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Perspective

Small Microplastics: A yet Unknown Threat in the Svalbard (Norway) Region

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Abstract: The Arctic Ocean is undergoing several transformations because of global climate change. Small microplastics (SMPs) or nanoplastics (NPs) carried by marine aerosols may settle in the land ice and be released to the waters, produced following its melting. As sea ice extent reduces and shipping and fishing activities increase, microplastics (MPs) may enter the region following ocean and maritime transports, with implications on Arctic biota, human health, and socioeconomic issues related to the exploitation of marine resources. First analyses on amphipods collected in Ny-Ålesund confirmed the presence of SMPs. Nevertheless, the threat posed by SMPs/NPs to polar biota and regional human health is not fully understood. This article addresses this issue and the need for organisms as potential bioindicators of plastic pollution, which is currently being carried out in the Svalbard region under the framework of the MICROTRACER project funded by the Italian Arctic Research Program (PRA, Call 2021). The outputs of this research are expected to contribute to deepening the current knowledge of SMPs in Svalbard, providing new insights on their occurrence, distribution, and transfer through the marine trophic web, to realize effective control and regulatory framework measures to implement an integrated multidisciplinary approach for monitoring and to reduce MPs pollution in this fragile polar environment.

Keywords: plastic pollution; ecotoxicity; bioindicators; Svalbard

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1. Introduction

Plastic, with a production reaching 390.7 million tons in 2021, is recognized as an emerging concern impacting both environmental and human health [1]. When not correctly disposed of, plastic can be dispersed in several environmental domains (the lithosphere, atmosphere, and hydrosphere); there, particles can be fragmented into different size categories: macroplastics (≥25 mm), mesoplastics (5–25 mm), microplastics (MPs, 5 mm–1 µm, or, for fibers, a length of 3 nm $\leq$ x $\leq$ 15 mm and a length: diameter ratio >3) [2], and nanoplastics (NPs, <100 nm). Macroplastics and MPs account for 73% of the global marine debris, and about 8 million tons/year of plastic move from the land into the ocean [3]. However, due to the lack of standardized pretreatment methods, different analytical techniques employed, and the different size classes of MPs investigated, study reports are difficult to compare. Additionally, small microplastics (<100 µm, SMPs) are always overlooked. Pretreatment methods using strong oxidants or aggressive reagents can result in the loss of relevant polymers, such as polyamides (especially polyamide 6), and/or can modify the sizes of the particles analyzed [4,5]. Hence, the use of mild solvents and a low temperature are recommended to prevent the underestimation of the particles' abundance [5–7]. Due to their sizes, SMPs can be easily ingested by organisms, according to the size of their mouthparts, and enter the trophic web and undergo biomagnification, moving from its lower to higher levels. Additionally, SMPs may be transferred from the gastrointestinal tracts to other tissues of organisms used as a food source by humans [6,7].

Polar regions are experiencing plastic pollution [8,9], and the list of studies on the sources and distribution of plastic fragments in the Arctic region is increasing [10–17], focusing on various size classes of MPs. In this polar environment, local inputs from wastewater discharges (including personal care products and fibers from synthetic textiles), fishing and aquaculture industries, shipping and tourism, long-range transport by marine currents, as well as atmospheric transport by winds and deposition, all together contribute to plastic pollution [13,16]. Nevertheless, SMPs are neglected. In this context the MICROTRACER project [funded by the Italian Arctic Research Program (PRA, Call 2021)] fits in; this research has among its goals the study of the abundance of SMPs, plastic additives, and other microlitter components in organisms, waters, and sediments, allowing the current knowledge gap to be filled.

SMPs and NPs may have severe implications for biota and human health, and may also impair the exploitation of marine resources in the Arctic area, therefore also negatively affecting the socioeconomic aspects in this polar region. Current knowledge of the sources, transport pathways, and fate of MPs/NPs, and their potential effects on the Arctic marine biota and environment, is, however, still incomplete, as previously mentioned.

This perspective article focuses on plastic pollution as an emerging threat in the Arctic region, and in particular in the Svalbard area, exploring in particular the following aspects:

- Plastic sources and transport pathways;
- Plastic and climate change;
- Unsolved questions;
- The need for bioindicators;
- Plastic's sentinel species and current knowledge in the Svalbard.

1.1. Sources and Pathways of Plastic Pollution in the Arctic: State of the Art

Plastic pollution in the Arctic poses a significant threat to this polar environment. In coastal marine areas, MPs accumulation is a frequently occurring event. In recent years, the observed rise in human activities has led to an increase in the number of MPs [18], thereby impacting the local food chain. In the Svalbard area, the state of the art of plastic pollution occurring in several environmental domains has recently been reviewed [16]. Particular attention has been given to updating the current knowledge and future perspectives of the studies of MIcroplastics in the REalm of Svalbard (MIRES). This includes a comprehensive understanding of various key points: the known and potential sources of MPs, their variability and transfer pathways among the cryosphere (glaciers and snow), marine (water and sediments, beaches), terrestrial environments (lakes and wetlands), and other matrices (atmosphere, biota), the possible effects of climate change on MPs distribution (concerning the melting of sea ice and glaciers or permafrost, as well as the changes in ocean circulation), and their ultimate fate and socioeconomic aspects (due to the transfer within the trophic webs up to predators, and the consequent risks for human and animal health).

Primary sources of MPs are wastewater from textile materials, urban dust, and human activities, such as scientific field stations or touristic activities, as documented by Kaliszewicz et al. [19], while the degradation of macroplastics is a secondary source of

MPs. Local and long-range distance sources can be distinguished [16]. Local sources include fishing, shipping, aquaculture, tourism, domestic activities (i.e., washing synthetic textile clothing, personal care products), dumping sites and landfills, sewage, and car tires/snowmobile belt tearing dust. In the Norwegian, Greenland, and Barents Seas, most of the plastic debris comes from fishing gear and packaging materials that are extensively utilized in various applications [8,10,17]. Long-distance sources include sources of plastics at a larger scale, like MPs' travel to Svalbard via atmospheric and ocean currents [13,20,21]. Up to a few years ago, ocean currents were thought to be the main transport pathways to remote locations, such as polar regions [15], but the detection of MPs in snow, ice, and air samples has proved that the atmosphere plays a critical role in their global spread to the Arctic [10,20,21]. In the Arctic region, MPs have been detected almost everywhere (i.e., rivers, oceans, sediments, and the associated biota) [10,22–37]. Regarding plastic pollution in marine biota, in Nordic marine environments, MPs were reported in 14 fish species, some of commercial importance, as well as in blue mussels and marine worms; ingestion of plastic particles was found also in many seabirds and mammals [38]. In organisms (bivalves, heart urchins, polychaetes, fish, and shrimps) collected from a Norwegian fjord (Jeløya), Bour et al. [39] found that the presence of MPs was related to the feeding modality but not to the habitat and trophic level. Plastic debris were retrieved by Fang et al. [40,41] from three benthic organisms i.e., one sea anemone, belonging to Actiniidae, one starfish, *Ctenodiscus crispatus* (Bruzelius, 1805), and one snow crab, *Chionoecetes opilio* (Fabricius, 1788) collected from the Chukchi Sea; MPs abundance in sea anemones was reported to correlate positively with the reduction in sea ice coverage, and the role of these organisms as potential bioindicators of MPs pollution in the Arctic was suggested.

1.2. Plastic Pollution and Climate Change

The Arctic Ocean is undergoing rapid changes in a climate-warming scenario. As sea ice acts as a temporary sink and a reservoir for MPs, and the extent and thickness of the sea ice are reducing because of global climate change, changing temperature and precipitation regimes and altered salinity values are also expected to potentially modify MPs abundance, with consequent impacts at different trophic levels. In marine environments, the presence of MPs can influence water temperatures and physicochemical properties, potentially initiating climate feedback cycles in ocean surface layers [42]. MPs from marine aerosol may settle in the land ice and be released to waters derived from its melting [20]. MPs settling in the soil can be transferred underground until they reach aquifers; the presence of plastic particles in the soil affects its texture, as well as the microbial activity and the transfer of nutrients. Arctic sea ice plays a role in capturing MPs from both seawater and the atmosphere, making it a recognized temporary sink for these particles [43]. Interactions between plastic pollution and climate can be envisaged in the reduction in glacier surface albedo and the consequent alteration of the energy balance caused by MPs [44]; nevertheless, the current understanding of the potential effects of airborne MPs on surface snow is still not complete. As the sea ice extent reduces, MPs may enter the region following ocean transport and increasing shipping and fishing activities, with implications on Arctic biota, human health, and socioeconomic issues related to the exploitation of marine resources.

1.3. Unsolved Questions

As aforementioned, there is a lack of information and understanding about the occurrence and conveyance pathways of SMPs and NPs. SMPs/NPs transported by marine aerosols can be deposited in the terrestrial ice and released into inland waters as glaciers melt. Additionally, they can easily be ingested by invertebrates, entering the trophic web and bioaccumulating or biomagnifying.

Some of the major knowledge gaps on plastic pollution concern the sources, distribution, fate, and effects of the particles. SMPs were found to derive from local and/or long-distance pollution sources, but it is often difficult to quantify the occurrence of SMPs in different environmental domains (i.e., land, ocean, atmosphere, and cryosphere), including the Svalbard area, due to the lack of standardized sampling protocols, preanalytical methods, and analytical techniques to be employed in the assessment. Additionally, these are also accompanied by logistical difficulties in reaching inaccessible areas (like the eastern ones) in the Svalbard Archipelago. Although MPs have been detected in fish and other marine organisms, there is still limited information on the MPs' effects caused directly by them, or by the leakage or uptake of plastic additives (plasticizers and flame retardants, etc.) and their toxicological effects. The abundance of SMPs in Arctic wildlife is still poorly documented, stressing the need to know if and to what level these organisms can accumulate and transfer SMPs to seafood consumers. In addition, the transport pathways and the fate of MPs and SMPs in the Svalbard environment still need to be studied; for example, the presence of plastic reservoirs where plastic can accumulate must be deepened.

1.4. The Need for Bioindicators

In the Arctic Ocean, plastic pollution has been found in several matrices, i.e., water, sediments, and biota; climate-related changes, like ice melt and glacier retreat, are likely to affect the distribution of small MPs and NPs. Concerning their shape and size, SMPs can be confused with food particles, thus entering the food web with ingestion. Ingested MPs can accumulate within organisms, causing physical harm, can be expelled, can become available again in the debris chain, or can be transferred to higher food web levels by predation. Arctic waters support very productive food webs vulnerable to marine pollution, like what is generally observed in other marine ecosystems [45], but wide knowledge gaps with respect to uptake and trophic transfer persist [46]. As extensive monitoring for plastic detection in all species/taxa of organisms is not possible in practice, being time- and labor-consuming, it is crucial to investigate the presence of MPs in target organisms chosen as candidate bioindicators of plastic pollution; furthermore, an accurate evaluation of the most efficient bioindicator species is recommended in a One Health perspective to monitor and assess plastic pollution in the environment [47].

Organisms can be considered suitable bioindicators of pollution if they satisfy some criteria regarding their abundance and widespread environmental distribution, ecological relevance, and tolerance to stressors and disturbances [48]. Moreover, the ecological niche and vagility of the organisms may affect the choice of potential candidates for plastic pollution and the establishment of monitoring plans. Under natural conditions, the variability of biological samples can affect the observed impacts; however, the biological responses have a greater ecological value than using laboratory species.

A list of marine species—including invertebrates and vertebrates, such as seabirds, sea turtles, and mammals—as potential bioindicators of plastic pollution in relation to the size of plastic particles ingested and their habitats has been compiled [49,50]. Considering the complex dynamics of plastics in marine environments, only a set of sentinel species allow a comprehensive plan for the effective biomonitoring of plastic debris. Significant relationships among the abundance of plastics in water and sediment and that of ingested plastics would be necessary to validate the suitability of organisms as bioindicators [51]. Also, other critical aspects include the lack of standardized sampling protocols and analytical methods, as well as toxicity thresholds to evaluate the effects of ingested plastics on marine biota. The use of bioindicators allows a direct quantification of the bioavailability of nutrients and pollutants for the organisms [52]; also, biomarkers (namely, a variation in cellular or biochemical components or structures, or functions/processes, induced by xenobiotics and measurable in a sample) were proposed to predict adverse effects earlier.

Several families of amphipods e.g., gammarids and corophids (Crustacea, Amphipoda) are sensitive to anthropogenic toxic compounds [53,54]. This characteristic, and their trophic role (primary consumers, detritivores, and polyphages) in aquatic environments, make them particularly suitable as bioindicators in toxicity tests [55]. MPs ingestion was documented in several marine species [56–58], and studies tested the MPs toxicity and genotoxicity on them at a lab scale [59–62].

MPs accumulation in invertebrates is of growing concern; they are the lowest marine trophic level, and predatory fish and birds fed on them. In recognition of the role of these organisms as potential indicators of plastic pollution, the occurrence and distribution of MPs in Arctic invertebrates have recently been reviewed [41,63], providing also recommendations for the next monitoring plans. However, regarding the smallest fraction of plastic items (e.g., SMPs and NPs), to date, the body burden of pollutants from invertebrates is still an unknown threat, especially considering that it may be susceptible to bioaccumulation and biomagnification across the trophic web up to humans. Additionally, SMPs and NPs present in digestive systems and fecal pellets enter the debris chain reduced in size [62]; this, likewise, enhances the transfer within organisms from the gastrointestinal system to other tissues [64], also increasing any toxic effects. Bivalve mollusks can concentrate several pollutants in their tissues and organs, including SMPs and NPs, due to their filter-feeding behavior; therefore, they are suggested as potential plastic pollution indicators [65].

Another suitable bioindicator for MPs pollution, because of its wide distribution, ecological niches, susceptibility to MPs uptake, and close connection with human health, is the mussel, *Mytilus* spp. [66]. Laboratory studies have shown that mussels can be good organisms for studying the uptake, accumulation, and toxicity of MPs. Results from field studies are sometimes not comparable due to the high spatiotemporal variability of these organisms and the lack of a standardized approach. A widespread oyster species, such as *Crassostrea gigas*, may also be employed as a bioindicator of SMPs ingestion [6,67,68]. However, a standardized protocol must be adopted for a large-scale MPs monitoring program.

Along the British Columbia coast (Canada), within the Pollution Tracker (2015–2018) program, Noël et al. [69] monitored MPs in sediment and mussel samples, using both microscopy and Fourier transform infrared spectroscopy (FTIR) to obtain detailed information on the size, shape, and polymer composition. Mussels have also been used as bioindicators of MPs, both alone (*M. galloprovincialis* (Lamarck, 1819), Provenza et al. [70]) and in association with another molluscan species, such as oyster (*M. edulis* and *Cassostrea virginica* (Gmelin, 1791) [71,72]).

Mussels (*M. galloprovincialis*) and polychaetes (*Hediste diversicolor*, O.F. Muller, 1776) were used in a microcosm study to monitor the fate of fluorescent polystyrene MPs (size 1 μm) at concentrations of 10^3 and 10^5 particles/mL for 1, 4, 24, and 72 h inside these benthic organisms: MPs were found to accumulate in the digestive tract of mussels [73].

In a sea urchin species (*Tripneustes gratilla*, Lamarck, 1758) feeding on algae and detritus, Pratita et al. [74] detected high numbers of MPs (mostly as films, fragments, and filaments) in the intestine, rather than in the gonads, suggesting this organism as an indicator of pollution in the coastal environment of Gunungkidul (Yogyakarta, Indonesia).

In the pelagic domain, jellyfish were reported to be target organisms for macro- and microplastics [48]; fish and seabirds (albatrosses and petrels) were also suggested as bioindicators for marine litter [75]. Regarding Mediterranean fauna, in the framework of the Plastic Blusters project (funded by the German Federal Ministry for Economic Cooperation and Development) [76], wide attention has been given to the selection of sentinel species to monitor the impact of marine litter according to specific criteria (i.e., available information on the ecology and biology of the species, habitat and trophic information, spatial distribution, commercial importance, and documented ingestion). Along the Spanish coast (Mediterranean Sea), the bogue (*Boops boops*, Lamarck, 1758) was indicated as an indicator of MPs pollution [77]. To detect the impact of plastic ingestion in bioindicator organisms, biomarkers should include the effects at the molecular (DNA damage, alteration in gene expression, and protein synthesis) cellular (cell functions), and tissue (histological alteration) levels.

1.5. Plastic's Sentinel Species and Current Knowledge in the Svalbard Area

Identifying the most suitable bioindicator species is a crucial point in developing plastic pollution monitoring. Taxonomic groups, such as amphipods and gastropod species, can be suitable candidates for this purpose due to their ecological relevance and previous knowledge that indicate them as entry points for MPs in the food web. The uptake of MPs ingested by selected benthic species of invertebrates (e.g., crustaceans, amphipods and mollusks, gastropods) should be studied. Amphipods can also be detritivores, thus providing an essential link in the food web to upper-level consumers. Gastropods are herbivore grazers and carnivore predators, covering, with the amphipods, a wide range of trophic habits. Additionally, both amphipods and gastropods are increasingly used as model organisms in ecotoxicological studies. *Gammarus setosus* (Dementieva 1931) is a common benthic amphipod that lives in subtidal and low intertidal environments from the Arctic to Penobscot Bay (Maine, USA), reaching densities of 3000 individuals/m^2 in some spots [78]. These organisms, primarily detritivores, may also be predators of small invertebrates [79]. In specimens collected from the Svalbard Archipelago, and analyzed using both the Nile Red staining technique and micro-FTIR, SMPs ingestion was proved, thereby recognizing polymers, such as polyamide 6, and plastic additives, such as polymethylacrylamide [11]. While identifying the polymers and their abundance indicates the possible source of contamination, the threats posed by MPs to polar biota and human health are not fully understood. The plastic body burden of amphipods and other invertebrates can be available for uptake by their predators, with possible negative consequences due to their composition, or as a vector of contaminants. The presence of MPs in the muscle tissue of fish was demonstrated [64]. The occurrence of plastic additives and other microlitter components was studied in the digestive apparatus of fish [7]. The plastic additives identified and simultaneously quantified were primers, coating agents, dispersant agents for paints and coatings, lubricants, antistatic agents, flame retardants, and vulcanizers. Considering the total abundance of particles (SMPs, plastic additives, and other microlitter components), the percentage of SMPs ranged from a minimum of 34% to a maximum of 82%. The gastrointestinal tract was indicated as the main route of entry of SMPs into the tissues [80]. MPs transfer along the trophic web can reach humans; thus, the selection of model species is crucial for studying these processes and monitoring the impact of SMPs.

In the framework of the research project "Small MICROplastics (<100 μm) bioindicaToRs in the changing Arctic EnviRonment (MICROTRACER)", funded by the Italian Ministry for University and Research (MUR) within the Arctic Research Programme (PRA21_0005, 2022–2024) at selected stations of the Western Svalbard region, the occurrence and distribution of small (<100 μm) SMPs and NPs, their chemical nature, their primary sources, and their fate in the environment, with particular reference to the chemical pollutants potentially adsorbed, are currently been investigated. To globally assess MPs impacts, the analyses also address the microbe–plastic interactions ("plastisphere") and the microbiome of bioindicators, since microbes are sentinels of environmental changes [81]. To investigate the effects of the ingested SMPs and related pollutants on the sampled benthic organisms, a set of biomarkers, including the body's biochemical composition and energy allocation, such as glucose, glycogen, and lipid levels, as already developed [59], antioxidant enzymes (catalase and SOD), detoxifying enzymes (glutathione S-transferases), and reactive oxygen species (ROS), will be analyzed. The whole-animal transcriptomic response in the selected species will be examined, and changes in gene transcription will be used to detect environmental stress related to the SMPs' presence and uptake. The effects that SMPs can have on different invertebrate species will be assayed, and this will allow us to evaluate the suitability of the assayed organisms as candidate bioindicators of MPs contamination in the Arctic marine food web.

2. Conclusions

Plastic pollution in Svalbard is a very recent research topic. Since the pioneer study by Lusher et al. [14], several studies have been focused on the occurrence and distribution patterns of plastic (mostly belonging to the MPs fraction) in different environmental domains, but SMPs have not been studied yet. Research activities carried out within the project MICROTRACER aim at assessing the accumulation of SMPs, plastic additives, and other microlitter components in the Svalbard marine ecosystem by invertebrate organisms and the potential threat they might represent to humans. The organisms collected will be analyzed by spectroscopic, microscopic, and molecular methods to confirm the suitability of these species and related parameters as bioindicators and biomarkers for plastic pollution monitoring. The data obtained will help to expand current knowledge about SMPs in Svalbard, providing new insights into their presence, distribution, and transfer through the marine trophic web. In addition, the results of this study will represent a baseline for implementing multidisciplinary and integrated monitoring; this will enable the design of mitigation actions to reduce SMPs pollution in polar environments, and plan efficient surveillance and regulatory measures.

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Data Availability Statement: Data will be available upon request.

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