Polarquest 2018 expedition: plastic debris at 82°07' North

Stefano Aliani, Gianluca Casagrande, Paola Catapano and Valeria Catapano

Abstract Many human perturbations have the potential of destabilizing the present functioning of the environment and marine plastic is one of them. Plastic debris was found everywhere on earth, including polar waters. The Polarquest 2018 expedition around Svalbard (July and August 2018) used sustainable sail vessel *Nanuq* as a platform to sample microplastic in seawater and macro debris stranded on beaches.

Eight stations were sampled trawling a Manta net in the top 50 cm of surface water and four stations filtering surface seawater from buckets. A record-breaking Manta net sample was carried out on the edge of the North Pole ice shelf at a latitude of 82°07' N. Flying drones made visual observations of debris on beaches of Alpiniøya island (North-East Svalbard) with ground truth by human visual sightings.

Citizen science cruises in the Arctic are likely to increase in the next years due to ice-free ocean parallel to growing interest in plastic in the ocean. The number of cleanups and microplastic surveys are likely to increase as well and Polarquest 2018 was the first expedition of this kind to reach and sample beyond 82° N.

Keywords: Arctic, microplastic, marine environment, North Pole, polar ice shelf, polar drones, 82nd parallel North, Svalbard

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1. INTRODUCTION

> *"The barrenness of the country and the severe weather conditions had attached to North East Land a peculiarly evil reputation, increased by the disappearance of Schroeder Stranz and three other members of the German Arctic Expedition in 1913, and by the Nobile disaster of 1928."*
>
> R. A. Glen, *Under the Pole Star*.

It is hard to imagine anything more remote and wilder than the Svalbard islands. The surrounding waters are uncharted and it takes some luck to set foot on Svalbard's northernmost islands: the weather is often bad, or the shore is blocked by ice or the beach is occupied by a polar bear or you can run onto an uncharted rock ... It is amazing how many things can go wrong in these remote places.

For many years and well into the 1990s, it would have been impossible to sail this route especially with a 60-foot (18.2 m) yacht, closed off as it was by dense drift ice for most of the year. Reaching the 82nd parallel on a sailboat and completing the circumnavigation of Svalbard archipelago around the ill-famed East coast of Nordaustlandet, was not just the work of the Arctic expertise, sailing ability and exploration talent of skipper and yacht builder Peter Gallinelli. Polarquest 2018 could sail to as high as 82°07'N, less than 900 km from the North Pole because the ocean was completely ice-free. Of course, 2018 has been an exceptionally warm year compared to the past and short-term fluctuations have been known since navigation in these waters started. But the exceptionally ice-free summer of 2018 is more likely not to remain an exception (Fig. 1).

The Polarquest 2018 expedition program included historical exploration, cosmic rays measurements, drone mapping of uncharted land territories and plastic debris sampling.

Historical documents and the chronicles of survivors show that on May 25 1928, the airship *Italia* crashed on ice. *Italia* was the very first airborne scientific laboratory flying over the North Pole, led by Air Force General and airship engineer Umberto Nobile in 1928, and crashed onto ice some 120 km Northeast of Nordaustlandet, Svalbard, on its return journey from the first airborne circling of the North Pole. The survivors radioed the coordinates (81°14'N, 25°25'E) and 8 of them were rescued after an unprecedented international rescue expedition effort. In summer 2018, the sea surface North of Svalbard was ice-free and taking advantage of this unusual situation, Polarquest 2018 echo-surveyed the sea bottom for metallic wreckage using an experimental 3D multi-beam sonar from *NORBIT Subsea* (a case study will be soon published on https://norbit.com/subsea/case-studies/).

The intensity of charged cosmic radiation had been measured using simple instruments built in collaboration with *CERN* (*European Organization for Nuclear Research*) by high school students supervised by scientists. The project had a strong education and communication dimension, with the involvement of 18-year-old students from Norway, Switzerland and Italy. The detector onboard *Nanuq* took data almost continuously, integrating at the end about 861 hours of data with a global efficiency of about 91% and the saturation of the cosmic ray flux at ground level has also been measured in these extreme regions near the North Pole.

The presence of microplastic debris on the ocean surface and macro debris stranded on beaches in the Northern and North-Eastern regions of the Svalbard archipelago, very rarely accessible due to sea ice, have been assessed. Floating microplastics were sampled filtering seawater and the presence of macro-debris on beaches was checked by sightings and by visible, infrared and near-infrared surveying performed with commercial drones.

1.1 Marine Litter in the ocean and a change in public awareness

The plastic itself is not intrinsically bad and it is conceivable that our dependence on it will still grow in the second part of the current century, given its durability, among other unique features. To understand the root of the plastic crisis today, it is worth dwelling a little on this exceptional material and the features that make it at the same time so unique.

Plastic makes up the largest quantity of the non-biodegradable human-produced material on Earth and has become a huge environmental concern. Because of its longevity, it can travel over great distances from its origin with sea currents and accumulate in remote places such as the Poles, a crucial area for the balance of our planet's sustainable future. Once in the ocean, physical and biological processes cause plastic debris to break down into microplastics, i.e. smaller than a few millimetres, which are difficult to remove from the ocean.

"Plastic"[1] is a common way to describe polymers we are familiar with. They are usually artificially produced from petroleum or natural gas and are long-chain molecules made of hundreds to thousands of links of single portions called monomers. Important physical properties such as strength and toughness, which short molecules simply cannot match, are the result of long-chain polymers. These peculiar durability properties are greatly appreciated in products but become a problem when dealing with waste management. As a result, improperly managed plastic waste is lost in the environment and as its ultimate destiny it ends up in the ocean, even if released thousands of km far from the coast (Lebreton et al. 2017).

Many other human perturbations have the potential of destabilizing the normal functioning of the environment, and, if these perturbations are global, pervasive, widespread, abundant and persistent, they are accounted for global change Planetary Boundaries (Galloway 2016). Nine planetary processes have been identified whose changes can drive the Earth system into a new state (Will et al. 2015), affecting basic functioning processes all over the planet. The most critical at present are climate change, biodiversity loss, nitrogen and phosphorus cycles, ocean acidification, land use, freshwater, ozone depletion, atmospheric aerosols, chemical pollution. The latter also includes a new category of pollutants: marine debris.

Floating litter in the oceans of the Earth has for a long time been considered a natural phenomenon and not necessarily as harmful pollution.

As late as 1974, Willard Bascom, a mining engineer turned oceanographer and at the time director of the *Southern California Coastal Water Research Project*, wrote in a *Scientific American* article (Bascom 1974) that:

> *”Contrary to some widely held views, the oceans are the plausible place for man to dispose of some of his wastes. If the process is thoughtfully controlled, it will do no damage to marine life”.*

In the same article, Bascom goes as far as stating that:

> *“Man must do something with his wastes, and the ocean is a logical place for some of them. Littering is an aesthetic problem rather than an ecological one.”*

He argued that most of the substances that are called pollutants are already present in the ocean in vast quantities: sediments, salts, dissolved metals and all kinds of organic material. According to Bascom, the ocean can tolerate more of them; the question is how much more it can tolerate without damage. Such a statement certainly sounds preposterous today, but at the time, when the world population was almost half of today’s, positions like Bascom’s were respected enough to deserve publishing on *Scientific American* and surely shared by most (Fergusson 1974). Although not by everyone.

Already in 1962, Rachel Carson had laid the foundations of the contemporary environmental movement with her seminal book “*Silent Spring*”, in which she describes the damage of DDT to all natural systems and to human health. Carson, a born ecologist and a passionate marine biologist, had become internationally famous in 1951 with her bestseller *“The Sea Around Us”*, for which she is remembered as the finest nature writer of the twentieth century, combining as she did scientific concern for the environment and human health with a sense of wonder for nature. This classic biography of the sea, still relevant today, was completed by two more science popularization chefs-d-oeuvres, *“Under The Sea”* and *“The Edge of The Sea”*. With her trilogy of the sea, Carson pioneered an environmental ethic leading to sustainability and anticipated the dangers of human impact on the sea as a threat to life itself. In the preface to the 1961 edition of *“The Sea Around Us”* she wrote:

> *“By its very vastness and its seeming remoteness, the sea has invited the attention of those who have the problem of disposal, and with very little*

discussion and almost no public notice, at least until the late fifties, the sea has been selected as a "natural" burying place for ... rubbish and other low-level wastes ..."

Rachel Carson spent most of her life engaging citizens from all walks of life with her sense of wonder for the beauty of the sea, making them aware at the same time of the dangers of reckless consumption of resources and the wastes they generate. Unfortunately, also Bascom's position, typical of the first ages of plastic, has had many supporters and a proper estimate of the dimensions of the problem is quite recent after the sea has become the largest waste disposal in the world. This is especially true for marine litter and plastics.

According to the widely accepted definition proposed by *UNEP* (*The United Nations Environment Programm*) and also adopted by the European Commission, marine litter is defined as "any persistent, manufactured or processed solid material discarded, disposed of, or abandoned in the marine and coastal environment." Litter consists of items that have been made or used by people and have been deliberately discarded or unintentionally lost in the sea or on beaches, including materials transported from land into the marine environment by rivers, run-offs, sewage systems or winds.

Today, we are all very familiar with floating macroscopic litter in the sea. Litter has become a common element of our beaches and coasts' landscapes and everyone has the direct experience of personal sightings of marine plastic debris. Synthetic polymers have joined the family of natural litter and the quantity of plastic in the sea largely outnumbers natural detritus such as wood, weeds and pumice. Plastic production has seen exponential growth since its entrance on the consumer stage, rising from a million tons in 1945 to about 350 million tons in 2017 (*Plastic Europe*, 2018), an 8% Compound Annual Growth Rate (CAGR). The trend is increasing with an annual growth rate of 3.5% and more plastic was produced in the 21st century so far than in the whole 20th century (Geyer et al. 2017).

Current estimates of floating marine debris in the ocean report millions of metric tons and we are now aware that considerable quantities of plastics contaminate the marine environment (Cozar et al. 2014; Jambeck et al. 2015). This pervasive and persistent pollutant is widely dispersed and its occurrence has been demonstrated worldwide, from densely populated areas to remote regions.

At first, the possibility of plastic accumulation at polar latitudes has been overlooked because of the lack of nearby pollution sources. For example, Jambeck and coworkers used estimates of coastal population densities to calculate plastic inputs into the ocean with impressive results. But the number of persons living near the coastline normalized by the marine surface area was extremely low for the Arctic Ocean, out of the range estimated for the rest of the world's ocean basins. While subtropical ocean gyres have been recognized as major marine accumulation zones of floating plastic debris and a lot of scientific and public interest arose on these accumulation areas, the possibility of large plastic accumulation at polar latitudes has been initially overlooked because of the lack of nearby pollution sources.

Nowadays, there are some clues that densities may be relevant in the Arctic as well (Cózar et al. 2017) and modelling experiments suggest that there is a possibility that a future 6th gyre of accumulation may develop in the Barents Sea (Van Sebille et al. 2015).

1.2 The Arctic today and how marine debris gets there

The Arctic Ocean has been an integral part of the Earth's history for the past 130 million years and contributes substantially to the current functioning of the planet and life as we know it. It is a closed basin, connected to the Pacific Ocean by the Bering Strait, to the Atlantic Ocean by the Fram Straits and the Barents Sea and through the Canadian Arctic Archipelago of the Baffin Bay. It has an area of about 15,558,000 km^2 and a total volume of 18,750,000 km^3, which represents 4.3% of the total area of the world oceans and 1.4% of the volume (Amante & Eakins 2015). This difference is because the continental shelf is about 70% of the Arctic Ocean: along the American side it is about 50-90 km wide, and on the Siberian side it is over 800 km. Apart from the central part of the basin, water depth is usually low and ranges from 20-60 m in the Chukchi Sea and probably in Siberia, to 10-40 m in the Laptew Sea, 100 m in the Kara Sea and 100-350 m in the Barents Sea. Many rivers flow into the Arctic, lowering salinity and greatly influencing the properties of its surface waters.

Floating marine debris is advected by surface currents and by winds, therefore the knowledge of surface water dynamic patterns is mandatory to understand how plastic debris arrives in the Arctic and how it leaves the Arctic.

The surface circulation within the Arctic basin has two main currents: the Transpolar Drift from the East Siberian continental shelf to East Greenland through the North Pole and the vortex of Beaufort (Beaufort Gyre) which, looking from the North Pole, usually turns clockwise in the Beaufort Sea, in the North of Alaska. The water trapped in the Beaufort Gyre can circulate the Arctic for many years while it is trapped in the Transpolar Drift and usually leaves the Arctic quickly, on average a couple of years.

The only passage between the Arctic and the Pacific is the Bering Strait, ~85 km wide and ~55 m deep. Although the total volume exchange is not very high if compared to deeper passages, Pacific waters have been regularly detected in the Atlantic due to their peculiarly high phosphate concentration relative to nitrite (Jones 2001).

The existence of Arctic pathways between the two oceans was also demonstrated by the floating plastic duck toys lost in the Pacific by container ship *Ever Laurel* on 10 January 1992 on its route from Hong Kong to Tacoma. Once a number of these plastic ducks were found stranded all over the Pacific, the oceanographers Curtis Ebbesmeyer and James Ingraham predicted that after 6 years some would be found in the Atlantic as well (Ebbesmeyer & Ingraham 1994). Media gave a lot of attention to the lost plastic ducks and the public was involved in their search along the US and UK coasts as one of the first examples of citizen science applied to plastic debris.

The exchanges of the Arctic to and from the Atlantic are more complex as they don’t take place across a single gateway but involve different water basins and passages (Beszczynska-Möller et al. 2011).

The Central Arctic Basin exports water to the North West Atlantic through the famous North West Passage across the Canadian Archipelago and the Labrador Sea between Canada and Greenland. These basins have complex ocean dynamics and are the final passages to the Atlantic. Inputs of surface Atlantic waters through this passage are reported and a westward branch of warm waters can recirculate in a gyre within the Labrador Sea where there are evidences of plastic pollution in seabirds (Provencher et al. 2015) (Avery-Gomm et al. 2018) (McWilliams et al. 2018) and on the shore (McWilliams et al. 2018).

The major surface outputs from the Arctic are on the western side of the Fram strait along the East Greenland coast, as a southward virtual continuation of the Transpolar Drift, which brings ice and cold water to the East Coast of North America. Information on the presence of marine debris along this entire pathway comes from spotted records (Morgana et al. 2018). Another output of Arctic waters is in the Barents Sea along the Eastern coast of Svalbard.

Major inputs to the Arctic Ocean come from along the Eastern side of the Fram strait and through the Central and Eastern parts of the Barents Sea. The northernmost vein of the warm surface water originated in the tropical Atlantic, which had flown along the heavily industrialised Western European Coasts, enters the Arctic basin in two separate branches: one directed northward to Svalbard and another directed eastward through the Barents Sea.

There are a lot of papers about the circulation in the Arctic, especially in surface waters, and descriptions more detailed than what is reported here can be found in literature (Beszczynska-Möller et al. 2011; Jones 2001; Østerhus et al. 2019; Rudels 1995). Fig. 2 provides a graphical representation (Arneberg, et al., 2009) (Rudels, 1995).

Recently, there have been signs of changes in the Arctic suggesting that the planet’s near future may be different from the present and the recent past. For example, satellite data show that the summer ice cover keeps decreasing to the lowest levels since the beginning of instrumental surveying. In September 2018 the sea ice extent, that is the integral sum of the areas of all satellite grid cells with at least 15% ice concentration, dramatically decreased. 2018 effectively tied with 2008 and 2010 as the sixth lowest summertime minimum extent in satellite record (https://svs.gsfc.nasa.gov/4684; see Fig. 1!). Many scientists now predict an ice-free Arctic within a few decades, much earlier than anticipated by previous *IPCC* (*Intergovernmental Panel on Climate Change*) predictions.

Invasive species, biodiversity loss at low and high trophic levels, acidification and new pollutants including marine litter have been reported in many areas of this basin.

The environmental and social implications are enormous because these changes that are appearing faster than expected catch many largely unprepared. Marine litter is one of the drivers of changes in the Arctic.

1.3 History of Plastic studies in the Arctic

Some of the world's first observations about plastics at sea and its consequences for marine life were made in the North Pacific and Alaska (Fowler 1987; Laist 2011; Laist, 1987; Merrell 1984; Merrell 1980; Day 1980; Threlfall 1968).

The European Arctic counterpart did not receive comparable attention in the past, but more recently a high number of studies on marine litter in the European Arctic have been published focusing on the presence of marine plastics in the ocean, in the fauna, especially birds, and the consequences for the environment (Buhl-Mortensen 2017; Hallanger & Gabrielsen 2018; Trevail 2015; Bergmann et al. 2016; Bergmann 2012; Bergmann et al. 2017). Dedicated working groups within the Arctic Council are now focusing on marine plastic. A panarctic review paper is under preparation under the coordination of *AMAP* (*Arctic Monitoring and Assessment Programme*) and *PAME* (*Protection of the Arctic Marine Environment Working Group*) and many Governments of Arctic states are now putting forward regional action plans for management and mitigation actions to reduce this pollution in the Arctic. An updated list of papers on plastic in the Arctic is reported in a recent desktop study (PAME 2019).

In the Fram strait and in the Barents Sea, plastic debris has been studied during an *AWI* (*Alfred Wegener Institute*) *Polarstern* expedition (Bergmann et al. 2016). They used visual sightings from the ship and helicopters to spot floating marine litter. Surface and subsurface microplastic was reported from the Fram strait and along the path from Europe to the Arctic in the warm Atlantic surface current (Lusher, et al., 2015). Plastic was also found in the sediments at the deep sea Hausgarten observatory in the Fram Strait (Bergmann 2012; Bergmann et al. 2016). Compared to the water column, sea ice and deep-sea sediments have microplastic concentrations that are several orders of magnitude higher.

Entanglement and ingestion of plastic by marine animals has been reported for hundreds of species (Laist 2011; Laist 1987) all over the Arctic. Seabirds are a particularly good indicator or sentinel species for marine plastics because birds can forage over large areas, essentially sampling for plastics over their entire living range (OSPAR 2016; Franeker et al. 2011; Jambeck et al. 2015).

Additionally, many seabirds breed in colonies that are relatively easy to access for study purposes (Piatt et al. 2007). The impact of plastic on seabirds is still uncertain, but may include chemical exposure (Carpenter & Smith 1972; Ryan 1987; Mato et al. 2001) and is pervasive and global (Wilcox et al. 2015). Other animals that suffer from entanglements are seals, polar bears and reindeers with many pictures on the web showing these species dealing with plastic macro debris.

Recent analyses of four ice cores collected across the Arctic Circle pointed to a considerable abundance of microplastics in the sea ice (Obbard et al. 2014). Annual sea ice is formed when the ocean surface freezes because of low air temperature. Nearly fresh water ice crystals are produced from saltier seawater, and thicken primarily by downward growth through a process called accretion. In the initial stages, small (<1 mm) ice crystals called frazil ice gather at the surface, aggregate, and grow. As they do, they tend to scavenge particulates in the water column, including floating microplastic that is then trapped and advected in ice.

A variable portion of this annual ice becomes multiannual, i.e. the quasi-permanent sea ice in the Arctic, and plastic therein is therefore the result of many years of plastic sequestration. Unfortunately, global warming has increased ice melting and we expect to have a massive reduction in sea ice cover in the next years, with consequent release of the microplastic trapped in the melting ice (Obbard et al. 2014). Peeken et al. (2018) found several orders of magnitude higher concentrations of microplastic in the sea ice than in sea water. Particularly abundant were the small particles (11 μm), which are a major concern as they can be more easily taken up within the lower levels of the food web.

The possibility that plastic pollution affects the Arctic food web is worthy of further consideration. Plastic ingestion in northern fulmars (*Fulmarus glacialis*) from the Svalbard Islands, between the Greenland and Barents Seas, has already been reported to exceed the recommendations for an acceptable ecological status (Trevail 2015). The growing level of human activity in an increasingly warm and ice-free Arctic, with wider open areas available for the spread of microplastics, suggests that high loads of marine plastic pollution may become prevalent in the Arctic in the future.

1.4 Sources of Plastic in the Arctic: long distance vs local

Although human population North of 60° latitude is relatively low, ocean circulation models predict a plastic accumulation zone within the Arctic Polar Circle, especially in the Barents Sea, and a Garbage-Patch-like scenario in twenty years (Van Sebille et al. 2012). But numerical observations have to be validated by real data. The longevity of plastic and microplastic means that they can be distributed over huge distances from their origin, and accumulate in remote areas. Sea currents are the highways of the oceans. Nowadays, the Arctic cannot be considered a pristine remote environment, with accumulations in the Greenland and Barents seas, which may constitute a dead end for the surface transport of floating debris produced at lower latitudes (Cózar et al. 2017).

Marine and maritime operations in the Arctic have recently increased following the increase in the exploitation of natural resources, so the economic ties between the Arctic and the global economy are due to expand. The reason is certainly to be found in the effects that global warming is showing on the sea ice coverage, which has always been the major limit to the exploration of this region of the planet, but it is also to be linked to the development of technology and science that mitigates some of the problems related to this extreme environment. Both trends are expected to continue soon. With the withdrawal of sea ice in the Arctic, greater access to the sea is expected, and potentially longer seasons are envisaged with greater possibilities for navigation and maritime operations. Among the emerging maritime activities in the Arctic are: new marine systems and platforms that support the development of offshore hydrocarbon research and resources; the expansion of marine tourism; summer transport routes at sea to support the mining and transportation of minerals, but also modest levels of growth of the trans-Arctic cargo movement; potential increases in fishing in coastal waters such as the Baffin Bay or the Davis Strait; a general increase in the summer presence of a large variety of ships of all sizes throughout the Arctic Basin and more and more scientific expeditions in the central part of the Arctic Ocean.

Therefore, also local sources of plastic pollution are not negligible in the Arctic. Any human settlement has an impact on the environment and in the past small communities had small frozen dump permanently stored in permafrost. The release of amounts of plastic in the sea from these sources was probably insignificant in the past but these traditional sources are now confronted with global change. For example: melting of old dumping sites that used to be frozen in permafrost and now are free to diffuse plastic; wastewater treatments plants that cannot sustain summer tourist blooms.

New sources have to be added to the traditional local inputs. The number of cruise and commercial ships in the Arctic has overgrown and in spite of *MARPOL (International Convention for the Prevention of Pollution from Ships) V* and *Polar Code* accidental plastic release has to be expected following accidents or as mismanagement of paint, wax or ballast water. The number of offshore rigs is on a rise as the sea becomes more and more ice-free, and we depend on industry regulations more than on laws to protect the sea, being industry often stricter than the law itself.

Safety and environmental protection in the Arctic will be significantly improved with the adoption and full implementation of *IMO* (*International Maritime Organization*) *Polar Code* obligation by *IMO* member states. Defining the risks for the various classes of ships in the ice-covered and ice-free polar waters is challenging, and particular attention has been paid to identifying hazards and consequences, including plastic.

There is an urgent need to assess the levels of plastic pollution in the Arctic, to allow for future monitoring and to assess the risk of the potential impacts of decreasing sea ice, increasing shipping and commercial activity in the area, as well as a need for a pervasive public awareness effort. Although climate change made the Arctic less extreme than before, it remains a remote harsh environment where monitoring is not an easy task and the few field studies available have not yet fully validated models of microplastic distribution within polar waters. Long-term environmental time-series data and improved modelling capabilities are necessary to enhance our predictive capacities. A significant investment in time and money is required to upgrade and expand the existing observing infrastructure, to support research and the sharing of data and information.

The management of plastic pollution in the Arctic is a complex issue. For example, burning plastic in situ is a global countermeasure to control marine debris, but not suitable for the Arctic because of the resulting increase of black carbon and other pollutants. The impact of black carbon on the ice needs special controls, which makes burning plastic probably not a suitable way to manage it.

Every country with commercial interests and consequent environmental responsibilities must have a long-term plan for Arctic research on potential pollution. *PAME* supported a desktop study (PAME 2019) summarizing present-day knowledge of marine plastic in the Arctic and is the baseline for a Regional Action Plan on Marine Litter under preparation. The plan should include an assessment of response technologies and related logistics, improving forecasting models and associated data. Industry, academia and governments should be included in the program, to be developed with peer review and transparency as working methods. Many countries already support polar research and several international initiatives are in progress. Collaborative mechanisms provide a solid platform but the pace of progress, the level of investment, and the extent of collaboration must increase significantly.

Public awareness and interest to collaborate and take part are growing, as many pan-Arctic citizen-science initiatives have demonstrated. Surfing the web, one quickly realizes that citizens in Alaska and Norway are among the most involved in monitoring and clean-up programs (or have a higher web presence). But citizens from other countries and not necessarily form Arctic regions only, are also increasingly involved and aware.

2. Polarquest

2.1 Citizen Science exploration projects in the extreme Arctic

The famous first historical polar expeditions were privately funded, or as we say now, they were a kind of Citizen Science. For example, Lincoln Ellsworth spent US$ 100,000 to fund Roald Amundsen's 1925 attempt to fly from Svalbard to the North Pole. Nobile's expedition was funded largely by the press and families from Milan, an early example of crowdfunding. Shackelton's Antarctic trip was funded by three major private sponsors, Stancomb Wills, Dudley Docker and James Caird and the *Endurance*'s lifeboats were named after them.

The recent *Tara* Oceans Arctic polar expedition was funded by the private foundation *Tara* (https://oceans.taraexpeditions.org) and several scientists supported by citizens sampled the Arctic also for floating plastic debris. From the Greenland Sea, the expedition circumnavigated the Arctic Ocean to the Labrador Sea. From June to October 2013 plastic samples were collected from 60° to 80° latitude North. To provide a first assessment of the plastic load in the Arctic surface waters, the Arctic Polar Circle was divided into two more uniform sectors in relation to plastic pollution: a highly polluted sector from the 35th meridian of longitude West to the 74th meridian of longitude East (Greenland and Barents Seas; including 17 net tows) and a less-polluted sector accounting for the rest of the Arctic Circle (including 21 net tows). The fragmentation and typology of the plastic suggested an abundant presence of weathered debris that mainly originated from distant sources. Some of these findings are summarized in Cozar et al. (2017).

Sailing yachts *Bagheera* and *Snow Dragon II* were on an Arctic Mission and on 29 August 2017 they reached their northernmost site at 80°10' North, 148°51' West. Sailing vessel *Bagheera* also sailed as far north as 82°26' in 2004, 2005 and 2006 and again as far as 80°N in the summer of 2017 in the Central Arctic Ocean, sailing from Alaska. The expedition was led by Timothy Gordon and hosted a microplastic project from Exeter University. This information is available on YouTube, Facebook and the website https://bagheerasailing.com/.

Another expedition in 2018 took place on board of *Blue Clipper*, a 33 m tall-ship where scientists, media experts and artists focus on plastic pollution in a cruise named *Sail Against Plastic*. The scientific direction was again from students and postdocs of Exeter University and the team included representatives from *Surfers Against Sewage*, the *Marine Conservation Society* and *Marine Megafauna Foundation*, which are well web-represented organizations against marine litter (https://www.sailagainstplastic.com/).

The *Alfred Wegener Institut*e (Germany) also endorsed expeditions in Svalbard run by *OceanExpeditions*, which included beach marine litter monitoring and cleanups and resulted in scientific papers (Bergman et al. 2017).

An ice-free Arctic will become a regular scenario in the next years and considering the explosion of interest from the media about marine litter, it's easy to foresee that the number of boats sampling the ocean for litter will increase.

Given the current relatively easy access to high latitudes, many commercial touristic expeditions offer sailing trips to the extreme North. These boats are rented by tourists to sail to northernmost latitudes and people on board are keen to provide some contribution, especially after the recent high interest of media on plastic studies. Cruises often have educational purposes but, without clear scientific objectives and comprehensive sampling design, the possibility to exploit their collected data for research may be affected. For example, the samples may not have sufficient quality to be used for scientific purposes due to contamination, which is a major issue when sampling microplastic. Even managing metadata and cruise logbooks may become a not so easy task for non-specialists.

Nevertheless, it's easy to foresee that the number of boats sampling the ocean for litter will increase. The *Association of Arctic Expedition Cruise Operators* (*AECO*) is an international association for expedition cruise operators operating in the Arctic and others with interests in this industry. *AECO* is working to drastically cut back on single-use plastics on Arctic expedition cruise vessels, as well as enhance cruise passengers' involvement in regular beach cleanups, but they have limited control over small vessels. Are small sailing boats suitable vessels to collect data about plastic in the Arctic? The experience of Polarquest 2018 and some recommendations from that experience may help similar future expeditions.

2.2 Polarquest 2018

In summer 2018 the Polarquest 2018 expedition on board sustainable sailboat *Nanuq* sailed to the edge of the Arctic ice-shelf reaching the northernmost part of the Svalbard Archipelago and circumnavigating the two largest islands of Spitsbergen and Nordaustlandet.

Nanuq (meaning polar bear in the Inuit language) is a 60-foot *Grand Integral* sailboat designed, built and skipped by architect Peter Gallinelli (Geneva, Switzerland) to explore polar regions and withstand arctic winters in a self-sufficient mode, using renewable energies (sun, wind, environmental heat), thanks to its innovative thermal insulation and heat recovery systems, coupled with an optimized energy management system (Fig. 3). This "passive floating igloo" is a minimal habitat designed to serve as a mobile scientific base camp and dwelling to accommodate, in complete self-sufficiency, a team of six scientists also during winters in Arctic regions. *Nanuq* is a demonstration pilot project that illustrates how simple, robust, constructive and technical solutions may challenge low-cost energy scarcity in a credible way.

The ultimate objective of this expedition was also to contribute to improve public awareness in non-Arctic countries of the far-reaching impact of human activities on our planet.

2.3 Description of the Polarquest 2018 expedition

The Polarquest 2018 cruise started in Isafjordùr (North Iceland) and the boat sailed to Longyearbyen (Svalbard) via Greenland but unfortunately, sampling of plastic was not possible during this first leg. Its main path was the circumnavigation of Svalbard's archipelago.

The expedition was organized by the Swiss cultural association *Polarquest 2018*. It was carried out by an international crew, led by Peter Gallinelli (Australia, skipper and expedition leader), Paola Catapano (Italy and Switzerland, project leader and science communicator) and Michael Struik (Netherlands and Switzerland, technical coordinator). It included three crew members: Remy Andrean (France, ITC expert, boatbuilder and sailor), Mathilde Gallinelli Gonzalez (Switzerland, co-skipper, sailor, manta operator), Dolores Gonzalez (Spain and Switzerland, architect and sailor) and three scientific operators: Safiria Buono (Italy and Switzerland, Manta net technical operator), Gianluca Casagrande (Italy, geographer), Ombretta Pinazza (Italy, physicist) and one photographer/cameraman: Alwin Courcy (France).

After leaving Longyearbyen, the expedition sampled microplastic from *Nanuq* in 8 locations during its circumnavigation of the Svalbard archipelago's main islands: Spitsbergen and Nordaustlandet (Fig. 4). The presence of macro debris on sea surface and beaches in remote zones was explored by non-quantitative visual sightings and by drones flying over beaches.

Microfibres and microplastics were collected trawling a manta net according to standard monitoring protocols and filtering surface water collected in a 10 l metal bucket.

The manta net had a metal rectangular opening of 0.7 m x 0.5 m and two lateral floats of 0.1 m in diameter, one for each side. It was equipped with a 330 μm mesh 2.5m long. The cod-end was fixed to the Manta with a metal ring. The nets were towed behind the boat for about 30 minutes at a vessel speed of around 3-4 knots (except for Manta #3 which was towed at approximately 7 knots) (Fig.. 5). Coordinates and time of starting and ending sampling points were recorded along with sea state conditions and water temperature. After retrieving the net from the sea, the cod-end was removed and transferred to clean jars and stored for laboratory analysis. It was possible to collect eight manta samples and they were stored in eight different code end nets (Fig. 6). Two code ends were lost during the sampling process due to bad weather and limited operator experience.

Bulk surface seawater was sampled using a 10 l metal bucket (Fig. 7). The water was gravity filtered through a 28 µm mesh and remaining particles were trapped in the 3 cm diameter metal filter that was put in closed envelopes after filtration. The samples have been opened again only in the laboratory for sorting and FTIR analysis.

Polarquest 2018 succeeded to collect samples and sightings and we can consider the expedition on small sailing boat *Nanuq* as a successful way to collect this kind of samples from the Arctic. Management of toxic chemicals created some problems in a small private owned boat, so no preservatives were used onboard and bulk samples were frozen after the end of the cruise. This was not critical during the expedition as Arctic low temperatures helped to keep samples intact, but it became an issue when samples reached lower latitudes. Our experience suggests that citizen science sampling projects shall put proper effort and attention to the management of chemicals. Polarquest 2018 plastic samples were not affected by lack of preservatives but processing in the lab was not comfortable.

Training courses, and possibly training tests, are also recommended when sampling is carried out by unskilled persons. In our experience, two manta code ends were lost due to inexperienced staff and rough sea.

Microplastic and fibers were found in all samples and macro debris was visible to the naked eye throughout our entire circumnavigation of the islands.

Every day, we saw floating plastic in the open sea; even while sampling seawater on the rim of the Arctic ice-shelf (82°07´N), our Manta net caught a visible piece of blue plastic and many microplastic pieces. At each landing, incredible amounts of plastic rubbish amidst tons of driftwood were lying on these remote beaches, which have rarely seen human feet (Fig. 8).

Sightings of marine debris are common to assess the amount of macro debris at sea and on beaches. Direct observations are the simplest tool and many guidelines for beach survey have been improved by *OSPAR*, *UNEP*, *NOAA* (*National Oceanic and Atmospheric Administration*) and *EU-Marine Strategy Framework Directive* with human observers on land as the core of these guidelines. Only recently there has been interest in remote sensing of marine litter (Maximenko et al. 2016; 2019).

The tools under development use high technology and complex airborne and satellite images and only a small part makes references to drones, especially low-cost drone at the consumer level, i.e. the level of drones usually available to Citizen Science.

During Polarquest 2018 the subproject *AURORA* (*Accessible Unmanned aerial vehicles for Research and Observation in Remote Areas*), led by Gianluca Casagrande (European University of Rome, IT), used flying drones of consumer-level to make visual observations of the Svalbard coastline.

Images in the visible spectra were used for analysis and some preliminary results are presented here. Four "off-the-shelf" drones in standard commercial configurations were released from *Nanuq* in several occasions when the boat was close to the coast or during on-land observation sessions. Video and still digital images from the flights were used to produce 3D models, orthophotos, audiovisual material and other types of documentation. Images were stored onboard the drones and processed after the end of the cruise.

One of the specific tests involved the possibility of spotting and mapping macroplastics scattered in various locations of environmental interest in northern Svalbard. The beaches of Alpiniøya (North-East Svalbard) have been particularly explored for this specific type of pollution.

The minimum survey flight height was set to 100 m above ground level and the minimum debris size that we considered useful for reliable identifications was 30-50 cm. Drones flew for about 2.5 hours in total covering about 1.6 km^2. Fragments of macroplastics spread along the beach-line were identified in the 20 megapixel images from the drones down to few decimeters size.

Wood and trunks (also known as "driftwood") were very common and abundant, suggesting long-distance sources of floating items because the Svalbard archipelago has no forests at present (Fig. 9). Most of man-made macro-debris visible from drones was accounted for lost fishing gears (fragments of nets, small buoys, boxes, tanks for fluids). In situ observations during walks on the beach (Fig. 10) had higher resolution and smaller spatial scale coverage, providing criteria for identification of items and ground truth.

Fig. 11 reports one example of pixel anomalies in drone image that were identified and verified. Several plastic pieces were identified and most common items were fluid tanks/containers, boxes, fragments of fishing nets, fishing net floaters and buoys, possible bucket covers, bottles (of different sizes) and tarpaulin fragments.

Box 1 – Starts

From *Nanuq's* Logbook, by Safiria:

Sampling microplastic in the Arctic, 31 July 2018, South Svalbard

One fact about microplastic sampling: I fought a little war during this past 24 hours with some yellow algae or organism. The accumulation of this yellow little thing on my really thin filter obstructed it and water couldn't pass through anymore! So, the first 7 litres of water were filtered almost drop by drop, then I had to change the filter to filter the 3 l left. In total, it took me more than one hour. Also, to complete the misadventure, it was 4 a.m., it was freezing outside, water was at 3 degrees C, we had more than 1-meter waves and 20 knots of wind freezing my naked, wet fingers. Positive fact: now every other sampling since seems fast to me! Another fact about plastic: we saw during our shifts a bit less than 10 big pieces of floating plastic in 7 days. The probability to encounter plastic so frequently in the open sea in the Arctic, so far from sources of pollution, is thin. So, that means 2 things: 1. there is a lot of plastic waste even in the Arctic; 2. Plastic travels a lot. Of course, we already knew it, but to see it is another thing: there are no airplanes, no boats, nothing, no trace of any other human being but us, except for one little detail: human pollution.

Box 1 - Ends

Box 2 - Starts

From *Nanuq's* Logbook, by Safiria:

The Northernmost Microplastic sample, 13 August 2018,
Edge of the Polar iceshelf, 82°07' N (876 km from the geographic North Pole

Today, 13 Aug 2018, we went up to 82°7´N, where I carried out what seems to be the northernmost microplastics sampling next to the ice shelf. We found a piece of blue plastic in the manta net filter, just next to a bird feather and other things that stink tremendously every time I open the box in which I collect the filters (often full of phytoplankton, algae, etc.). I swear I'm going to pass out after filter number 20. It was so cold during the sampling: my hands were hurting so much (I only had some blue latex gloves), that I had tears streaming down my cheeks and freezing after a while. They were so frozen that I couldn't grab the bottle anymore, or unhook my lifeline to go inside.

Besides that, Mathilde and I are spending time reading the same books, creating crosswords, playing card games or memorizing all the possible historical dates we can (don't ask us why, we do what we can to have fun, and we enjoy it).

We are now heading South again. Direction: Alpiniøya.

Box 2 - Ends

3. Recommendations from Polarquest 2018 experience for sustainable development

Polarquest 2018 confirmed that the presence of plastic debris extends up to remote Arctic waters, emphasizing the global scale of marine plastic pollution and suggesting the role of global oceanic circulation patterns in the redistribution of these persistent pollutants. The uniqueness of the Arctic ecosystem makes the potential ecological implications of exposure to plastic debris of special concern.

Monitoring is not a goal in itself, but a way to show the scale of the problem, and start to try and solve it.

Plastic is necessary for our modern technologies. Its production and industry have grown fast and plastic is now a pillar of our economics and society. Most of macro debris found in northern Svalbard was single-use domestic plastics and fishing gears, i.e. nothing that proper management cannot keep out of our ocean.

Citizen science cruises in the Arctic are likely to increase in the next years due to ice-free ocean parallel to growing interest in plastic in the ocean. The number of cleanups and microplastic surveys are likely to increase as well and Polarquest 2018 was the first expedition of this kind to reach and sample at 82°N and future cruises would benefit of the experience of Polarquest. Through a heavy media presence and communication activity, also the Citizens of non-Arctic European countries have been made aware of the presence of our litter as far as the boundary between the ocean and the Arctic permanent sea ice.

In 1921, Vilhjalmur Stefansson famously predicted that the Arctic would soon become a region of great strategic and commercial importance (Lajeunesse 2012). Continuously crossed by the air and sea traffic of many nations, the region is expected to be the Mediterranean of the modem age. While Stefansson's prediction was certainly premature, recent economic and environmental developments suggest that a sea change may finally be taking place and plastic pollution is one among many priority challenges of the 21st century the Arctic has to face.

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