Science of the Total Environment 650 (2019) 1913–1922

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Microplastics in the Northwestern Pacific: Abundance, distribution, and characteristics

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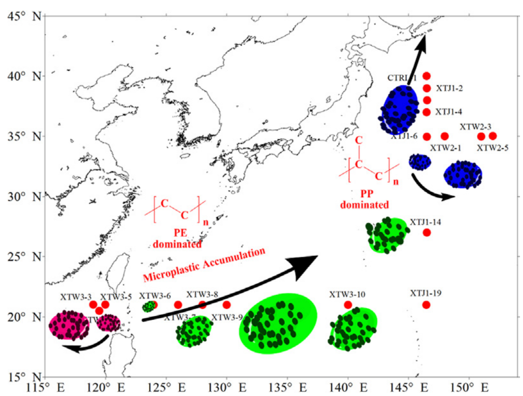
HIGHLIGHTS

- The microplastics were surveyed and the physical oceanographic parameters in the Northwestern Pacific were measured.
- Microplastics are prevalent with various colors, sizes, shapes and chemical compositions in the open sea.
- The mechanisms for microplastic distribution were proposed by chemical composition and the physical oceanographic data.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 21 March 2018
Received in revised form 18 September 2018
Accepted 18 September 2018
Available online 19 September 2018

Editor: Kevin V. Thomas

Keywords:
Microplastic
Northwestern Pacific
Abundance
Chemical fingerprint
Distribution

ABSTRACT

Prevalence of microplastics (MPs) throughout the world's oceans has raised growing concerns due to its detrimental effects on the environment and living organisms. Most recent studies of MPs, however, have focused on the estuaries and coastal regions. There is a lack of study of MPs pollution in the open ocean. In the present study, we conducted field observations to investigate the abundance, spatial distribution, and characteristics (composite, size, color, shape and surface morphology) of MPs at the surface of the Northwestern Pacific Ocean. Samples of MPs were collected at 18 field stations in the Northwestern Pacific Ocean using a surface manta trawl with a mesh size of ~330 μm and width of 1 m from August 25 to September 26, 2017. The MPs were characterized using light microscopy, Micro-Raman spectroscopy, and scanning electron microscopy (SEM). Our field survey results indicate the ubiquity of MPs at all stations with an abundance from 6.4×10^2 items km^{-2} to 4.2×10^4 items km^{-2} and an average abundance of 1.0×10^4 items km^{-2}. The Micro-Raman spectroscopic analysis of the MPs samples collected during our field survey indicates that the dominant MPs is polyethylene (57.8%), followed by polypropylene (36.0%) and nylon (3.4%). The individual chemical compositions of MPs from the stations within the latitude range 123–146°E are comparable with each other, with PE being the dominating composition. Similar chemical fingerprints were observed at these field stations, suggesting that the MPs originated from similar sources. In contrast, the major MPs at the field stations adjacent to Japan is polypropylene, which may originate from the nearby land along the coast of Japan. Physical oceanography

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https://doi.org/10.1016/j.scitotenv.2018.09.244

parameters were also collected at these stations. The spatial distribution of MPs is largely attributed to the combined effects of flow pattern, adjacent ocean circulation eddies, the Kuroshio and Kuroshio Extension system.

1. Introduction

The world has seen explosive growth in the production and consumption of plastic materials in the past decades due to their versatility, lightweight, low cost, durability, and pliability. The annual plastic production surged 20% in five years from 279 million tons in 2011 to 335 million tons in 2016 (PlasticsEurope, 2018; Zhang, 2017). The sheer volume of plastic pollution in the environment owes largely to the persistence of plastics. A substantial amount of plastics end up in waterways, particularly in the marine environment. It was estimated that 4.8–12.7 million tons of plastic wastes were pumped into the ocean in 2010. This number is expected to grow by an order of magnitude by 2025 (Jambeck et al., 2015; Kooi et al., 2017). MPs were initially defined as the microscopic plastic debris in the 20 μm scale (Thompson et al., 2004) and later as the plastic particles <5 mm in diameter (Andrady and Neal, 2009; NOAA, 2016), albeit not a standard definition. MPs can be either primary or secondary MPs (Li et al., 2018; Piñon-Colin et al., 2018). Primary MPs comes from personal care products in the form of microbeads (e.g., exfoliating facial cleansers, cosmetics.), plastic products (e.g., resin pellet.), and synthetic textiles. A portion of MPs comes from fiber-containing laundry effluents released into the environment since wastewater treatment plants fail to retain and eliminate MPs. For example, Browne et al. reported that ~1900 synthetic fibers may be shed from one synthetic garment during each washing cycle (Browne et al., 2011; Cauwenberghe et al., 2015). A large marine plastic debris becomes brittle with time and breaks into small pieces, so-called secondary MPs through various environmental processes such as biological activities, UV irradiations, mechanical abrasions, temperature fluctuations, wind and wave actions (Auta et al., 2017; Barnes et al., 2009; Bergmann et al., 2017; Ling et al., 2017).

The abundant and widely spread floating marine plastics around the globe introduce massive amounts of MPs into the marine environment, which constitute the vast majority of buoyant marine plastics (Mauro et al., 2017). MPs have been identified across the worldwide's oceans, from nearshore to offshore and pelagic regions, at sea surfaces, in water columns and seabed sediments, and from the Arctic to the Antarctic (Abayomi et al., 2017; Cauwenberghe et al., 2013; Isobe et al., 2017; La Daana et al., 2017; Lots et al., 2017; Lusher et al., 2015; Waller et al., 2017; Zhang et al., 2017). As the infinitesimal fragments of plastic, MPs are expected to increase exponentially with shrinking size and time due to its longevity (Cózar et al., 2014; Kooi et al., 2017). As a result, the MP abundance is likely to grow dramatically in the future unless effective mitigation measures are implemented in a timely fashion.

Persistent organic pollutants (POPs), including polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and polybrominated diphenyl ethers (PBDEs), have a great propensity to cling to MPs, due to their hydrophobic nature (Mato et al., 2001; Ogata et al., 2009). MPs may also adsorb heavy metals such as lead, copper and nickel (Brennecke et al., 2016; Rochman et al., 2014). It follows that MPs act as vehicles for transferring toxic chemicals through trophic levels (Bakir et al., 2012; Browne et al., 2008; Teuten et al., 2007; Wessel et al., 2016). MPs may be ingested by marine organisms and cause blockage of metabolic channels (e.g., alimentary tract and gut), physical damages, reduced appetite, altered feeding behavior and fatigue. MPs may transfer their associated organic contaminants or toxic additives to living organisms and hinder the growth, development, and reproduction of marine life (Cole et al., 2015; Hamlin et al., 2015; Von Moos et al., 2012; Watts et al., 2015; Wegner et al., 2012; Wright et al., 2013a). Environmental impacts of MPs have raised growing public concerns. Furthermore, there is an increasing awareness of a growing threat from MPs to human health due to human exposures to MPs and their associated toxins via food chains or inhalation of MPs in the air (Vethaak and Leslie, 2016; Wright and Kelly, 2017).

The growing concerns of adverse impacts of MPs have spurred a wide array of studies of the abundance, distribution, fate, and transport of MPs in the marine environment. Majority existing studies have focused on the widespread occurrence and distribution of MPs in the aquatic environment, however, research on abundance, distribution, and characteristics of MPs in the pelagic zone is currently lacking. The objective of the present study is to conduct field observations to investigate the abundance, distribution, and characteristics (composite, size, color, shape and surface morphology) of MPs in the Northwestern Pacific Ocean. MPs are characterized using light microscopy, Micro-Raman spectroscopy, and scanning electron microscopy (SEM). Physical oceanography parameters were also collected at these stations. The sources, distributions, and generation mechanisms of MPs in the pelagic zone are evaluated based on the field observations at these 18 stations across the Northwestern Pacific Ocean and link with flow patterns, adjacent ocean circulation eddies, the Kuroshio Current and Kuroshio Extension system.

2. Materials and methods

Although the benchmark methodology for MPs analysis has not been established, the following procedure has been used widely: (1) MPs collection; (2) MPs isolation (separation, digestion, filtration, drying); (3) visual identification; (4) Characterization by Fourier Transform Infrared Spectroscopy (FTIR)/Micro-Raman/Scanning Electron Microscopy-Energy Dispersive Spectroscopy (SEM-EDS); (5) identity assignment (Ribeiro-Claro et al., 2016). In the present study, a revised National Oceanic and Atmospheric Administration (NOAA) protocol (NOAA, 2015) is adopted for MPs sample collections and preparations.

2.1. Study area

Surface MPs sampling were collected at 18 stations across the Northwestern Pacific Ocean (cf. Fig. 1 and Table 1). Three stations XTW3-3, XTW3-4, and XTW3-5 are located evenly along the same latitude in the west of Luzon Strait (118–120°E). Six stations (XTW3-6, XTW3-7, XTW3-8, XTW3-9, XTW3-10, and XTJ3-19) are located in the latitude direction from 123 to 146°E. Another six stations (XTJ3-19, XTJ1-14, XTJ1-6, XTJ1-4, XTJ1-3, and XTJ1-2) are located in the longitudinal direction from 20 to 38°N. Four stations XTJ1-6, XTW2-1, XTW2-3, and XTW2-5 span eastward from 146 to 151°E. Locations of MPs field stations, sampling dates, abundance, and chemical composition of MPs are listed in Table 1 and illustrated in Fig. 1.

2.2. MPs sampling

A large volume of water samples are required during the MPs field survey, due to low concentration of MPs in the ocean (Bergmann et al., 2015), particularly in the pelagic zone. Floating MPs were collected from 18 stations (Fig. 1) in the Northwestern Pacific using a surface manta trawl with a mesh size of ~330 μm and width of 1 m from August 25 to September 26, 2017. The manta trawl was deployed to sea surface via a reel-operated lift on the side of the research vessel. The angle between trawling and shipping route is about 20°. The MPs at the ocean surface were sampled by trawling horizontally between