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Baseline

Citizen scientists reveal: Marine litter pollutes Arctic beaches and affects wild life

Melanie Bergmann[a,*], Birgit Lutz[b], Mine B. Tekman[a], Lars Gutow[a]

[a] Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Am Handelshafen 12, 27570 Bremerhaven, Germany
[b] SV Antigua, c/o Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Am Handelshafen 12, 27570 Bremerhaven, Germany

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ABSTRACT

Recent data indicate accumulation areas of marine litter in Arctic waters and significant increases over time. Beaches on remote Arctic islands may be sinks for marine litter and reflect pollution levels of the surrounding waters particularly well. We provide the first quantitative data from surveys carried out by citizen scientists on six beaches of Svalbard. Litter quantities recorded by cruise tourists varied from 9–524 g m^{-2} and were similar to those from densely populated areas. Plastics accounted for > 80% of the overall litter, most of which originated from fisheries. Photographs provided by citizens show deleterious effects of beach litter on Arctic wildlife, which is already under strong pressure from global climate change. Our study highlights the potential of citizen scientists to provide scientifically valuable data on the pollution of sensitive remote ecosystems. The results stress once more that current legislative frameworks are insufficient to tackle the pollution of Arctic ecosystems.

Marine litter is widespread and has made it even to Earth's remotest environments such as the deep ocean floor and the Polar Regions (Bergmann et al., 2017). Still, there is a peculiar, several orders of magnitude mismatch between projected litter emissions into the ocean (Jambeck et al., 2015) and global estimates based on field data (e.g. van Sebille et al., 2015) indicating hitherto insufficiently accounted sinks such as remote beaches.

Marine litter contamination in coastal waters and large stretches of Open Ocean has been investigated intensively, but there are still many blind spots (Bergmann et al., 2017). These are mostly open ocean and remote regions, to some of which access is seasonally restricted and research is expensive and challenging, such as Polar Regions. For a long time, Arctic and Antarctic waters were considered the last pristine ecosystems on Earth. However, recent studies indicate that polar waters are more polluted by plastic waste than previously thought (Bergmann et al., 2015; Isobe et al., 2017; Lusher et al., 2015) with a tendency to increase (Tekman et al., 2017). Modelling oceanographic studies and recent empirical evidence even suggest the formation of extensive litter accumulation areas in the Arctic, which are likely fuelled by debris from temperate European waters (Cózar et al., 2017). However, knowledge on litter densities, composition and distribution on remote Arctic beaches and the implications for Arctic wildlife is still scarce.

Blue environments provide a rare sense of connectedness with nature to humans, which is, however, significantly compromised by the presence of anthropogenic litter (Wyles et al., 2016). In addition, litter pollution comes at significant economic cost (Newman et al., 2015) and is hazardous to marine wildlife (Bergmann et al., 2017). Therefore, many citizens are concerned and wish to contribute to mitigation, for example, through beach clean-ups, public campaigns and engagement in citizen science campaigns (Nelms et al., 2017). Marine litter is easily identifiable and quantification requires relatively little scientific training. This environmental topic is thus particularly well suited for engaging citizen scientists in order to generate valuable scientific data (Hidalgo-Ruz and Thiel, 2015). Such data can expand our knowledge of the distribution of marine litter by increasing both temporal scales and spatial coverage, especially in remote, under-sampled areas. For example, bimonthly nationwide monitoring efforts by citizens enabled the identification of aquaculture and fisheries as the main source of litter pollution at South Korean beaches (Hong et al., 2014) and data compiled over a decade by volunteers from the Marine Conservation Society showed a significant increase in plastic fragments on British beaches (Nelms et al., 2017). In addition to data provisioning, however, citizens' engagement in beach surveys leads to positive behavioural change (Hartley et al., 2015) with potential multiplying effects.

The receding sea ice has opened up the Arctic Ocean to human activities including tourism (Bergmann and Klages, 2012). Tourists that visit the Arctic are classically drawn to this region as it is still perceived as one of the last great wildernesses characterised by a pristine white

* Corresponding author.
E-mail address: Melanie.Bergmann@awi.de (M. Bergmann).

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environment. They want to experience connectedness with unspoiled nature and are aware of the vulnerability of the Arctic environment and the necessity to safeguard its ecosystems. In addition, a number of local cruise tourism operators endeavour to be environmentally sound, engage in environmental education and support the Governor of Svalbard's campaign ‘Clean-Up Svalbard’. Therefore, tourists visiting the Arctic are particularly well-suited candidates for the collection of scientific data on the pollution of the remote Arctic environment.

The aim of this study is to provide the first baseline of litter pollution on Arctic beaches by engaging cruise tourists in a citizen science campaign. Additionally, citizen scientists as well as other non-scientific local actors were asked to document effects of marine litter on sensitive Arctic wildlife in order to better understand the implications of the pollution of sensitive Arctic ecosystems.

This study was conducted in collaboration with two tourist cruise operators, on a sailing vessel with 32 guests and 10 crew/staff and on a motor vessel with 100 guests, 45 crew and 8 staff that had already carried out beach clean-ups in Polar Regions during previous cruises as part of the ‘Clean Up Svalbard’ campaign. Cruise participants, including both tourists and expedition staff (guides accompanying tourists on land and leading the beach clean-up with tourists), were supplied with a simple protocol for categorising and quantifying marine litter on beaches that were visited during tourist cruises around the Svalbard Archipelago. Hand-held GPS devices (Garmin eTrex 30 ×) were issued to determine the geographic positions of sampling sites and the dimensions of the search transects. Additionally, spring balances (KERN 285-052: ≤ 5 kg and 285-502; ≤ 50 kg) (± 0.3% accuracy) were supplied for weight recordings.

During six cruises in summer 2016, beaches were accessed by a zodiac and photographs were taken to illustrate the general pollution state of each beach. A constant watch for polar bears was maintained by the ship's crew during all surveys. Transects between 90 and 120 m length and 14–20 m width depending on beach morphology were laid out for sampling (Table 1). Site characteristics such as beach sediment type and distance of transect from water line at the time of sampling were recorded. Litter items, which were visible by eye, were collected by 12–32 volunteers and assigned to litter categories (plastic, fisheries-related plastic, clothing including shoes, metal, glass, biotic). Only those items were collected, which lay on the beach surface or were partly buried in the sediment but still visible without digging. The bulk mass (g) was determined for each litter category. All beaches harboured large quantities of driftwood, which presumably originated from Siberian forestry. Since it was impossible to weigh large trunks driftwood was not included in the analysis. After completion, the litter was delivered to the ship and disposed of at the port of Longyearbyen.

All cruise participants as well as other non-scientists that operate in that region were asked to deliver photographs of biota interacting with marine litter. The data (MS Excel files) and photographs were transmitted by email to the scientists of the Alfred Wegener Institute in Bremerhaven, Germany. After the cruise season, single members of the cruise team shared additional information about their activities and the local circumstances during the survey via Skype calls.

Brucebukta is located on Prins Karls Forland, the only beach on the western flank of Spitsbergen (Fig. 1). It is a 6-km wide, open bay on the southwestern coast of Forlandsundet. The five remaining beaches are located in the north of the Svalbard Archipelago (Fig. 1). Reinstrandodden and Crozierpynten are part of Spitsbergen, the latter of which is situated on the eastern shore of Sorgfjorden. Alpiniøya is an island of the Svalbard Archipelago, north of Orvin Land in Nordaustlandet. It is located off the headland Bergströmodden, at the mouth of Finn Malmgrenfjorden. Isflakbukta is a bay on the southeastern side of the island of Phippsøya. It is the northernmost beach of this study and often besieged by drift ice. Sørvika is a bay on the southern shore of Murchisonfjorden on Nordaustlandet. It is the easternmost beach of this survey and had been cleaned 10 months before (10/8/2015). Sampling areas were calculated based on the length and width of the surveys conducted (Table 1). At Sørvika, an irregular polygon-shaped area was sampled. This area was calculated based on the GPS fixes of the corner points using ArcGIS 10.4. The mass of litter categories (kg) was standardised to area (g m^{-2}) by dividing litter mass by area. All categories were added up to gain the total litter mass per area for each beach. A mean ± SEM litter mass per area of the six beaches was calculated.

This citizen science campaign involving participants of tourist cruises revealed considerable contamination of Arctic beaches of the Svalbard archipelago with marine anthropogenic litter. A total of 991 kg of litter was collected from an overall sampling area of 11,732 m^2 distributed over the six beaches (Table 1). The litter quantities varied substantially between the beaches ranging from 9 to 524 g m^{-2} with a mean (± SEM) mass of 102 ± 84 g m^{-2}. Litter quantities were highest at Reinstrandodden (524 g m^{-2}), consisting almost exclusively of fisheries-related plastics including a heavy fishing net (Fig. 1) and fenders. Litter quantities at Alpiniøya, Brucebukta, Sørvika, Isflakbukta and Crozierpynten were about 20 to 60 times lower than at Reinstrandodden.

Although our data represent the northernmost report of marine litter to date litter quantities were within the range or even higher than masses of macro-litter found on beaches in other regions of the world, which are known to be heavily polluted with marine litter. For example, the mean macro-litter mass reported from beaches of S China was about 3 g m^{-2} (Cheung et al., 2016) and Indian beaches harboured amounts between < 1 and 29 g m^{-2} (Jayasiri et al., 2014; Kaladharan et al., 2012). However, the quantities at Svalbard beaches were still up to two orders of magnitude lower than global maxima reported from beaches of Japan (5800 g m^{-2}; Nakashima et al., 2011) and the remote

Table 1
Summary of beach surveys undertaken by citizen scientists around the Svalbard Archipelago. All litter quantities were converted to g m^{-2}. P: pebble, S: sand, M: mud, G: gravel; +: present. (*) Area calculation based on GPS corner coordinates.

	Brucebukta	Reinstrandodden	Sørvika	Isflakbukta	Crozierpynten	Alpiniøya	Total	Mean	± SEM
Date	31/05/16	08/06/16	20/06/16	28/07/16	18/08/16	22/08/16			
Longitude (°N)	78.449936	79.73336	79.95949	80.69094	79.91858	80.35131			
Latitude (°E)	11.71226	13.85031	18.64714	20.91088	16.83768	24.75289			
Distance to water (m)	20	0.2	0.5	0.5	0.5–2	5.7–7			
Sediment characteristics	P, S	P, S	P, S, M	P	P, S	S, G			
Survey length × width (m)	90 × 20	120 × 14	n.a.	90 × 20	90 × 20.5	100 × 52			
Area sampled (m^2)	1800	1680	2048*	1800	1845	2559	11,732	1955	130
Plastics	6.78	0.91	6.23	6.53	3.94	4.38	28.77	4.80	0.91
Plastics (fisheries)	11.11	522.77	13.13	6.08	4.89	21.65	579.63	96.61	85.27
Clothing	1.11		0.61	0.32	0.21		2.26	0.38	0.17
Metal	0.06			0.26			0.32	0.05	0.04
Glass	2.67			0.52		0.31	3.49	0.58	0.43
Biotic						0.002	0.002	0.00	0.00
Total	21.72	523.67	19.98	13.71	9.04	26.35	614.48	102.41	84.29

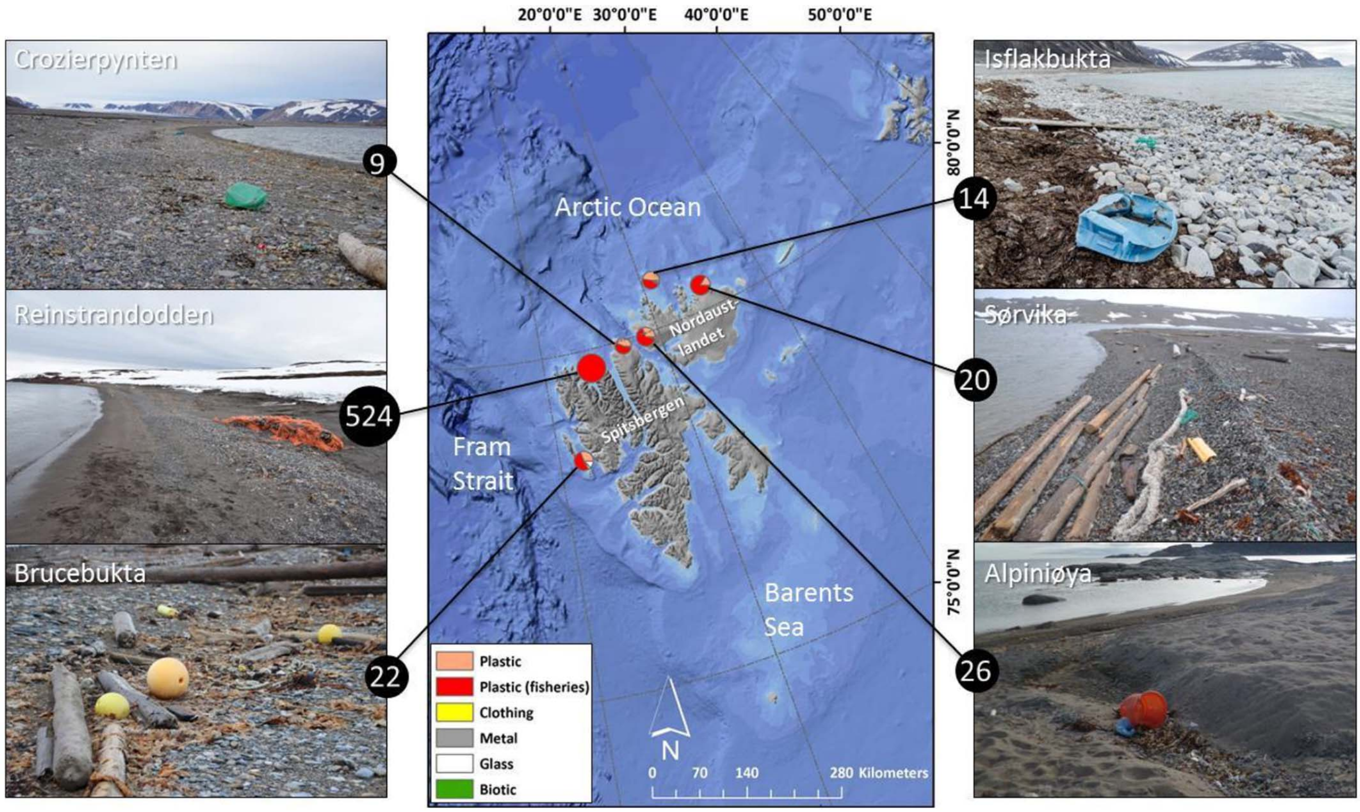

Fig. 1. Location and photos of beach surveys conducted by citizen scientist on the Svalbard Archipelago. Pie charts reflect litter mass (log (g m^{-2})) and composition and numbers refer to total litter mass (g m^{-2}). All images were taken by B. Lutz except for Brucebukta (J. Hager) and Alpiniøya (F. Kruse).

Henderson Island in the S Pacific (40–1250 g m^{-2}; Lavers and Bond, 2017). The considerable amounts of litter washed onto beaches of remote locations, such as the Svalbard archipelago, may indicate that these sites reflect the actual pollution of the oceans with marine litter particularly well. Beach clean-ups are conducted only rarely if at all allowing for an undisturbed accumulation of litter according to the contamination of the adjacent water body. Accordingly, the considerable amounts of litter on the beaches of Svalbard mirror a massive pollution of the Arctic Ocean. Indeed, high and continuously increasing densities of litter were reported from the deep seafloor of the Nordic Seas (Buhl-Mortensen and Buhl-Mortensen, 2017) and the nearby HAUSGARTEN observatory in the Fram Strait (Bergmann and Klages, 2012; Tekman et al., 2017). Furthermore, an accumulation zone for floating litter, potentially originating from temperate European waters, has recently been identified south of Svalbard and in the northern Barents Sea (Cózar et al., 2017).

The relative contribution of plastic to the overall litter mass at Svalbard ranged from 82 to 100%. This is slightly higher than the current global figure of 72% of the beached anthropogenic litter consisting of plastics (LITTERBASE, 2017). The contribution of fisheries-related plastic was particularly high on the Svalbard beaches. Such items included ropes, buoys, floaters, nets and pieces thereof. This category accounted for 44–100% of the litter mass, followed by other plastic items (0–48%), glass (0–12%) and clothes (0–5%). Plastic items not related to fisheries were mainly packaging material, beverage containers (bottles and cups), use articles (e.g. plastic spoons, tooth brush and lighters) and toys (head of plastic raven, doll's foot, plastic wheel, Barbie horse, toy light). Large quantities of small plastic debris (1–20 mm) were reported from Sørvika. However, the contribution of this size fraction to the overall mass of plastic litter at that beach was not quantified separately. In front of this beach, small debris was also observed floating in the water and submerged on the sea bed. Metal and biotic debris contributed generally < 2% to the litter mass on the beaches. Litter diversity (i.e. number of litter categories) was highest on the beaches of Isflakbukta and Brucebukta, where five out of six litter categories were found each. Additionally, the litter at Brucebukta was characterised by a relatively high share of glass and clothing indicating that this beach receives litter from other sources than the remaining beaches. The Svalbard archipelago is essentially influenced by the West Spitsbergen Current, which carries relatively warm, saline Atlantic Water from the south (Svendsen et al., 2002). Brucebukta on Prins Karls Forland, W Svalbard, likely intercepts higher amounts of floating litter from northern Europe carried along by the West Spitsbergen Current (Bergmann et al., 2015) according to the predictions made from recent oceanographic models that essential amounts of litter in Arctic waters originate from the south (Cózar et al., 2017). In addition, this region is influenced by the East Spitzbergen Current from NE Svalbard (Misund et al., 2016) and may also receive litter carried along from Barents Sea fisheries. By contrast, litter diversity was lowest at Reinstrandodden, which harboured almost exclusively fisheries-related plastics and only a miniscule fraction of other plastics. Plastics and fisheries-related plastics were found on every beach whereas biotic debris was the least frequently encountered litter category with a single item, cork, encountered solely at the beach of Alpiniøya.

Fisheries-related debris also accounted for the majority of litter stranded in other regions, for example, on remote beaches of S Australia (Edyvane et al., 2004), Alaska (Merrell, 1984) and South Georgia (Walker et al., 1997). It also dominated litter on the seafloor of the Norwegian and southern Barents Seas (Buhl-Mortensen and Buhl-Mortensen, 2017). The dominance of fisheries-related litter on the beaches of Svalbard may be partly due to the unit used in our study to express litter quantities (g m^{-2}), which is sensitive to the occurrence of single particularly heavy items such as the fishing nets at Reinstrandodden. Still, its strong dominance at all beaches examined clearly points to fisheries as a major source of litter pollution. This also highlights the substantial contribution of local sources. Indeed, fishing effort in the region has increased markedly over recent years (Bergmann and Klages, 2012; Misund et al., 2016; Tekman et al., 2017), evidence of which is also already imprinted as trawl marks on the seafloor surrounding Svalbard (Sswat et al., 2015). Misund et al. (2016) reported high fishing effort in some areas north of Svalbard. Still, debris from more distant North Atlantic fisheries may also contribute their share as indicated by a recent map of fishing intensity (Misund et al., 2016) and high amounts of fisheries-related debris reported from areas of high fishing intensity in the Norwegian and Barents Seas (Buhl-Mortensen and Buhl-Mortensen, 2017). Plastic items (fish boxes) collected by the Governor of Svalbard included a box from Caley, a Scottish supplier of marine equipment and boxes from Årnsbruket, Batsfjord (northern tip of Norway) and Norges Makrellag, a Norwegian fisheries organisation. During our surveys, a plastic tag from BP was recovered, as were carriers of the beer brands Mack (Norway) and Tuborg (Denmark).

The images provided by the visitors of Arctic beaches document hitherto unreported interactions between eight Arctic species and marine litter with potentially deleterious implications for sensitive organisms. They belonged to various groups of organisms such as seaweeds (*Fucus* sp., cf. *Ulva* spp.), Arctic whitlow-grass (*Draba bellii*), seabirds (*Sterna paradisaea*), and terrestrial and marine mammals (*Rangifer tarandus platyrhynchus*, *Erignathus barbatus*, *Phoca vitulina*) including polar bears (*Ursus maritimus*) (Fig. 2). All interactions with marine litter were entanglement occasionally causing severe injury. An Arctic tern was found dead. However, it was not possible to ascertain from the imagery if entanglement caused death. Most litter items that were found to interact with organisms were fisheries-related, including ropes, fishing nets and net fibers.

Interactions of marine litter with Arctic biota (e.g. sponges, sea anemones) were recently also reported from the deep-sea observatory HAUSGARTEN (Bergmann and Klages, 2012; Tekman et al., 2017), which is located in the Fram Strait, west of Svalbard. Plastic debris was also recorded in Greenland shark (*Somniosus microcephalus*) caught near Svalbard and Greenland (Leclerc et al., 2012; Nielsen et al., 2014). In addition, microplastic was recently detected in polar cod (*Boreogadus saida*) caught in waters around Svalbard (Kühn et al., in press).

Wilcox et al. (2015) recently showed that anthropogenic litter has serious impacts on seabirds globally. Lydersen et al. (1989) recorded plastic debris from the intestines of little auks (*Alle alle*), Brunnich's guillemot (*Uria lomvia*), kittiwakes (*Rissa tridactlya*) and northern fulmars (*Fulmarus glacialis*) from the Hornsund area. Today, already 88% of the northern fulmars from Svalbard have plastic debris in their stomachs (Trevail et al., 2015). New photographic evidence suggests that Arctic terns (*Sterna paradisaea*) from Svalbard become entangled in fishing nets (Fig. 2F), most likely impeding hunting and foraging success leading to starvation. Biofilm on marine debris exudes an odour of dimethyl sulphide, an infochemical which may attract seabirds rendering them particularly susceptible to interactions with marine plastic litter (Savoca et al., 2016). Similarly, decaying seaweeds entangled in marine litter (Fig. 2A, J) may attract foraging seabirds.

Recently, skulls of reindeer (*Rangifer tarandus platyrhynchus*) entangled in fishing nets deposited on the beaches of Svalbard have become a regular sight (Fig. 2A). In the absence of more suitable food

Fig. 2. Images taken by citizen scientists showing interactions of Arctic biota with marine litter on Svalbard beaches: (A) fishing net entwined with fucoid macroalgae and two entangled antlers and skulls of reindeer (*Rangifer tarandus platyrhynchus*) from Chermsideøya (Nordaustlandet) (credit: J. Hager); (B) harbour seal (*Phoca vitulina*) entangled in rope cutting through the skin, (C) causing severe wounding (credit: F.D. Haug/Governor of Svalbard); (D) bearded seal (*Erignathus barbatus*) with rope tied around its belly in the Hornsund/Bellsund area; (E) polar bear (*Ursus maritimus*) with plastic shred in its mouth on ice floe in Hinlopenstreet (credit: David Shaw Wildlife); (F) dolly rope fibers wrapped around the beak of a perished Arctic tern (*Sterna paradisaea*) (credit: Governor of Svalbard); (G) polar bear with fisheries rope tangled around its neck in the Raudfjord area; (H) Arctic whitlow-grass (*Draba bellii*) in contact with plastic container; (I) polar bear with beached fishing net at Sorgfjorden (credit: T.-A. Hansen/Governor of Svalbard); (J) conglomerate of green algae (cf. *Ulva* spp.) and dolly rope fibers (credit for D, G, H, J: B. Lutz).

during winter, reindeer increasingly forage on macroalgae in the intertidal (Hansen and Aanes, 2012) thereby increasing the risk of encountering beached fishing nets. It could be even speculated that in addition to visual cues, the odour of decaying seaweeds entangled in the nets may attract reindeer much in the same way as seabirds (Savoca et al., 2016). The curious absence of the remaining reindeer carcasses suggests that predators, such as polar bears or foxes, have utilised this resource spreading the bones elsewhere. However, this 'ghostfishing' effect bears the risk that scavenging organisms also become entrapped in marine debris. Indeed, polar bears are also attracted to nets (Fig. 2I) and entangle in fisheries debris (Fig. 2G), which they may have encountered during hunting efforts either on land or at sea. Polar bears may also eat plastic debris (Fig. 2E) when in desperate search for suitable prey. Fisheries-related plastic debris of Svalbard is also seen wrapped around bearded seals (Fig. 2D) and harbour seals (Fig. 2B), which may cause death through wound infection (Fig. 2C) or strangulation.

Tourism has been identified as an important source of litter in other parts of the world (Alshawafi et al., 2017; Carić and Mackelworth, 2014) and is also suspected to contribute to pollution in the Arctic (Tekman et al., 2017). However, campaigns such as 'Clean-Up Svalbard', which engage visiting tourists in beach clean-ups may help to counteract some of the effects and enables the collection of data from remote, poorly sampled areas. In addition, it helps to educate people (Eastman et al., 2013; Hartley et al., 2015), can have multiplying peer effects if word is spread and creates a feeling of ownership and responsibility.

The data generated during tourist cruises show clearly that Arctic beaches are home to plastic pollution at levels similar to those situated closer to more populated coastal areas. Litter quantities were reported in a rather uncommon unit ($g\,m^{-2}$) and could therefore be compared with only a limited number of previous studies. Still, counting single litter items is time-consuming whereas bulk measurements of entire litter categories can be done relatively quickly. It has to be taken into account that tourists mostly visit the Arctic (1) for recreational purposes and (2) to experience one of the supposedly last unspoiled ecosystems of the world. However, extensive litter sampling campaigns easily counteract this experience and may drastically affect the recreational value of the voyage, especially under harsh weather conditions. Accordingly, compromises have to be accepted when conducting citizen science projects in Polar Regions.

Annex V of the MARPOL Convention and the London Convention generally prohibit the disposal of litter in the sea. In addition, § 27 of the Norwegian Pollution Control Act forbids the disposal of litter on both land and sea, and the Norwegian Marine Resources Act prohibits the dumping or abandonment of fishing gear. The Svalbard Environmental Protection Act also bans the discharge of litter from vessels. Still, the evidence presented highlights that current legislation is insufficient to tackle the pollution of Arctic ecosystems. This adds further stress to Arctic wildlife, which is already under strong pressure from global climate change.

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