concern worldwide and is recognized as a threat to marine ecosystems due to the vast amounts involved (Jambeck et al., 2015). Plastics are man-made materials comprising a wide range of organic polymers. They are semi-persistent and known to break down from macroplastic particles (>5 mm in size) to smaller plastic particles through exposure to ultraviolet (UV) light and physical abrasion, but total degradation is slow (Gewert et al., 2015). Most of the plastic material floating in the world's oceans is microplastic debris (<5 mm) (Cózar et al., 2014; Law et al., 2014b). Plastics are released into the environment during industrial activities such as commercial fishing, use of plastic abrasives, and spillage of plastic pellets, but also from domestic applications such as washing of plastic microfiber clothes, use of personal care products containing microplastics (e.g. toothpaste and exfoliators) and municipal wastewater.

Owing to the great connectivity between the Arctic Ocean and adjacent seas through Fram Strait and the Bering Strait, the problem of plastic litter is likely to extend into the Arctic Ocean. However, there are few studies in this region. To understand the distribution of plastic litter in the Arctic Ocean, knowledge of local sources is as important as an understanding of transport pathways from the more densely populated areas further south. As well as the five known 'great garbage patches' of the world oceans, a sixth is predicted for the Barents Sea based on calculations from drifter buoy data (van Sebille et al., 2012) but has still to be seen. Many coastal areas and inland waters also have high levels of plastic pollution, including some in the Arctic (Strand et al., 2015). Although marine plastic has been observed globally and in the Arctic for decades, only recently have national and international scientific efforts begun to understand the sources, occurrence and fate of marine plastics in the Arctic.

There is growing evidence of the broad impact of marine plastics on the marine ecosystem (Rochman et al., 2016 and references therein). Marine plastics affect marine organisms in several interlinked ways; through mechanical interactions such as entanglement, ingestion, blockage of intestines and/or hindering limb movements (Laist, 1987) or through toxicological effects of harmful plastic-related chemicals (Koelmans et al., 2014). Although the entire marine foodweb, from plankton to large organisms such as sea turtles, seals and whales, is known to be affected by marine plastic, the complex interactions of physical-chemical and biological processes are not well known (Figure 2.125). How the extreme environmental conditions of the Arctic might affect plastic transport and degradation processes is not yet known. Emerging knowledge from lower latitudes may not be transferable to the Arctic environment, so studies specific to Arctic conditions are needed. Increased human activity, a changing climate and shifting migration routes of marine organisms also have the potential to increase marine plastic pollution in the Arctic in the future.

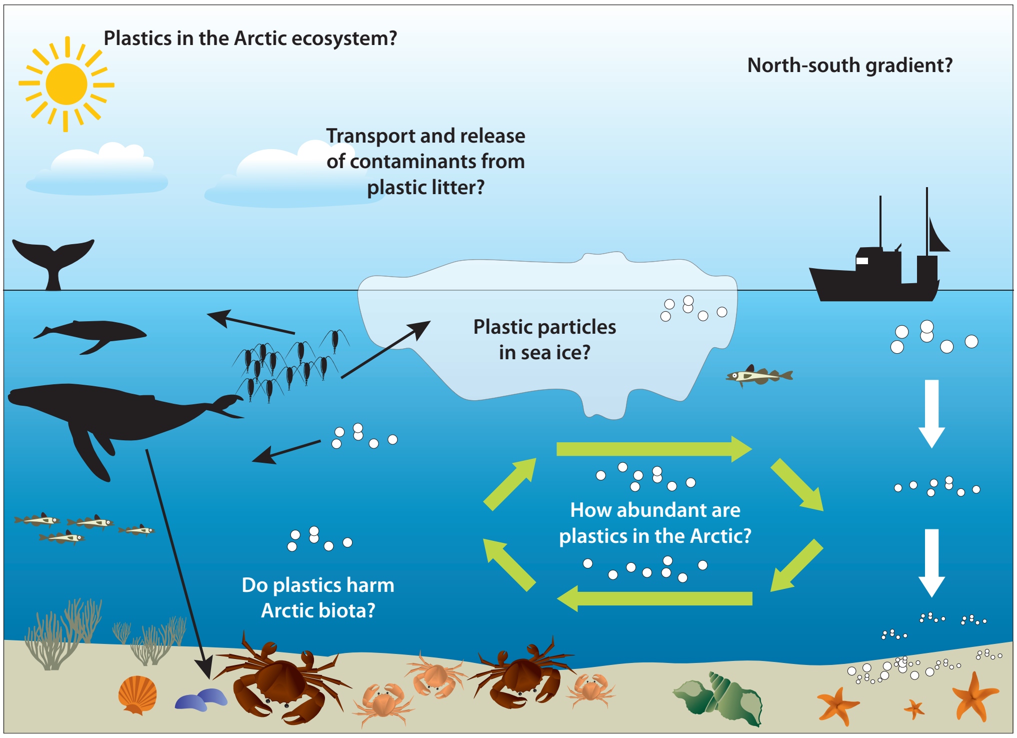

Figure 2.125 Examples of knowledge gaps on the impact of plastic litter in the Arctic (Herzke and Bjørklid, NILU, Norway; Halsband Akvaplan-niva, Norway).

2.17.2 Physical-chemical properties

Marine litter and especially plastic debris, comprises many different compounds and complex polymer materials. Depending on their composition, density and shape they may be found throughout the water column and in or on sediments and beaches. Most polymers in use, such as polypropylene (PP) and polyethylene (PE) exhibit a density lower than water, causing them to float at the sea surface. Higher density polymers such as polyvinylchloride (PVC) and polyethylene terephthalate (PET) are prone to sink to the seafloor (Woodall, 2015). However, the situation becomes more complex in relation to moving water masses and marine microorganisms. Low-density materials are found in the sea surface microlayer, although wave action and wind velocity can affect mixing patterns and temporarily submerge low density materials. In estuarine habitats, low density plastics may become submerged where fronts converge. As well as altering the ecology of litter-associated species assemblages, the fouling of debris, accumulation of biofilms and colonization by algae and invertebrates may also affect the density of the litter, causing it to sink. Marine litter can also act as a vector for hydrophobic chemicals (Rios et al., 2010). Organic pollutants, such as polychlorinated biphenyls (PCBs) and brominated flame retardants (BFRs) present in seawater can adsorb onto the plastic surface during its residence in the water. Sorption increases as the plastic weathers due to the increase in available surface area (Mato et al., 2001). Certain polymers, such as polypropylene and polyethylene have been shown to adsorb a broad variety of organic pollutants as polycyclic aromatic hydrocarbons (PAHs) and PCBs (Teuten et al., 2009; Bakir et al., 2012; Rochman et al., 2013). Conversely, polymers can also act as a source of pollutants, leaching chemicals used as additives (e.g. UV stabilizers, softeners, flame retardants) (Hirai et al., 2011).

2.17.3 Sources, production, use and trends

The quantities of plastics produced each year are enormous, increasing from the onset of plastic mass production (1.7 million t/y in 1950) to today (288 million t/y in 2012) (PlasticsEurope, 2014). Between 4.8 and 12.7 million tonnes were estimated to have entered the oceans in 2010 alone (Jambeck et al., 2015).

Locating the sources of plastic litter is often difficult, especially for microplastics, because the nature of the original plastic items can only be inferred from polymer identity and – where analyzed – the composition of additives such as plasticizers and colors. Summaries of current knowledge on the distribution, composition and abundance of marine litter and plastics, as well as on the sources and pathways of microplastics (Bergmann et al., 2015; GESAMP, 2015) indicate that plastics are the most common type of marine litter (representing up to 95%) and ubiquitous in all world oceans, originating from numerous sources. A major input comes from land, but also from ships and other installations at sea. There are both point sources and diffuse sources, and once at sea this debris can travel long distances before being deposited on beaches or on the seafloor, or degraded to form microplastics with their own set of pathways, including the marine food web. The amount of human plastic waste production is enormous, but varies between countries. How much of this enters the environment depends on local and regional development and on the implementation of appropriate disposal and recycling measures – or the lack thereof. Despite standardized monitoring methods now beginning to emerge, there is large spatial and temporal variability in marine plastic occurrence and this hampers quantitative assessments of the extent of the problem. Terrestrial plastic occurrence is even less well studied, although point sources do exist and may represent a source of marine microplastics through runoff from land to sea. There are several hypothetical pathways of marine plastics and microplastics into the Arctic. First, transport via ocean currents from populated areas further south is highly likely (Lusher et al., 2015). Large amounts of Atlantic water enter the Arctic Ocean through Fram Strait containing variable amounts of plastic items and microplastics, as is also the case for other pollutants such as POPs and metals (Bergmann et al., 2015). Second, local sources will add to the overall flux of marine plastic entering the Arctic by municipal and commercial activities on land or at sea. Trevail et al. (2015a) summarized the state of marine microplastic pollution in the Arctic, distinguishing between primary and secondary sources of microplastics. Lusher et al. (2015) found mainly synthetic fibers (95%) between mainland Norway and Svalbard. These were hypothesized to be breakdown products from larger plastic items derived from sea-based activities (shipping, fishing, recreation, offshore industries). Fiber input from households (from washing textiles such as plastic-based fleece) in waste water is likely to be another source (Browne et al., 2015). However, it is challenging to distinguish inputs generated by the few Arctic human settlements (directly through coastal littering and wastewater discharge and indirectly through runoff from land via Arctic catchment areas) from those originating from sources outside the Arctic.

Merrell (1980) observed marine plastic on ten 1-km beaches at Amchitka Island, an Aleutian Island in the Bering Sea back in the 1970s. Most of this litter had originated from fishing vessels, but some items were from the Asian coast, at least 1150 km away. In 1974, 345 kg of plastic litter were found per kilometer of beach. The same author reported that in 1972, an estimated 1664 tonnes of plastic litter had been lost or dumped from fishing vessels in the Bering Sea and North Pacific Ocean. Only a few years later, Lucas (1992) observed marine plastic litter on beaches of Sable Island, Nova Scotia, Canada. The litter came from the ocean, and had not originated from the island itself, confirming that marine plastic was also present in the North Atlantic Ocean. Plastic ingestion by marine biota has also been observed since the 1970s. Bourne (1976) found 1 to 2 particles per stomach in North Sea fulmars (*Fulmarus glacialis*) in the early 1970s. In the 1970s and 1980s, several studies showed the global oceanic presence of virgin industrial pellets (Colton et al., 1974; Wong et al., 1974; Gregory, 1978; Shiber, 1979, 1982; Morris, 1980) and their ingestion by a wide range of marine wildlife (e.g. Bourne and Imber, 1982; Connors and Smith, 1982; Laist, 1987).

2.17.4 Transformation processes

Transformation or rather decomposition of marine plastic can happen along three, often parallel, routes. First, larger plastic parts are quickly broken down into smaller particles caused by mechanical forces of waves and photo-degradation. However, when plastic litter starts to sink, decomposition is reduced dramatically due to the lack of light and the low temperatures leading to half-lives of plastic litter of up to several hundred years. Second, chemical degradation by UV and/or hydrolysis can result in a rapidly growing number of chemicals released into the marine environment. Third, biofouling of the plastic by bacteria, algae and other organisms might lead to breakdown by mechanically eroding the surface. Fotopoulou and Karapanagioti (2015) found weathered high density polyethylene (HDPE) had an uneven surface, was yellow, and occasionally, colonized by microbes. Pathways for degradation of marine plastic were recently reviewed by Gewert et al. (2015). They concluded that biodegradation and photo-initiated oxidization led to chemical attack of the carbon-carbon backbone of the polymer (polyethylene, polypropylene, polyvinylchloride). Hydrolysis is another breakdown mechanism and affects polymers with additional elements in their main structure (polyethylene terephthalate, polyurethane). As a consequence, oxygen-containing functional groups are added to the molecular structure, speeding up the degradation process to form many different molecules. All processes start on the surface, causing the surface to become brittle and porous (Gewert et al., 2015). Biological transformation may originate from organisms that bore into the material and through colonization by rafting organisms. Only a small proportion of plastic fragments north of 60°N are colonized (Barnes and Milner, 2005), for example by barnacles (Barnes and Milner, 2005) or bryozoans (Winston et al., 1997).

2.17.5 Modeling studies

Few modeling studies have considered the distribution and transport of plastic debris to the Arctic. Van Sebille et al. (2012) used observational data from the Global Drifter Program in a particle-trajectory tracer approach to model the fate of debris from coastal sources on time-scales of years to centuries. Their model predicted six major garbage patches, one in each of the five subtropical basins and one so-far unreported patch in the Barents Sea. They concluded that the connectivity between the ocean basins is higher than expected at centennial scales and as a result a significant amount of marine debris could eventually accumulate in the North Pacific patch.

Zarfl and Matthies (2010) attempted to estimate the influx of organic pollutants adsorbed to plastic debris to the Arctic. Estimates ranged from 62 000 to 105 000 t/y, subject to spatial and temporal variability and sampling bias. They then estimated the mass fluxes of PCBs, polybrominated diphenyl ethers (PBDEs), and perfluorooctanoic acid (PFOA) in plastics transported into the Arctic via the main ocean currents and compared these fluxes with those in the dissolved state and in air. The calculated mass fluxes of the chemicals studied were several orders of magnitude higher in air than in seawater, suggesting that plastic plays a minor role in transporting these compounds northward. High uncertainty in the field data (i.e. plastic concentrations in the pelagic realm) results in large variation in the estimated mass fluxes.

2.17.6 Environmental concentrations

2.17.6.1 Air and precipitation

There are no published data on plastics and microplastics in air and precipitation in the Arctic region.

2.17.6.2 Terrestrial environment

There are no published data on plastics and microplastics in the terrestrial Arctic.

2.17.6.3 Freshwater environment

Current knowledge of microplastics distribution and impacts in freshwater systems was reviewed by Wagner et al. (2014) and Eerkes-Medrano et al. (2015), who highlighted the lack of data on distribution, transport and effects on biota. No data from Arctic freshwater systems exist to date and methods for detection, enumeration and identification remain to be developed. However, some similarities with the marine environment may be expected in terms of particle transport by currents, ubiquity of plastic particles within the system, and impacts on biota. A major difference could be the typically smaller size of freshwater systems, which could result in different spatial and temporal patterns in the transport and mixing of plastic particles within the water column (Eerkes-Medrano et al., 2015). For benthic systems, Corcoran (2015) described the pathways of plastic litter from land to marine and brackish/freshwater environments and concluded that the controlling parameters are similar in both, i.e. proximity to human point sources, river input, geomorphology of the basin, and the behavior of water circulation. Nevertheless this is an important knowledge gap in the Arctic (Table 2.87).

2.17.6.4 Marine environment

Little information is available on plastic debris concentrations in the Arctic marine environment (Trevail et al., 2015a). Most monitoring efforts in the Scandinavian countries have excluded inaccessible Arctic regions, such as the coasts of Svalbard and Greenland and the open Arctic Ocean. A collaboration between Norway and Russia documented marine litter, including macroplastics, in the Barents Sea (Prokhorova and Krivosheya, 2014). This showed the highest plastic litter concentrations to occur along the major ocean currents in areas of intensive fishery and shipping activity. Plastic debris was recorded on the surface, in the water column, and at the seafloor, with the number of items being highest in the pelagic trawls. In the Arctic Pacific, the only information on marine plastic litter distribution is available from dietary studies of seabirds. The northernmost survey of pelagic microplastic distributions

Table 2.87 Summary of Arctic media for which marine plastics and microplastics data have been reported.

	Air		Terrestrial		Freshwater			Marine			Sea ice
	Air	Snow	Soil	Biota	Water	Sediment	Biota	Water	Sediment	Biota	
Macroplastics (>5 mm)								×	×	×	
Microplastics (<5 mm)								×	×	×	×

was conducted in the Bering Sea (Doyle et al., 2011), looking at plastic concentrations in zooplankton net samples. These were collected in Northeast Pacific ecosystems during research cruises in the southeastern Bering Sea in spring and autumn 2006. Plastic particles (items ≥0.5 mm in size) occurred at both shallow and deep water stations along the Alaska Peninsula in the Bering Sea, but not at the shallowest stations furthest to the east along the Alaska Peninsula. Plastics were found in 9–84% of the surface samples, while microplastics were only found in sub-surface layers in one winter survey. Concentrations were estimated at 0.004–0.19 particles/m^3 and 0.014–0.209 mg dry mass m^3, and were comparable to the levels recorded for regions along the Californian coast with a mean of 0.045 pieces/m^3. Macroplastics were observed floating on the sea surface in Fram Strait and were counted by visual observation during helicopter surveys (Bergmann et al., 2016a). Observation of the deep Arctic seafloor (Bergmann and Klages, 2012) showed plastic debris at densities of 7710 items/km^2, comparable to densities observed in the deep northern Gulf of Mexico (Wei et al., 2012) and even higher than those for marine canyons near Lisbon (Portugal) (6600 items/km^2), which were classified as moderately high (Oliveira et al., 2015).

Systematic sampling of the water column was conducted in June 2014 between Tromsø (Norway) and Svalbard to 78.08°N (Lusher et al., 2015). Two particle sampling methods yielded different results for the 200–500 µm size class. The average concentration of microplastics sampled with a Manta net (mesh size 333 µm), which filters large volumes of water (and plankton) in a small geographic area in the upper few centimeters of the water column, was 0.34 particles/m^3. In comparison, subsurface sampling with the ship's pump, which collects small volumes of water over long distances at 6 m depth gave an average particle count of 2.68/m^3 (after sieving over a 250 µm sieve). Almost all samples contained microplastics, 95% and 93% respectively. The results are comparable to those from other studies around the world and slightly higher (but not statistically significant) than counts using the same methodology in the North Atlantic (Lusher et al., 2014).

The speed of horizontal transport of macro- and microplastics in open water differs: large buoyant debris is exposed to wind stress, while most microplastics are completely submerged. Transport of submerged marine debris from the Tohoku Tsunami was predicted to reach the International Dateline after six months and then to slow and require another 2.5 years to reach 130°W, the latter equivalent to the speed of the north Pacific current (Lebreton et al., 2012). Also important when assessing environmental fate are the physical-chemical properties of the monomers and additive chemicals (boiling point, vapor pressure, water solubility, octanol-water partitioning) as well as the properties of the polymers themselves (size, shape, pore size) (Teuten et al., 2009; Lithner et al., 2011).

The current lack of QA/QC tools and standardized methodology for sampling and identification, means distribution and transport data from different studies cannot be compared. This remains a major challenge worldwide, not only in the Arctic.

Another important matrix for microplastics in polar regions is sea ice. High concentrations of microplastics in Arctic sea ice were found in a study on multi-year ice. Obbard et al. (2014) found up to 250 particles/m^3 in sea ice cores collected at several sites across the Arctic Ocean. The polymers found in various shapes and colors were rayon (a man-made semisynthetic, 54%), polyester (21%), nylon (16%), polypropylene (3%), polystyrene (2%), acrylic (2%), and polyethylene (2%). More recent studies showed even higher concentrations of microplastics in ice cores from the Fram Strait, exceeding the values of Obbard et al. (2014) a hundred-fold (Bergmann et al., 2016b). The sources are difficult to determine, but two pathways are probable: entrapment of marine microplastics during ice crystal formation and atmospheric deposition with snowfall. However, declining sea ice will eventually release these particles into the water column, potentially presenting a major source of plastic pollution for pelagic organisms. Beyer (2015) suggested a procedure to prepare ice cores for microplastics analysis. Standardized methods for the extraction of microplastics from sea ice and other ice environments (e.g. glaciers) are needed.

Indirect evidence for plastic transport into the Arctic is available from seabirds. Seabirds appear particularly vulnerable to marine plastic ingestion (Robards et al., 1995). The northern fulmar (*Fulmarus glacialis*) is a surface feeding seabird with an extensive foraging range over offshore areas throughout its entire lifecycle. This makes it an ideal monitoring sentinel for marine plastic litter (van Franeker et al., 2011; Avery-Gomm et al., 2012; Kühn and van Franeker, 2012; Bond and Lavers, 2013; Rebolledo et al., 2013). The ingested plastic particle load in beached dead fulmars is monitored annually as a contribution to the monitoring of OSPAR's Ecological Quality Objectives (EcoQOs) (OSPAR, 2009a; van Franeker et al., 2011). Ingestion behavior of northern fulmars has been reported from a number of Arctic regions by van Franeker and Law (2015), where plastic items weighing more than 0.1 g were found to decline in number along a south-north gradient. Plastic has also been found in the stomachs of other seabirds, for example thick-billed murre (*Uria lomvia*) in the eastern Canadian Arctic (Provencher et al., 2010). Blais et al. (2005) showed that Arctic seabirds transport marine-derived contaminants into the Arctic and Kühn et al. (2015) hypothesized that much of that may come from plastic. Dietary studies of birds from the Canadian and European Arctic have reported ingested plastics (Mallory, 2008; Provencher et al., 2010). Trevail et al. (2015b) investigated fulmars from Svalbard and found that 88% of the 40 birds examined had ingested plastic, averaging 0.08 g or 15.3 pieces per individual, and 22.5% exceeded OSPAR's EcoQO. Herzke et al. (2016) reported ingested plastic in fulmars caught slightly further south, in the Norwegian Arctic (Finnmark). In this study, 36% exceeded the EcoQO threshold (n=75) and 81% of all investigated individuals contained ingested plastic. Particle size varied from 1.8 to 9.1 mm (mean 5.0 mm) in addition to some longer threads. Of 20 subsampled individuals, an average of 0.2 g or 24 plastic pieces were found with a maximum of 106 plastic pieces.

Plastic ingestion by other Arctic marine biota

Owing to their resemblance and overlap in size range with food items, plastic litter is ingested by marine organisms of all sizes and trophic positions. Together with the high plastic loads in the world's oceans, plastic items have been found in the gut of a wide range of marine species, from small plankton to top predators

(Colabuono et al., 2009; Law et al., 2010; Collignon et al., 2012; Fossi et al., 2012; Desforges et al., 2015). The largest of these animals may help transport microplastics into, around and/or out of the Arctic region independent of the major physical transport mechanisms, such as ocean currents and prevailing winds. The consequences of plastic ingestion for health and fitness parameters such as growth, survival, performance and reproduction are largely unknown, although several studies have investigated such effects in various organisms (reviewed by Cole et al., 2011; Wright et al., 2013). Particles of plastic may be retained in the digestive system causing a decrease in feelings of hunger and thus a reduced intake of food (do Sul and Costa, 2014). Plastics can be transferred to seabird offspring if they are fed by regurgitation (Henry et al., 2011). Plastic consumption can also occur by consuming plastic-contaminated food items. Pollutants can be released from ingested plastic and transferred into tissues, causing potential toxicological effects.

Coastal environment (beaches)

Monitoring data for plastic litter on beaches in Europe has been collected under the OSPAR Convention since 2001. Beaches in the Arctic were included in 2011, located in northern Norway and Svalbard (Figure 2.126). In the latest OSPAR assessment of marine litter in the North-East Atlantic region (OSPAR, 2009b), Contracting Parties provided qualitative data only for Arctic waters. Several types of plastic litter were found on the Norwegian coast (bags, boxes, buckets, helmets, nets, trawls) and Icelandic coast (including plastic bags). Tourism and recreational activities are a significant land-based litter source on the Norwegian coastline. There has been no research on land-based sources of marine litter in the Faroe Islands, but an estimate based on the litter landed as part of the project *Fishing for Litter* in port Tofta Havn indicates that municipal waste management, rivers, tourism and recreational activities could be direct input sources. Fishing boats and the fishing industry in general as well as other types of marine transport sea are the main sea-based sources of plastic litter in the European Arctic seas, including offshore oil/gas installations. In Norway, the aquaculture industry makes a significant contribution at the local scale, and in some areas contributes ~30% of the total quantity in the Norwegian Arctic (OSPAR, 2009b).

Marine litter observed on beaches varies from place-to-place and year-to-year depending on changes in ocean currents, weather conditions and incidents on vessels and offshore installations that result in the loss of materials to the sea. For example, on a 100-m section of beach in Rekvika (Troms, Norway) the number of plastic items collected varied between 2670 (1 October 2011) and 12 928 (1 May 2012). For comparison, the average number of all plastic items found on 100-m sections of beaches on Svalbard and the Norwegian Arctic mainland in 2013 were between 300 and 12 000 items, respectively. Figure 2.126 illustrates the average composition

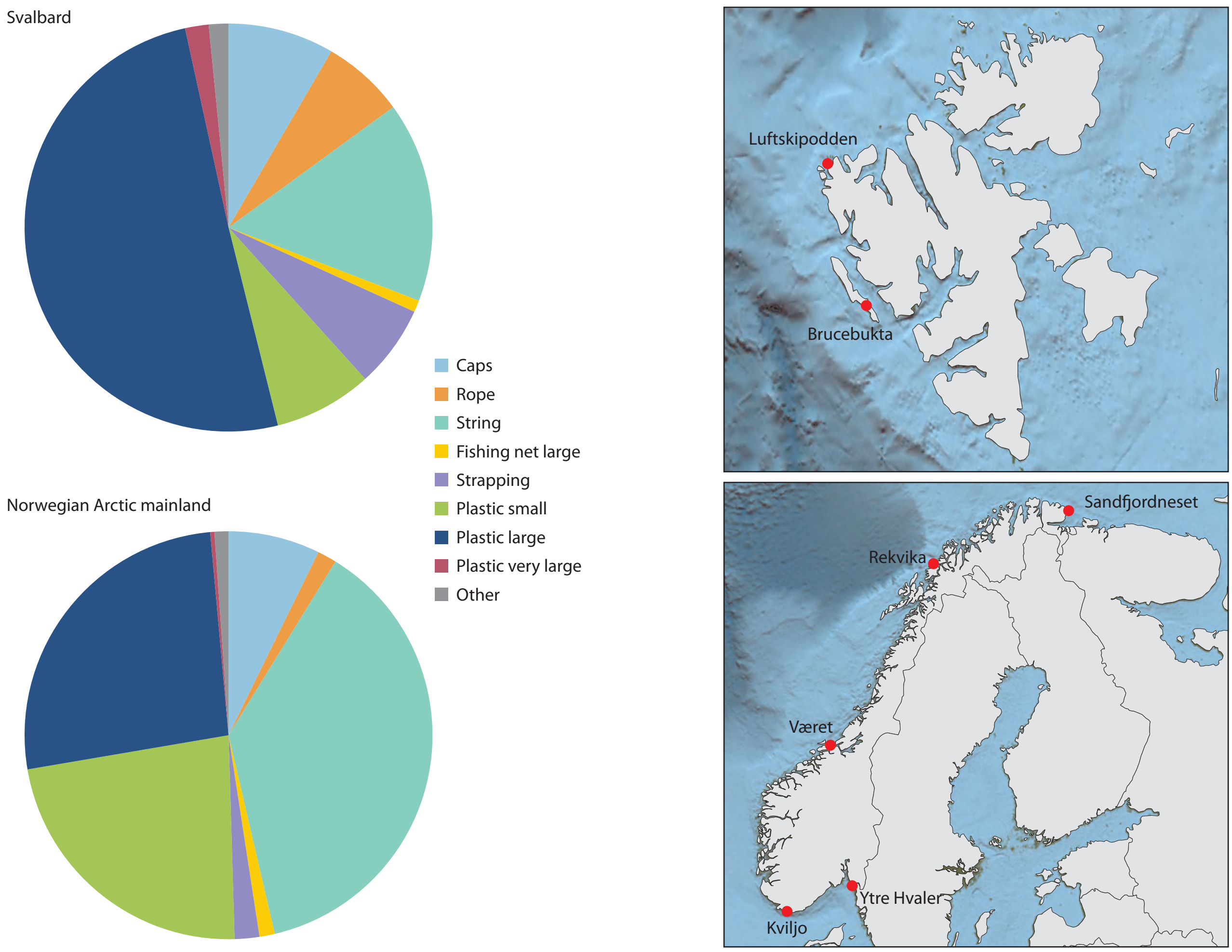

Figure 2.126 Composition of main plastic items found on a 100-m section of beach located on Svalbard and the Norwegian Arctic mainland coast (OSPAR, 2009b), and locations of the beach monitoring sites.

of plastic items collected in both regions on a 100-m length of beach. The composition of plastic beach litter found on Svalbard seems more diverse (which suggests a wider range of sources) compared to the items found on the Arctic mainland of Norway.

2.17.7 Environmental trends

Methods for defining debris, sampling, and interpreting patterns in space or time vary considerably among studies, making it difficult to draw conclusions about trends.

2.17.7.1 Spatial trends

Cózar et al. (2014) described global accumulation zones for plastic debris in the convergence zones of each of the five subtropical gyres. They hypothesized that the majority of particles were not recorded in their synthesis of surface water estimates for plastic concentrations due to fragmentation, sinking, food web processes, and unknown processes.

Lusher et al. (2014, 2015) found higher concentrations of microplastics in the northern North Atlantic (between mainland Norway and Svalbard's southwest coast) than in the northeast Atlantic off Ireland. Whether this represents a latitudinal gradient is still to be confirmed, but several mechanisms could explain this difference. The Arctic may act as a sink for marine plastics, with debris transported northward via the Gulf Stream and then into the Arctic Ocean. Plastics may accumulate in these currents along the way and receive inputs from mainland Europe and Scandinavia, and perhaps even further afield. Plastic particles trapped in multi-year sea ice for long periods (decades) may be released into the water column through ice melt, which is expected to increase as the climate continues to warm (Obbard et al., 2014). Information on the distribution of marine plastics and microplastics in the North Pacific is limited to the band between 20° and 52°N (Goldstein et al., 2013; Desforges et al., 2014; Law et al., 2014b). For the Arctic, there are only indirect estimates based on seabird (northern fulmar) ingestion (Avery-Gomm et al., 2012). However, there are no regional trends available, probably owing to small sample sizes, long retention times for plastics in intestines, and long migration routes from the subarctic North Pacific along the continental shelf to Baja California.

At smaller geographical scales, Browne et al. (2010) studied the distribution of macro- and microplastics along an estuary on the UK south coast, and found distinct patterns of debris accumulation in downwind habitats. Such patterns can also be assumed for Arctic estuaries and coastal runoff sites into fjords.

2.17.7.2 Temporal trends

Rising sea levels, altered rainfall patterns, and changes in solar radiation, wind speed, waves, and oceanic currents associated with climate change are all likely to increase the transfer of debris from coastal cities to marine and coastal habitats, including those in the Arctic (Browne et al., 2015). Few studies have investigated temporal trends in marine litter, especially in the Arctic.

According to the most recent OSPAR data, the amount of plastic beach litter at Svalbard showed little change between 2011 and 2014, but declined over this period on the Norwegian

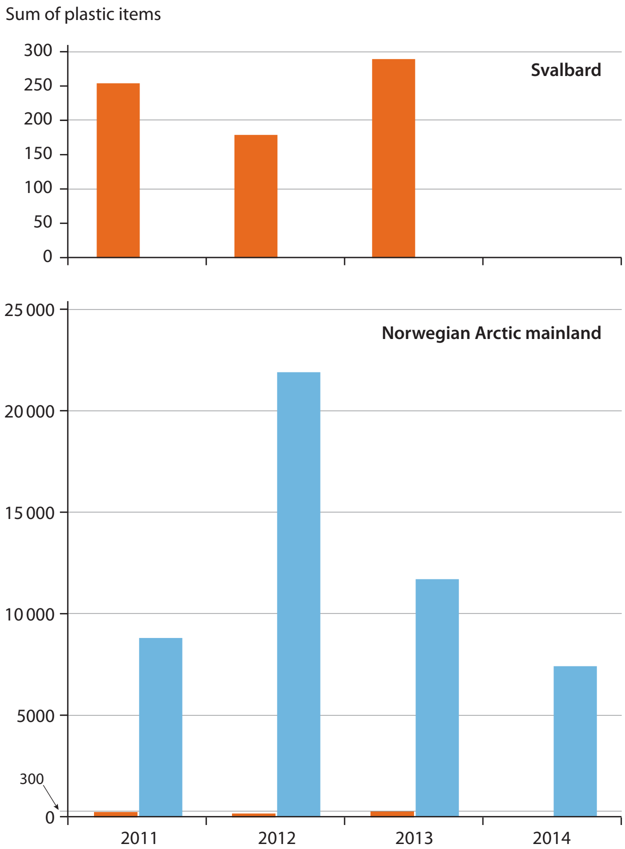

Figure 2.127 Total number of plastic litter items collected on a 100-m section of beach on Svalbard and on the Norwegian Arctic mainland (data from www.mcsuk.org/ospar/survey/export).

Arctic mainland. However, abundance is generally much higher along the Norwegian Arctic mainland coast than on Svalbard (Figure 2.127). Available data cover only 3-4 years and changes over time can not yet be estimated.

The Alfred Wegener Institute for Marine and Polar Research established the deep-sea observatory HAUSGARTEN in eastern Fram Strait west of Svalbard. This comprises nine stations along a bathymetric gradient crossed by a latitudinal transect of eight stations at the central HAUSGARTEN station. Bergmann and Klages (2012) analyzed photographs taken at a set camera transect at the HAUSGARTEN observatory in 2002, 2004, 2007, 2008 and 2011 to study the quality and quantity of macro litter in the deep Arctic sea. This involved 2878 images or an area of 8570 km^2 (excluding 741 images from 2008). Between 2002 and 2008 the number of images with litter decreased followed by a period of strong increase; from 0.54% of images showing litter in 2008 to 2.87% in 2011. When grouping litter into size categories, most items were of medium size (10–50 cm; 67%), followed by small (<10 cm; 30%) and large items (>50 cm; 3%). Litter items per km^2 over the study period as a whole varied between ~1000 (2007) and ~7500 (2011) (Bergmann and Klages, 2012).

Three bottom trawl surveys in inlet and offshore locations of Kodiak Island (Alaska) between 1994 and 1996 gave some information on the composition and abundance of benthic marine debris in that region (Hess et al., 1999). The surveys comprised benthic tows roughly 1.85 km long. The number of plastic items collected varied little between years at 77 (1994), 115 (1995) and 74 (1996).

Obbard et al. (2014), who identified plastic particles in sea ice cores at several sites across the Arctic Ocean, suggested that sea ice cores may provide a valuable retrospective record of the historical deposition of plastic litter in the Arctic.

2.17.8 Conclusions

Despite the exponential increase in available data on marine plastic debris globally, including the Arctic, status reports are limited by a lack of standardization in methodology and reporting consistency. This makes it difficult to draw general conclusions about temporal and spatial trends. Harmonized methodology is required for sampling, identifying and quantifying plastic items across the full size range. How Arctic conditions influence plastic transport, sedimentation and breakdown is not well known. The few reports of *in situ* measurements in Arctic and subarctic regions, together with experimental evidence for temperate organisms and reports of high amounts of plastics in Arctic seabirds, show marine biota are exposed to plastic pollution and experience negative effects. Marine litter floating in surface waters provides an artificial substrate/habitat, potentially accumulating persistent organic pollutants that are then accessible to marine life (Hirai et al., 2011; Tanaka, 2013; Herzke et al., 2016). Because macro- and microplastics cannot be effectively removed from the ocean, research is needed to understand how biological systems, such as fish and seabirds and their associated food webs are affected by ingestion, accumulation, chemical leakage and further breakdown of microplastics, particularly in a warming climate. To enable better understanding of the fate of plastic waste in the Arctic environment and to assess changes over time, current ‘benchmarks’ must be established against which changes can be compared. This requires a strengthening of research efforts in the Arctic regions.

Research topics that will improve understanding of marine plastic pollution and effects in the Arctic include: the identification and quantification of sources of marine plastic pollution in the Arctic; the occurrence, characteristics and distribution of marine plastic in the Arctic marine, freshwater and terrestrial ecosystems; the identification of hot-spots and local sources; the role of Arctic conditions on the fate and transport of marine plastic in water, ice and air; the potential changes in plastic distribution and transport to and within the Arctic under climate change; the impact of plastic pollution on Arctic food webs; and the remediation and avoidance of plastic pollution in the Arctic.