Contamination of beach sediments of a subalpine lake with microplastic particles

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Plastic waste is of increasing concern in marine ecosystems [1–3]. Buoyant plastic particles accumulate in pelagic habitats whereas non-floating debris accumulates on the seafloor and in beach sediments, posing risk to the respective communities [1–4]. Microplastic particles (<5 mm) are either directly introduced via sewage discharge or formed by biofouling and mechanical abrasion, making them more prone to consumption by aquatic organisms [2,3]. As a consequence, they can accumulate in higher trophic levels [3–5]. A variety of harmful effects of plastic and associated chemicals has been shown [2–4]. Moreover, plastic debris can act as vector for alien species and diseases [2,6]. A large portion of the plastic waste is produced onshore and reaches the marine environment, which is considered the main sink of plastic debris. There is, however, a considerable lack of knowledge on the contamination of freshwater ecosystems with plastic debris. We here show that freshwater ecosystems also act, at least temporarily, as a sink for plastic particles.

We examined the abundance of plastic particles in beach sediments from the subalpine Lake Garda, Italy. The lake is used for drinking water supply and is one of northern Italy's most popular tourist destinations. Among the main land-based sources of plastic waste entering the lake are discarded plastic products and debris which may originate from landfills. For the quantification of plastic particles, we collected sediment samples from two beaches at Lake Garda using a random grid sample technique. The sample preparation was based on density separation. Identification and quantification was performed using Raman microspectroscopy which allows for analysis of particles down to the µm-range (Supplemental information). We found the majority of plastic particles at the north shore of Lake Garda with 483 ± 236 macroplastic particles/m^2 and 1,108 ± 983 microplastic particles/m^2. At the south shore, extrapolations revealed 8.3 macroplastic particles/m^2 (only one replicate contained macroplastic) and 108 ± 55 microplastic particles/m^2, respectively. The high concentration of particles at the north shore may result from the strength of the wind 'Ora' blowing from south to north, resulting in a strong surface circulation and a counter clockwise rotating eddy at the northern tip of Lake Garda (Supplemental information). Our results are in concordance with a study from Lake Huron (Great Lakes) were 94% of plastic pellets were found at a single beach [7]. The found numbers of microplastic particles are in a similar range as reported in studies performed on marine beach sediments (0.21–77,000 particles/m^2), though not as large as in cases of highly contaminated marine beach sediments [8]. Nevertheless, our results indicate a similar relevance of microplastic contamination in lakes.

Similar to marine environments and the Great Lakes, with ocean-like characteristics, we found primarily low density polymers, namely polystyrene (45.6%), polyethylene (43.1%) and polypropylene (9.8%). However, in the size class of very small microplastic particles (9–500 µm), also polyamide and polyvinylchloride were identified (Figure 1). Polyvinylchloride was ranked among the five most hazardous plastic polymers and by far the most additives are used for its production [9].

In general, the particles we found were fragments of larger particles, most likely originating from post-consumer products. The found fibres (2.3%) rather originate from lakeside sources (e.g. rope, fishing gear) as fibres were not in the size range found in sewage effluents [3] (Supplemental Information).

An exemplary examination of nine randomly chosen plastic particles (0.781–3.016 mm) using scanning electron microscopy revealed diverse surface textures which closely resembled degradation and fragmentation marks of plastic particles found in marine environments (Figure 1) [8]. Signs of degradation in plastic pellets from Lake Huron (Great Lakes) already suggested mechanical degradation of plastics in freshwater systems into smaller fragments resulting from sometimes high wave actions at the beaches of this large lake [7].

The continuous discharge of microplastic into freshwater ecosystems renders it potentially hazardous to the biota [3,10]. Although the uptake of plastic particles has already been shown for a variety of marine invertebrates [5], there is a lack of knowledge for limnetic organisms. The size range of microplastics found in our study strongly supports the probability of uptake of these particles by a variety of organisms. We show that artificially ground fluorescent microplastics (polymethyl methacrylate, 29.5 ± 26 µm) were ingested by a wide range of freshwater invertebrates of different feeding guilds, indicating the risk of bioaccumulation (Figure 1, Supplemental Information).

Contamination with plastic debris in freshwater habitats has rarely been shown and concentrated on sewage treatment plant effluents [3,10], river mouths [5] and great lakes with ocean-like characteristics [7]. We show that even in a subalpine lake the amount of plastic particles is reaching similar magnitudes as in marine environments, suggesting that freshwater systems do not only act as a source for marine contamination. In this context, microplastic particles are generated in high amounts from larger fragments, persist due to their longevity and will therefore accumulate in freshwater habitats.

As Lake Garda is located close to remote alpine areas, the contamination with plastic debris may be of even higher significance in low-land lakes and streams. Their highly diverse properties make plastic particles prone to ingestion by a wide range of freshwater invertebrates originating from different habitats and different functional levels. The resulting bioaccumulation of microplastic particles underpins that contamination with plastic debris may be as hazardous to the biota of freshwater habitats as for marine organisms. Hence, further research and standardized surveillance guidelines to control for microplastic contamination in freshwater ecosystems, such as is required for marine systems, is a crucial prerequisite to identify potential hotspots of plastic particle accumulation, high risk

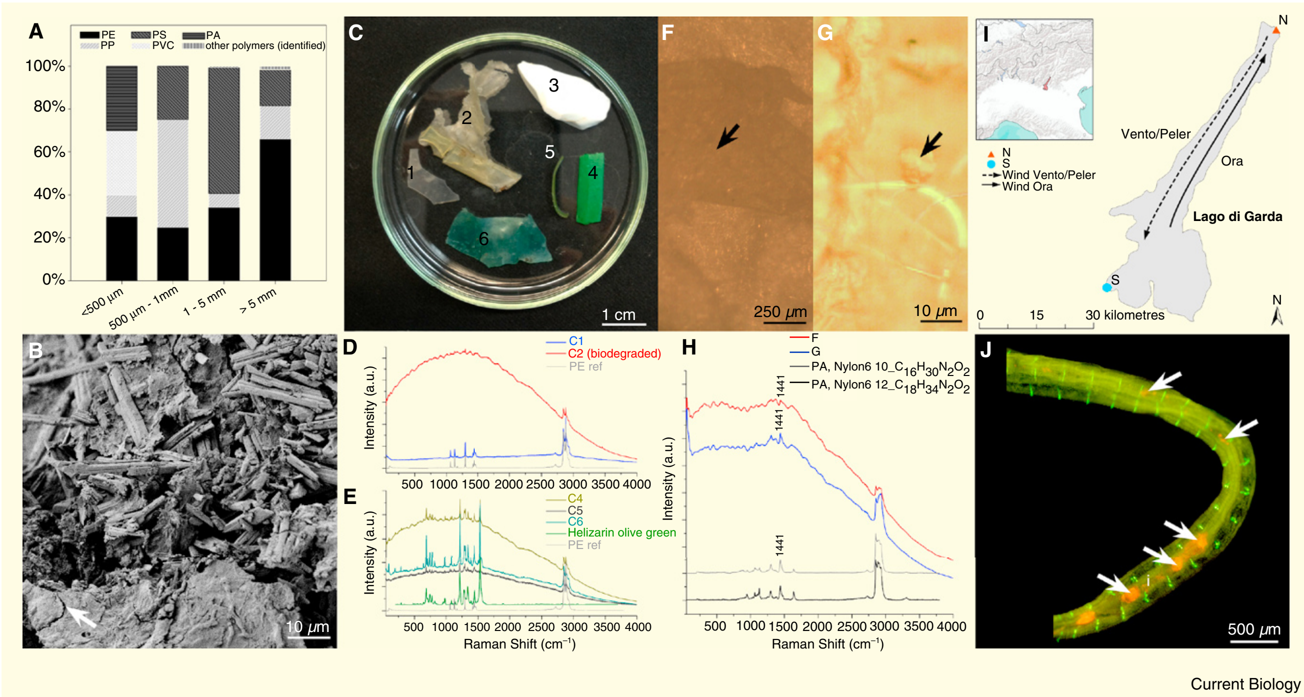

Figure 1. Macro- and microplastic particles from a freshwater ecosystem.
(A) Polymer type abundance (in percent) in the different particle size classes found at beach sediments of the subalpine Lake Garda, Italy. (B) Scanning electron microscope image of a decaying polystyrene particle with multiple adherent particles and cracks (white arrow), showing the possible fragmentation into tinier microplastic particles. (C) Photograph of particles identified using Raman microspectroscopy. Particle 1 & 2 are polyethylene (PE), particle 2 shows distinctive signs of degradation; particle 3 shows no Raman bands, i.e. is not plastic; particles 4, 5 & 6 are polyethylene particles and containing Helizarin olive green as colour pigment. (D) Corresponding Raman spectra of the PE particles 1 (blue spectrum) and 2 (red spectrum) from (C). Grey spectrum is the reference PE spectrum. Note that visible degradation of particle 2 is also reflected in the Raman spectrum. (E) Corresponding Raman spectra of the PE particles 4 (olive spectrum), 5 (grey spectrum) and 6 (light blue spectrum) from (C). The grey spectrum is the reference PE spectrum. The green spectrum identifies the colour pigment Helizarin olive green. (F) Optical microscope image of a large polyamide fragment (black arrow). (G) Optical microscope image of a smaller polyamide fragment on the same filter (black arrow). (H) Corresponding Raman spectra of the polyamide particles in (F, red spectrum; G, blue spectrum). The grey and black spectra are the polyamide references. (I) Map of the study area. Depiction of the main wind directions at Lake Garda. The 'Ora' (solid line) blows from the south-west to the north-east in the early afternoon and the 'Peler' (dotted line) blows during the night in the opposite direction. Red triangle: Sampling site at the north shore. Blue dot: Sampling site at the south shore. (inset) Lake Garda (marked in red) located in the Italian Alps. (J) Deposit feeding clitellate worm *Lumbricus variegates*; fluorescent particles (white arrows) are visible in the entire gut system.

products and groups of organisms that are more vulnerable to the impacts of plastic debris and its associated chemicals [4]. This may help to foster future risk assessment and conservation strategies.

Supplemental Information

Supplemental Information including experimental procedures and two figures can be found with this article online at http://dx.doi.org/10.1016/j.cub.2013.09.001.

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