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Baseline

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

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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

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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