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Sources and distribution of microplastics in China's largest inland lake – Qinghai Lake☆

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Microplastic pollution was studied in China's largest inland lake – Qinghai Lake in this work. Microplastics were detected with abundance varies from 0.05×10^5 to 7.58×10^5 items km^{-2} in the lake surface water, 0.03×10^5 to 0.31×10^5 items km^{-2} in the inflowing rivers, 50 to 1292 items m^{-2} in the lakeshore sediment, and 2 to 15 items per individual in the fish samples, respectively. Small microplastics (0.1–0.5 mm) dominated in the lake surface water while large microplastics (1–5 mm) are more abundant in the river samples. Microplastics were predominantly in sheet and fiber shapes in the lake and river water samples but were more diverse in the lakeshore sediment samples. Polymer types of microplastics were mainly polyethylene (PE) and polypropylene (PP) as identified using Raman Spectroscopy. Spatially, microplastic abundance was the highest in the central part of the lake, likely due to the transport of lake current. Based on the higher abundance of microplastics near the tourist access points, plastic wastes from tourism are considered as an important source of microplastics in Qinghai Lake. As an important area for wildlife conservation, better waste management practice should be implemented, and waste disposal and recycling infrastructures should be improved for the protection of Qinghai Lake.

1. Introduction

World annual production of plastics has increased by nearly 20 fold since the 1950s and reached 322 million metric tons in 2015 (PlasticsEurope, 2016). Although the use of plastic products brings great benefit and convenience to people's lives, inappropriate disposal of plastic wastes has been causing serious environmental problems. Pollution of microplastics, which usually refer to plastic debris < 5 mm, is drawing closer attention in recent years (Cole et al., 2011; do Sul and Costa, 2014). Occurrence of microplastics in many marine environments has been extensively reported (Desforges et al., 2014; Lavers and Bond, 2017; Law et al., 2010). Presence of microplastics in the marine environment can adversely affect the health of marine organisms, and effects such as loss of energy, intestinal blockage, alteration of hormone levels, growth inhibition, and delayed maturity have been observed (Chae and An, 2017; Galloway et al., 2017). Many previous studies have demonstrated that microplastics can be ingested by invertebrates, fishes, seabirds, and even marine mammals (Devriese et al., 2015; Jabeen et al., 2017; Lusher et al., 2015; Zhao et al., 2016). Due to the potential risks of microplastics, legislation to ban the use microbeads in personal care products has been introduced in the United States, Canada, Australia, and some European Union countries (Rochman et al., 2016).

Although major research efforts have been focused on microplastics related issues in the marine environment so far, inland water is facing similar problems. It was estimated that less than 5% of the total 275 million metric tons of plastic wastes generated in 192 coastal countries were discharged into the ocean in 2010 (Jambeck et al., 2015). The remaining 95% of the plastic wastes were either degraded or remained in the terrestrial environment. Therefore, inland water could also be very vulnerable to microplastic pollution. Microplastics have been detected with high

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abundance in lakes and rivers under intensive human impact (Baldwin et al., 2016; Klein et al., 2015; Su et al., 2016; Zhang et al., 2017). However, in remote areas such as Mongolia, subalpine area of Italy, and Qinghai-Tibet plateau, occurrence of microplastics has also been observed (Free et al., 2014; Imhof et al., 2013; Zhang et al., 2016).

Qinghai Lake is the largest lake in China, which is a remote lake located on the northeast edge of Qinghai-Tibet Plateau. Qinghai Lake is a closed lake with a salinity of ~11‰ and an average depth of ~20 m. The surface area of the lake is about 4500 km^2 and the watershed area is about 30,000 km^2 (Ao et al., 2014). The population density around the Qinghai Lake area is about 9.3 person per km^2. There are neither urban centers nor industry around the lake, and animal husbandry and tourism are the major human activities. The whole watershed is in the semi-arid region and the prevailing wind is westerly. More than forty rivers and creeks flow into the lake, most of which are seasonal, and seven major rivers account for about 95% of the total discharge into the lake (Xu et al., 2010). The Qinghai Lake basin is a closed watershed with no river outflow and thus the lake can easily become a sink of pollutants from the watershed.

Qinghai Lake area is also a very important habitat for many species of birds, fish and wild animals including several endangered ones. In recent years, tourism is blooming but infrastructure construction and management systems lag behind, which brings great pressure on the Qinghai Lake protection. No study on microplastic pollution has been performed previously in this area. Clear watershed boundaries and relatively simple human activities in the Qinghai Lake area make it an ideal place to study the source and distribution of microplastics. Therefore, microplastic pollution was investigated in Qinghai Lake in this work with the purpose of 1) revealing microplastic pollution characteristics and distribution patterns; 2) illustrating sources of microplastics; and 3) discussing the fate of microplastics.

2. Materials and methods

2.1. Sampling

The Sampling campaign was carried out in July 2016. Geographic location and sampling sites are presented in Fig. 1 and Fig. S1. Microplastics in the lake surface water were collected following a previous method (Zhang et al., 2015, 2017). Briefly, a trawl net (50 cm × 100 cm × 150 cm, 112 μm mesh size) was towed on the surface of the lake by the side of a vessel at a speed of 5 km h^{-1}, approximately. The towing distance was 2 km as indicated using a Garmin Map62s Global Positioning System (GPS). After each sampling, the trawl net was rinsed with deionized water. The floating debris retained in the net was transferred into a 1 L glass bottle, and preserved with 5% methyl aldehyde before further treatment. The trawl was rinsed three times before the next sampling to reduce the cross contamination.

Four major inflowing rivers were selected for the investigation (Table S1). One sample was collected for each river. Microplastics in the rivers were also collected using the trawl net but the net was held vertically to the flow direction for 10–20 min according to the flow velocity, which was measured using a starflow ultrasonic flowmeter (Streamline Measurement Ltd., Derbyshire, UK). The cross-section area of water passed through the net was calculated by multiplying the flow velocity and the sampling time.

Sediment samples were collected from 7 sites around the lake. At each site, samples were taken above the lakeshore line (up) and at the lakeshore line (down). Top 0–2 cm sediment in a 20 cm × 20 cm quadrat was collected using a stainless-steel shovel and transferred into a stainless-steel container. Three replicates about 10 m away from each other were collected for each sample.

Ten fish (*Gymnocypris przewalskii*) samples from the estuarine area of Buha River were obtained from the local fishery administration department and were frozen before analysis. *Gymnocypris przewalskii* is an omnivorous and migratory fish belonging to cyprinid, which is endemic to the Qinghai Lake basin and is the dominant fish species in the Lake. It is listed as endangered on the China Species Red List due to over fishing and habitat loss.

2.2. Sample analysis

Water and sediment samples were pretreated following previously described methods with some slight modifications (Zhang et al., 2015, 2017). Water samples were passed through a 1 mm mesh size stainless steel sieve. Materials retained on the sieve were visually examined. Suspected microplastics were transferred to petri dishes for further examination. Water passed through the sieve was collected and transferred into a 1 L separating funnel. Potassium formate was added to a density of 1.54 g mL^{-1}. Samples in the funnel were settled overnight, then the settled materials were discarded through a valve at the bottom of the funnel. Floating particles were digested using 30% hydrogen peroxide at 60 °C overnight, then filtrated onto GF/C filters (1.2 μm pore size), and dried in desiccators.

Sediment samples were sieved with 2 mm mesh size sieves. Materials retained on the mesh were visually examined. Suspected microplastics were transferred to petri dishes for further examination. Samples passed through the sieve were transferred to a 2.5 L flask and separated with the potassium formate solution (1.54 g mL^{-1}). Samples were settled overnight. The floating debris in the flask was overflowed into a stainless-steel tray by adding potassium formate solution from a tube at the neck. Then materials on the tray were transferred into a 500 mL beaker and filtrated onto GF/C filters. The process was repeated for three times. The retained particles were digested using 30% hydrogen peroxide at 60 °C overnight, then filtrated onto GF/C filters, and dried in desiccators.

The gastrointestinal tract of each fish was dissected and digested using a 10% potassium hydroxide solution (Foekema et al., 2013). The digested solutions were filtrated onto GF/C filters. All prepared samples on the filters were stored in covered petri dishes for further examination.

All filters were visually examined under a stereomicroscope up to 40 × magnification. Suspected microplastics were identified based on their morphology. The quantity, shape, color, and size of microplastics were recorded. Microplastics were divided into three categories according to their sizes (0.112–0.5 mm; 0.5–1 mm; 5-1 mm) and four categories according to their shapes (sheet, fiber, fragment, and foam). The suspected microplastics were randomly picked out with tweezers for the further confirmation using a Renishaw inVia Raman microscope (Wotton-under-Edge, Gloucester-shire, UK). For those sites with a high microplastic abundance (>100 items), 10–15% of the suspected microplastics were identified. For those sites with a low microplastic abundance (<100 items), all suspected microplastics were identified. During the identification, suspected microplastics in different size and shape categories were approximately equally represented. Microplastics <200 μm were not identified due to the difficulty in handling.

To prevent contamination during sample analysis, nitrile gloves, cotton laboratory coat, and shower cap were worn during the whole process. All containers were covered with aluminum foil if not in use. Sample pretreatment was performed in a fume hood, and a sticky dust drum was used to clean the desktop, hands, and clothes. Blank controls were also carried out following the same procedures to assess the contamination.