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Microplastics in Polar Regions: The role of long range transport

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Abstract

Microplastics (particles <5 mm) pose a threat to the marine ecosystem that is disproportionate to their tiny size. They have been found in high numbers in sea water and sediments, and are interacting with organisms and the environment in a variety of ways. Recently their presence has been confirmed in Polar water, sediment, and sea ice. We review the recent literature on microplastic distribution and transport in marine environments, primarily in the Northern Hemisphere, summarize current understanding, identify gaps in understanding, and suggest future research priorities.

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Microplastic, Ocean, Pollution, Polar, Arctic, Transport.

Introduction

Given the ubiquity of plastics, no one should be surprised that they have made their way into the most remote environments. Microplastics, manmade polymers <5 mm in their largest dimension, have been found in seawater, sea ice and sediment in Polar Regions [1,2**,3*,4]. Because these regions are thinly populated and remote, long range transport must play a key role.

Microplastics are common in other parts of the world's oceans. They have been found in over 90% of surface water samples worldwide, as well as in coastal and benthic sediments [5,6]. They are taken up by marine organisms, including many that are commercially fished, and cause direct physical and toxicological harm. Their potential act as vectors for other organic pollutants is also of enormous concern [7–15].

In order to address the problem, we need to better understand how microplastics are distributed in the Polar Regions, both geographically and within the marine ecosystem. Long range transport is an important part of the picture not only because it supplies the Polar Regions, but also because it affects the size distribution of debris. In short, while it is taking place, debris is fragmented into more pieces, which can affect more organisms [16].

Over the past 42 years, there have been many efforts to collect marine microplastics, the majority in the North Atlantic and North Pacific accumulation zones, but increasingly in other parts of the world. The recent study by Munari et al. [4] is the first to document microplastic presence in the Antarctic, but there is overall far less data available for the Southern Hemisphere. Thus here we will draw examples from the Northern Hemisphere and the Arctic. It can be assumed that transport of microplastics to Antarctica is taking place through similar mechanisms. Because it is farther from major sources of production and use, transport to that region may take longer and fragments may be on average smaller. This may mean that biofouling, sedimentation and uptake will yield differences in the amounts, sizes and locations of microplastics found there. But the basic long range transport mechanisms and our reasons for concern remain the same.

Data: microplastic types and sources

Types of microplastics in the environment

Microplastics are found in every part of the marine environment: in the air, water, coastal and deep sea sediments, and in marine animals [6,7,17–19]. There are fragments of larger plastic objects that have been broken by mechanical (e.g. wave) action, films from plastic bags or other packaging, and pellets from preproduction plastics and personal care products. Fibers, which are defined by a width to length ratio of 1 to $\geq$1.5, and include polypropylene (PP), polyester, polyamide, acrylic, and polyethylene (PE), come from clothing, disposable diapers, cigarette filters, and marine industry [20,21*]. Common types of synthetic plastics are PE, PP, Nylon 6.6, polystyrene butadiene styrene (SBS), polyvinyl chloride, polystyrene, thermoplastic polyurethane, and ethylene propylene rubber. Anthropogenic sources also contribute fibers of natural polymers, such as wool, cotton, bamboo, silk and rayon. The objective of a given study will determine whether these are important to include or not.

Quantity and sources of microplastics in the environment

The annual PlasticsEurope report [22] is a widely used source of annual worldwide production. In 2015, 269 million metric tons (MT) of thermoplastics and polyurethanes, the largest categories, were manufactured. If we include thermosets (most rubber products) as well as adhesives, coatings and sealants, there were 322 million MT of plastic manufactured in 2015.

Most plastic debris enters the sea through waste streams, but it's difficult to determine exactly how much the waste stream carries, and even more difficult to know how much of that makes it into the ocean. Efforts to do so have been based in large part on solid waste management figures and population density. Using these and economic variables, Jambeck et al. [23] estimated that 275 million MT of plastic waste was generated in 192 coastal countries in 2010, 4.8 to 12.7 million MT of which entered the ocean through the waste stream. Lebreton et al. [24] have developed a global model that puts the riverine input at between 1.15 and 2.41 million MT [24]. Other, lesser sources include fishing boats (losses of nets and line) and input from sporadic natural disasters such as floods [25]. Plastics that are denser than seawater soon sink unless filled with air (e.g. disposable water bottles made of polyethylene terephthalate). But buoyant polymers travel long distances [26].

Finding and identifying microplastics in the Polar marine environment

Globally, many efforts have been made to sample microplastics in water, sediments, and marine organisms. Attempts to aggregate this data, however, are hampered by the different sampling methods used [27**]. While spatial and temporal heterogeneity in source and polymer type produces uncertainty on the input side, sampling methods can bias our understanding of the microplastic budget in transport. Most devices used to sample microplastics were designed for other purposes; and capture and separation techniques differ for each part of the marine ecosystem: surface water, the water column, coastlines, benthic sediment, biota, and ice. Different sampling techniques capture different sized particles. Even for a specific marine environment, sampling methods can differ from study to study, depending on the location being sampled, the reason for sampling, and the available equipment.

In this section, we discuss collection methods in general and give examples from Polar Regions. We do not include sampling from marine biota, but there is growing knowledge on ingestion of plastics by fish that could lead to an estimate of the biological reservoir and potential for transport [27**].

Water

Unlike larger debris, which may float proud of the surface and be subject to wind stress, microplastic particles are entirely submerged, and this slows their transport [28]. It can take many months or even years for microplastics to cross the Pacific Ocean, for example [25].

In the ocean, surface collection is generally done by towing a plankton, manta, or neuston net. Mesh sizes range from 0.1 to 3 mm, 0.333 or 0.335 mm are common, so smaller microplastic particles may be missed and the total quantity of microplastics underestimated [21*,27**]. On the other hand, nets can capture, and researchers may count, particles larger than 5 mm [29]. Sampling can also be done using a vessel's on board sea water pump, but these are typically located at depths of 4–6 m so don't capture the surface fraction [25].

Recently, Cózar 2017 reported that most of the surface ice-free waters in the Arctic Polar Circle are slightly polluted with plastic debris, which is abundant and widespread in the Greenland and Barents Seas [3*]. They also found 37% of the samples in the circumpolar track were entirely free of plastic, but it's possible that this is related to the collection method - they used a 0.5 mm mesh net, and excluded fibers from their count – or to the size-segregation processes discussed later.

It is difficult to compare or combine the results of studies using different sampling methods. Statistical methods can be used to resolve sampling method biases [27**]. Van Sebille [27**] did this to produce a standardized data set from 27 floating debris studies over all major ocean basins, except the Arctic, over the 42 years ending in 2013.

Sediment

Marine sediment includes sand collected on beaches and benthic sediment collected from depths of tens or hundreds of meters. Microplastics are separated from sediment by density-based extraction and filtration, and solvents used to segregate manmade polymers from biota. Once this is done, polymer types can be identified using Fourier Transform Infrared Spectroscopy or Raman spectroscopy [29].

Many coastline sediment surveys have been conducted around the world [e.g. [30]]. Just as is the case with surface water sampling, they're not conducted in any geographically systematic manner. To our knowledge, none have been done in the Arctic Basin.

Munari et al. [4] used a Van Veen grab (surface area 0.18 m^2) to collect benthic sediment from locations near Italy's research station in Terra Nova Bay (Ross Sea, Antarctica). They found higher concentrations of microplastics at the locations closest to shore, which perhaps unsurprisingly contained a high fraction of SBS, a hard durable rubber used for boot soles and vehicles. About half of all manufactured plastics have a density higher than that of seawater and therefore a higher settling velocity - these are less likely transported long range (>1000 km). However, Munari et al. [4] also found nylon in all samples, which could have come from local or remote sources.

Less data is available on benthic and pelagic sediment content than on water because sampling at depth is more difficult, and transport deeper in the ocean is less well understood than surface transport [31].

Sea ice

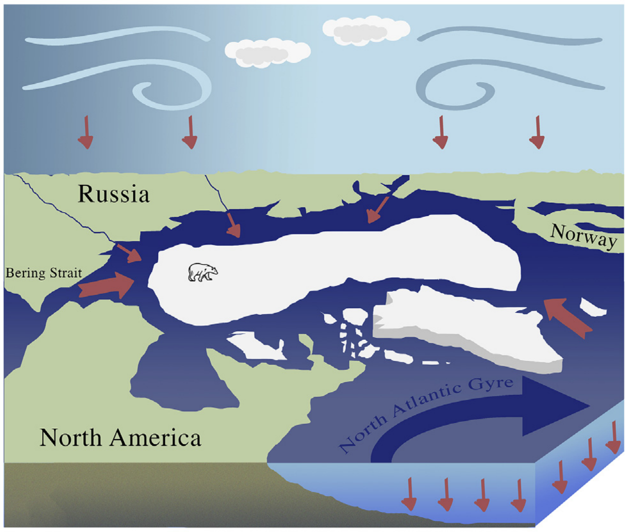
As sea ice grows, it scavenges particulates suspended in the water column. Particles less dense than the seawater, particularly those with irregular shapes, are more effectively trapped than silt and sand [32,33]. Sea ice also entrains particles when ice frozen to the bed is later rafted [34*]. Sea ice can drift far from where it has formed [35]. It has been shown to transport contaminants (e.g. radionuclides) long distances, depositing ones accumulated during the fall and winter during the spring melt season, just when Arctic marine organisms begin to feed [36].

Microplastics have been collected from sea ice by melting and then filtering sections of the sea ice core [1]. The filtride contains natural inorganic and organic particles and sediment as well as microplastics, and the latter has until recently been separated visually by hand [1]. This leaves the potential for undercounting as a result of mistaking synthetic particles for natural ones. There now exists a fluorescent dying technique that is more likely to produce accurate counts [34*].

Models for understanding transport

Long range microplastic transport vectors include ocean currents, wind, and sea ice (Fig. 1).

Fig. 1



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Long range transport vectors of microplastics to the Arctic include ocean currents from the Atlantic and Pacific, rivers, and wind. Once in the Arctic Ocean, water currents and sea ice transport microplastics. Microplastics sink as a result of biofouling and are taken up by biota. (Source: Theodore Obbard).

Ocean transport

In the ocean, geostrophic circulation and wind driven surface currents carry plastic debris long distances [27**]. Oceanographic global accumulation models (GAM) based on surface drift data have been used to predict accumulation zones, and results agree generally with empirical data [5,26,38–42].

Accumulation zones, sometimes called 'garbage patches,' are located in the Atlantic and Pacific subtropical basins and in the Barents Sea. The highest numbers of microplastics are found in these locations, with the largest amount by mass in the North Pacific Gyre. In the North Atlantic, there are discrepancies between modelled and observed distributions with models producing lower than observed particle counts, particularly in the center of the gyre, and predicting the highest concentrations around 60°W, although observations suggest they are farther east [27**].

Although they are accumulation zones, research has shown that all except the North Pacific Gyre are dispersive on longer (i.e. centennial-millennial) timescales; hence over time the North Pacific garbage patch will grow [40]. Exactly what will become of the microplastics trapped, and created, in such gyres, is unknown.

Air transport

Studies have shown that microplastics, mostly fibers, are also transported in the atmosphere. For instance, atmospheric fallout is 28–280 particles m^{-2} day^{-1} in Paris, France, admittedly an urban area [18]. But microfibers have been found in remote mountain lakes as well [43]. So atmospheric fall out may be a significant source of microplastics even in distant oceans, but this input requires further research, both sampling and modelling.

Sea ice

The potential for sea ice itself to transport pollutants was first recognized by Pfirman et al., in 1995 [44] in the course of research on the transport of heavy metals and organochlorines by Siberian rivers. Once in the Arctic, floating pollutants can become incorporated in sea ice. Much of the sea ice forms over shallow marginal shelves and then moves into the central Arctic ice pack. Pfirman et al. developed a model to run back trajectories on ice pack drift to identify where it originated [36] that was later used when microplastics were discovered in Arctic sea ice cores [1].

Challenges: results and discussion

Vertical heterogeneity

In recent years, a number of authors have modelled the transport of floating marine litter [45**]. To do so rigorously requires including ocean currents, waves, and wind, as well as processes that affect the fate of the debris. Sedimentation and biological ingestion and egestion are incompletely understood, and these and other factors that influence the vertical position of microplastics in the water column affect their availability for transport with currents [46].

Positive buoyancy and chemical stability, or persistence, are what make long range transport of microplastics possible [47]. Most common plastics range in density from 0.85 to 1.41 g cm^{-3} and those used in single use packaging (i.e. PP and PE) are typically less dense than seawater (1.03 g cm^{-3}). Unfortunately, when modelling, we can't assume that plastics that start out floating remain that way. Instead, their depth and availability for transport is strongly affected by vertical mixing and biofouling.

Vertical mixing is produced by wind driven turbulence, and affects the size distribution of small particles in the water column [48–50]. Both observational and modelling studies have shown that the proportion of the smallest size range particles increases with depth [5,41].

Biofouling has a similar effect. The accumulation of algae and other microscopic organisms on marine debris eventually makes initially buoyant items heavy enough to sink. The largest effect occurs within the top few metres of water, where concentrations of the finer particles drop exponentially with depth [51]. On an individual basis, the effects of biofouling are greater for microplastics than for larger pieces of debris, due to their increased surface to volume ratio [52]. As a result, the average size of floating debris increases with distance from coastal source area, another factor which may help explain the lower than predicted numbers of microplastics offshore [25,37,52]. To further complicate matters, particles in benthic sediment can be resuspended as a result of turbulence produced by tidal or wave action [31,48].

Fiber: a knotty problem

The annual PlasticsEurope figures for worldwide production do not include the production of synthetic polymers made of polyethylene teraphthalate (PET), polyamides (PA), polypropylene (PP), and polyacrylonitrile [22]. This is an important omission. Synthetic fibers are commonly used in textiles and clothing, automobiles, and carpets. Polypropylene, the lightest of all synthetic fibers, is used in cigarettes, clothing, industrial fabrics, and carpets, filters, and medical disposables. Polyacryolonitrile is used as a precursor for carbon fiber found in fiber-reinforced polymers.

Fibers are typically the most prevalent shape of microplastic found in the air [17,18], water [6], sediment [19], and marine life [5,7,53,54]. There are four major types of synthetic fiber: polyester, nylon, and acrylic (polymethymethacrylate), and polypropylene. Even natural fibers may contain resins, flame retardants, and polybrominateddiphenyl ethers, which slow their degradation and carry risks to animals which ingest them [8,10]. Anthropogenic microfibers break free from clothing in the course of normal wear, and washing, and enter the marine environment directly through atmospheric transport, and through wastewater treatment plants [17,18].

Conclusions

Efforts to produce global mass balance budgets for microplastics have revealed order-of-magnitude discrepancies between models and observations [27**]. There are many reservoirs (e.g. benthic) and transport vectors (e.g. atmospheric and biologic) that are incompletely understood. It has been estimated that 50% of microplastics in the ocean are located in relatively low concentration regions [27**]. And, while more sampling needs to be done, there is ample evidence of microplastics in the Arctic. We must assume that dwindling sea ice cover and increased human presence will lead to more [55].

In order to know how much more, we need both a better global plastic budget and a more complete understanding of long range transport vectors. Models will need to include all sources, sinks, and pathways, the effects of biofouling, vertical mixing, sedimentation and uptake. This will require that we better understand each of those parts of the system.

We also need to collect empirical data to validate these models. To do so, we should standardize the design of sampling apparatus for surface waters, the water column, benthic and coastal sediment, and sea ice, and make sure the sampling techniques capture the smallest size fraction, particularly fibers [56]. And we need to standardize the categories and units used to report microplastics types and number concentrations. We recommend that a working group of the researchers mentioned in this manuscript be formed and funded to take these vital steps.

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