Chemosphere 180 (2017) 500–505

Contents lists available at ScienceDirect

Chemosphere

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

Monitoring of styrene oligomers as indicators of polystyrene plastic pollution in the North-West Pacific Ocean

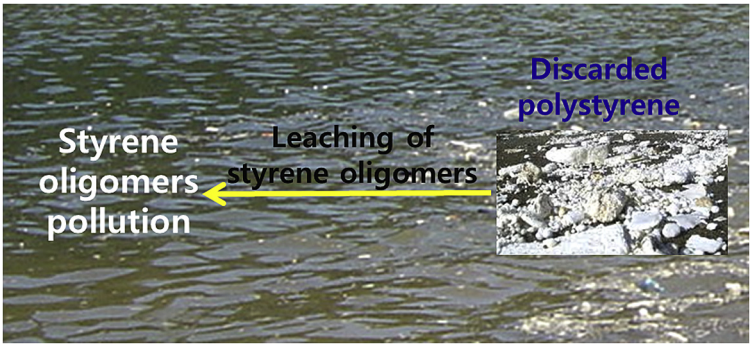
Bum Gun Kwon [a, *], Keiji Amamiya [b], Hideto Sato [b], Seon-Yong Chung [c], Yoichi Kodera [d], Seung-Kyu Kim [e, f], Eung Jae Lee [a], Katsuhiko Saido [d, g, **]

[a] Department of Bioenvironmental & Chemical Engineering, Chosun College of Science and Technology, 309-1 Pilmundae-ro, Dong-gu, Gwangju, 501-744, Republic of Korea
[b] Department of Chemistry, College of Science & Technology, Nihon University, 7-24-1, Narashinodai, Funabashi-shi, Chiba, 274-8501, Japan
[c] Department of Environment and Energy Engineering, College of Engineering, Chonnam National University, 77 Yongbong-ro, Buk-gu, Gwangju, 500-757, Republic of Korea
[d] National Institute of Advanced Industrial Science and Technology (AIST), 16-1 Onogawa, Tsukuba, Ibaraki, 305-8569, Japan
[e] Department of Marine Science, College of Natural Sciences, Incheon National University, 119 Academy-ro (Songdo-dong), Yeonsu-gu, Incheon, 22012, Republic of Korea
[f] Research Institute of Natural Sciences, Incheon National University, 119 Academy-ro (Songdo-dong), Yeonsu-gu, Incheon, 22012, Republic of Korea
[g] School of Ocean and Earth Science and Technology (SOEST), University of Hawai'i at Mānoa, 1000 Pope Rd, MSB 629, Honolulu, HI, 96822, USA

HIGHLIGHTS

- This study reports the distribution of styrene oligomers (SOs) in the marine environment.
- SOs are an indicator for polystyrene (PS) plastic pollution.
- This study can contribute to assessing the fate of PS plastic.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 10 October 2016
Received in revised form
17 March 2017
Accepted 13 April 2017
Available online 14 April 2017

Handling Editor: Tamara S. Galloway

Keywords:
Styrene oligomers
Polystyrene

ABSTRACT

Styrene oligomers (SOs) as global contaminants are an environmental concern. However, little is known on the distribution of SOs in the ocean. Here, we show the distribution of anthropogenic SOs generated from discarded polystyrene (PS) plastic monitored from the coastal ocean surface waters (horizontal distribution) and deep seawaters (vertical distribution) in the North-West Pacific Ocean. SOs concentrations in surface seawater and deep seawater ranged from 0.17 to 4.26 μg L^{-1} (total mean: 1.48 ± 1.23 μg L^{-1}) and from 0.31 to 4.31 μg L^{-1} (total mean: 1.32 ± 0.87 μg L^{-1}), respectively. Since there is no significant difference in the mean concentrations, SOs seems to be spread across marine environment selected in this study. Nevertheless, regional SOs appears to persist to varying degrees with their broad horizontal and vertical distribution in the ocean. Each horizontal and vertical distribution of SOs differs by approximately 1.95–2.57 times, probably depending on the events of weather and global

* Corresponding author.
** Corresponding author. Department of Bioenvironmental & Chemical Engineering, Chosun College of Science and Technology, 309-1 Pilmundae-ro, Dong-gu, Gwangju 501-744, Republic of Korea.
E-mail addresses: kwonbg0@daum.net (B.G. Kwon), katsu.saido@gmail.com (K. Saido).

http://dx.doi.org/10.1016/j.chemosphere.2017.04.060

Monitoring
Distribution
Marine
Ocean

ocean circulation. These results provide the distribution pattern of SOs for assessing environmental pollution arising from PS plastic.

1. Introduction

The well-known widespread occurrence of plastic debris has considerably increased since the early 1970s and plastic waste is a category of serious pollution ubiquitous in marine environments (Carpenter and Smith, 1972; Barnes et al., 2009; Thompson et al., 2009; Law et al., 2010; Rochman et al., 2013; Rochman, 2013). In oceans and coastal aquatic environments, the adverse effects of plastic debris are of considerable concern (Laist, 1987; Derraik, 2002; Moore, 2008; Gregory, 2009; Avery-Gomm et al., 2012; Browne et al., 2011; Cole et al., 2013; Besseling et al., 2013). Furthermore, the transportation of persistent organic pollutants (POPs) adsorbed onto the surfaces of plastic debris can adversely affect the ecosystem (Rochman, 2013; Teuten et al., 2007; Rios et al., 2007; Hirai et al., 2011; Bakir et al., 2014). Therefore, plastic marine pollution is an important environmental issue.

Up to now, in marine environments, most scientific studies have reported ubiquitous plastic debris including microplastics or nanoplastics (Frias et al., 2010; Andrady, 2011; Ivar do Sul and Costa, 2014) as well as plasticizers (Flint et al., 2012; Huang et al., 2012). More recently, low molecular weight chemicals derived from polystyrene (PS) polymer itself such as styrene oligomers (SOs) have been investigated in coastal beach environment (Saido et al., 2014; Kwon et al., 2014, 2015). However, little is known about the SOs chemicals generated from PS plastic in the coastal ocean surface and deep seawaters. Thus, the distribution trend of PS plastic contamination by SOs chemicals in oceans needs to be better understood.

In this study, we show analytical results of SOs sourced from the coastal ocean surface and deep seawaters in the North-West Pacific Ocean. We conducted a field study to measure the geospatial distribution of SOs derived from PS plastic polymer, focusing particularly on styrene trimer (ST1: mainly 2, 4, 6-triphenyl-1-hexene), styrene dimer (SD1: mainly 2, 4-diphenyl-1-butene), and styrene monomer (SM). Hereafter, the sum of the concentrations of SM, SD1 and ST1 will be mainly referred to as SOs. As a result, this study could provide a new direction for the assessment of the fate and behavior of PS plastic discarded into the ocean.

2. Materials and methods

2.1. Study areas

Coastal marine surface and deep seawater samples were collected from each sampling site selected in this study. The sampling locations are detailed in Fig. 1. The inset figure of Fig. 1 shows the collection sites of the coastal marine surface and deep seawater samples from various depths (0–4000 m) in the North-West Pacific Ocean during the Hakuhomaru voyage (H-voyage, May 18th to June 4th, 2010) and the Tanseimaru voyage (T-voyage, October 31st to November 7th, 2010). The sampling locations are detailed further in Table 1.

2.2. Sampling methods and sample preparation

At the sampling points (inset figure of Fig. 1), 12 L seawater samples were collected using 12 bottles of a Niskin seawater sampler which was composed of polyvinyl chloride (PVC) material. Furthermore, material containing PS plastic was excluded from all sampling and extraction procedures to eliminate any errors.

In the field, the seawater samples collected were subjected to cotton plug filtration. The seawater sample spiked with surrogate biphenyl prior to extraction was immediately extracted four times with 100 mL dichloromethane (DCM, reagent grade, Wako Chem., Tokyo, Japan) using a portable shaker (Sanada Co., Tokyo, Japan).

In the laboratory, about 100 mL of the DCM extract was mixed with approximately 10 g anhydrous sodium sulfate (ACS grade, Sigma-Aldrich, USA) and left overnight. The extract was evaporated by a rotary evaporator at 30 °C until it was dry. After adding

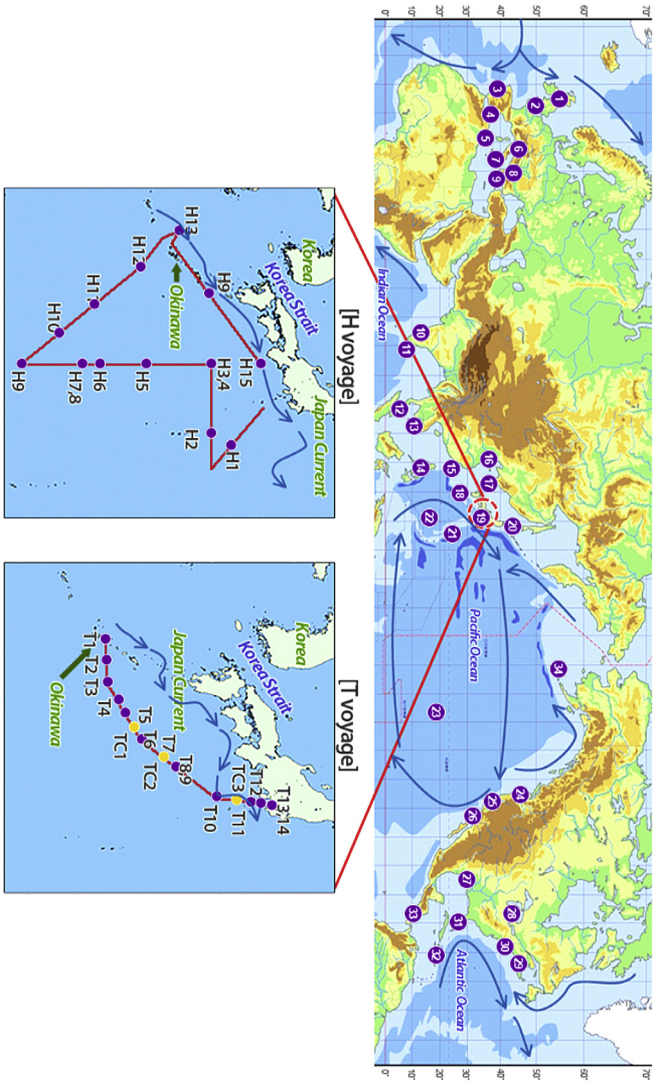


Fig. 1. Locations of samples collected in the North-West Pacific Ocean. The inset figure shows the sampling locations of the surface seawater and deep seawater samples. Numbers indicate the study number of each sampling location in our previous study (Kwon et al., 2015).