

Potential Threat of Microplastics to Zooplanktivores in the Surface Waters of the Southern Sea of Korea

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Received: 9 March 2015 / Accepted: 1 August 2015 / Published online: 12 August 2015
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Abstract The potential impact of microplastic to zooplanktivores was assessed by measuring a ratio of neustonic microplastics to zooplankton by abundance in the southern sea of Korea. Neustonic microplastics and zooplankton (0.33–2 mm) were collected using a 330- μ m mesh Manta trawl in Geoje eastern Bay and Jinhae Bay before and after the rainy season in 2012 and 2013. The mean microplastic to zooplankton ratios were 0.086 (May) and 0.022 (July) in 2012, and 0.016 (June) and 0.004 (July) in 2013, indicating that zooplanktivores could be more likely to feed on microplastics than natural preys before the rainy season in 2012 and 2013. In particular, the relatively high ratio occurred in a semi-enclosed bay characterized by a shipyard and a beach resort in Geoje Bay, and at stations close to a wastewater treatment plant and an aquaculture facility in Jinhae Bay before the rainy season. Among dominant microplastics and zooplankton before the rainy season, meroplankton of macrobenthos could be confused with paint particles in Geoje Bay, 2012, whereas

Styrofoam could be mistaken as immature copepods by predators in Jinhae Bay, 2013. These observations suggest that zooplanktivores could be more likely to feed on microplastics than natural preys around Geoje and Jinhae Bays before the rainy season.

It is not surprising that the ecological impact of microplastics has increased, because smaller pieces of plastic debris are occurring widely in the marine environment (Andrady 2011; Wright et al. 2013). Microplastics (<5 mm) fragmented from macrodebris or commercially manufactured for use as scrubbers or exfoliating cleansers fall within the size range of zooplankton as food items to higher trophic level organisms. In the marine environment, particular hotspots for the accumulation of microplastics are associated with North Pacific Subtropical Gyre and urban runoff from major conurbations and industrial coastal waters (Moore et al. 2001, 2002; Lattin et al. 2004; Cole et al. 2011; Kang et al. 2015). The numerical increase of microplastics may enhance possibility of mixing with surface food sources and may affect ability of planktivorous fishes to distinguish between plastic and their natural food (Boerger et al. 2010). In the hot spots, the high microplastic to plankton ratio has the potential to affect many types of biota, indicating that neustonic zooplankton itself or their predators can encounter microplastic debris in terms of the degree of risk (Moore et al. 2001; Lattin et al. 2004; Cole et al. 2011; Collignon et al. 2014). Microplastics are ingested by a variety of planktonic organisms (Setälä et al. 2014) as well as epipelagic, mesopelagic, and demersal fish inhabiting different depths of the water column irrespective of feeding habitat (Boerger et al. 2010; Davison and Asch 2011; Lusher et al. 2013).

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Incidence and sizes of most microplastics observed in the fish guts were from 9.2 to 36.5 %, and from 1 to 3 mm (Boerger et al. 2010; Davison and Asch 2011; Lusher et al. 2013; Possatto et al. 2011). Moreover, type of microplastics found in the guts of fishes showed wide range of diversity such as hard plastics, fibers, films, fragments, fishing line, Styrofoam, rubber, and bead. Ingested or entangled microplastics in a variety of shapes can cause adverse physical and chemical effects on the organisms in terms of blocking appendages, clogging digestive systems linking to false satiation and transport of chemical contaminants to organisms (Derraik 2002; Browne et al. 2008; Wright et al. 2013).

Boerger et al. (2010) suggested that high ratio of neuston plastics to zooplankton, implying relatively high number of microplastics may cause confusion with natural food by fishes in the North Pacific Central Gyre (NPCG), supported by Carlos de Sá et al. (2015). This ratio indicates the degree of interaction between neustonic zooplankton and microplastics and indicates the potential contamination level for the consumer (Collignon et al. 2014). Consequently, a strong negative impact of microplastics would be expected on high level consumers in the marine food chain (Moore et al. 2001; Andrady 2011).

Jinhae Bay and Geoje eastern Bay, with average depth of 11–23 m, function as major spawning and nursery habitats for fishes, such as anchovy, sardine, and cod, which prefer zooplankton as prey items when they are in the stages of fish larvae and adults (Yoo et al. 1992; Kim et al. 1994). From spring to summer, planktivorous anchovy (*Engraulis japonicus*) dominated in the surface waters of the both bays and consumed preferentially zooplankton (Kim and Kim 1993; Kim and Kang 2001; Park et al. 2004). Generally, the rainy season sets in about the middle of June and ends in July in the study area (www.kma.go.kr). During the rainy season, highest river flow was accompanied with a large quantity of microplastics leading to the increased encounter between zooplanktivores and microplastics (Lima et al. 2014; Kang et al. 2015). There is possibility that negative impact of microplastics on zooplanktivores can be higher after the rainy season in the study area. However, little is known about information for potential impact of microplastics on planktivores using ratios of microplastic to zooplankton collected with a Manta trawl in the southern sea of Korea.

We investigated microplastics and zooplankton with a Manta trawl around the highly industrial and urbanized coastal areas under influence of the Nakdong River located in the southern coast of Korea. The possible vulnerability of zooplanktivores to temporal variability in microplastic abundance and composition was compared before and after the rainy season based on the ratio of microplastics to zooplankton.

Methods and Materials

Study Area

The survey areas were located in coastal and offshore waters under the mouth of the Nakdong River and on the eastern coast of Geoje Island in 2012 and inner waters on the west coast of Geoje Island in 2013 (Fig. 1). The 2012 study area was directly influenced by water discharged from the Nakdong River barrier, which is controlled by a floodgate depending on weather conditions (Lee and Kim 2007; Yoon et al. 2008). However, the 2013 study area was mostly influenced by the Masan–Changwon municipal wastewater treatment plant with outlets toward sea and water discharged from the climate-induced heavy precipitation in Masan and Jinhae Bays (Kang et al. 2000; Jung et al. 2011).

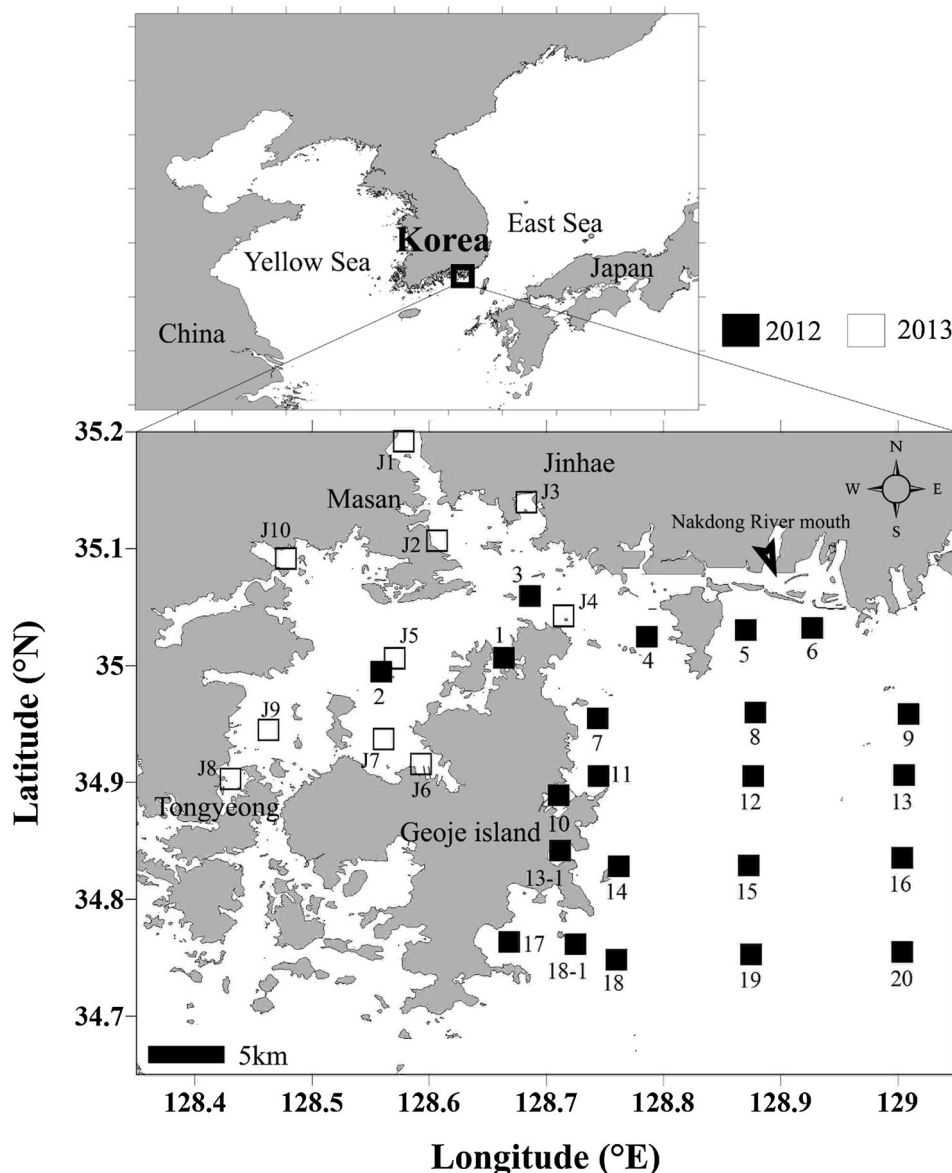
Sampling

Floating microplastic and epineuston were collected around the mouth of the Nakdong River in the daytime during the dry period of May 29–30 and July 23–24 after the rainy season in 2012. In addition, we sampled those in Jinhae Bay during the dry period of June 4–5 and July 10 after the rainy season in 2013 (Fig. 1). The microplastics and epineuston were sampled using a Manta trawl (0.4 × 0.195 m rectangular opening and 3 m long; 330 µm mesh net). The trawl was towed askew from the stern in surface waters outside of the effect of the bow wave for about 10 min at a vessel speed of 1.5–2.5 knots. After recovering the net, it was carefully washed from the outside with pre-filtered seawater to confirm that all debris and epineuston had been washed into the cod-end bucket. The bucket contents were reduced and transferred to a 1-L sample bottle. The concentrated sample bottles were stored at 4 °C and transported to the laboratory. The volume filtered by the net was calculated in m³ based on a flowmeter (Model 438–115; Hydro-Bios, Kiel, Germany) fixed at the mouth of the net frame. Temperature and salinity in the surface water were determined using a thermometer (Digital Thermometer: DAIHAN-NTC Lab Equipment, Seoul, South Korea) and a refractometer (MASTER-S/Millim; Atago, Bellevue, WA).

Analysis of Plastic and Epineuston

Large-sized particles were sorted out from the samples with a 5-mm mesh sieve and intermixed plastic was removed from living macroalgae and animal tissue using forceps. We selected a 2-mm mesh sieve for further size

Fig. 1 Map showing the sampling stations for collecting floating microplastic and epineuston using a Manta trawl net around Geoje and Jinhae Bays in 2012 and 2013



separation because the trawl-collected samples were not easily run through a 1-mm mesh sieve due to land and marine-based organic debris, particularly gelatinous material. The microplastic and epineuston <2 mm were investigated for analysis of concentration and composition. Half the filtrate after running the entire volume through a 2-mm mesh sieve was used to analyze microplastics and the other half was used to analyze epineuston. The epineuston filtrate was transferred to 1-L bottles and immediately fixed to a final concentration of 5 % with borax-neutralized formalin.

H₂O₂ solution was poured into the sample bottle to a final concentration of 20 % to remove living tissue and the bottle was placed in a temperature-controlled room in the dark for 2 weeks before the microplastics analysis (Song et al. 2014; Kang et al. 2015). The filtrates were filtered on

GF/F filters aided by a low-pressure vacuum <100 mm Hg. The GF/F filters were dried at 60 °C for 24 h and inspected under a stereomicroscope (Model Discovery SV8; Zeiss, Zena, Germany). The subsequent analysis focused on classifying the plastic components by their morphological and physical characteristics. Microplastic particles were classified into fibrous particles (fiber), hard plastic, Styrofoam, paint resin particles, film, spheres, and other polymers. The microplastic particles were randomly selected, and the specific polymer type was confirmed by Fourier-transform infrared microscopy (Thermo Nicolet 6700 and continuum, Thermo Scientific, Waltham, MA). The abundance of each plastic type was converted to number of particles/m³ seawater. Lengths of microplastic pieces <2 mm were determined using an image analysis system

(AxioCam ICc 3, ZEN 2011 program, SteREO Discovery, V8).

The epineuston were sorted into taxonomic groups and enumerated under a stereomicroscope. The epineuston were identified according to Chihara and Murano (1997) and classified into heterotrophic dinoflagellate *Noctiluca scintillans*, thaliaceans, pteropods, chaetognaths, appendicularians, cladocerans, adult copepods, immature copepods, amphipods, meroplankton of macrobenthos, fish larvae, fish eggs, euphausiid larvae, and eggs. The abundance of epineuston in all samples was expressed as individuals/m³ seawater.

The abundances of microplastic and epineuston (330 µm–2 mm) were determined to establish the microplastic to zooplankton ratio. Temporal differences in mean abundances of microplastic particles and epineuston before and after the rainy season were statistically analyzed with an analysis of variance (ANOVA) using SPSS version 12.0 (SPSS, USA).

Results

Environmental Factors

Monthly accumulated precipitation in the study area was 18.3–418.8 mm with a mean of 169.8 mm in 2012 and 12.2–166.4 mm with a mean of 104.8 mm in 2013 (Fig. 2). The highest precipitation was recorded in July 2012 and in June 2013. The rainy season each year was announced

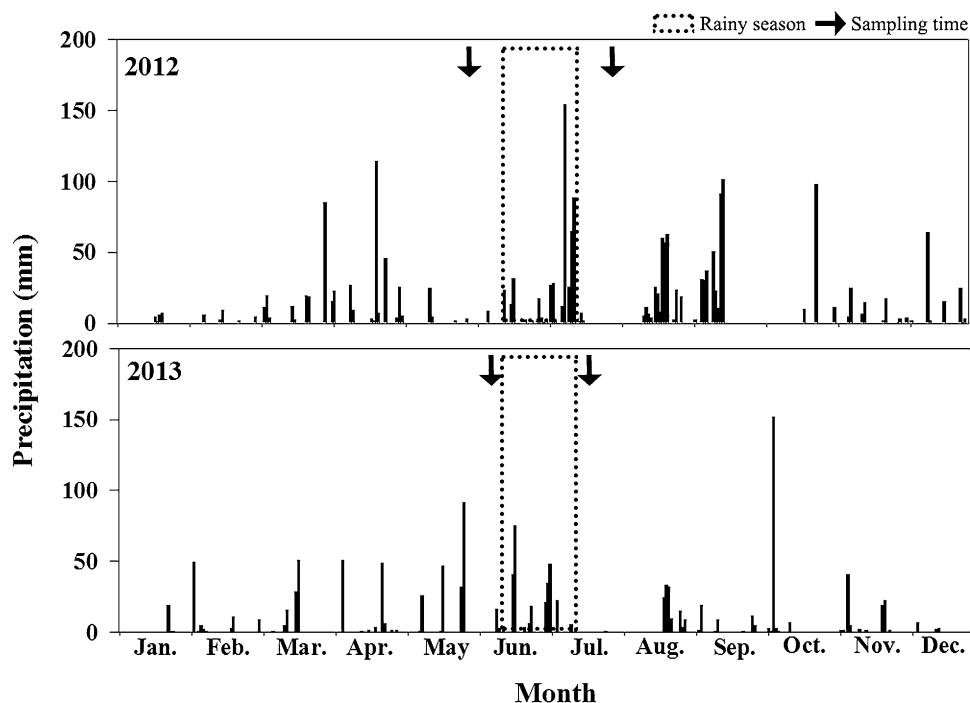
officially by the Korean Meteorological Administration (WWW.kma.go.kr) (Fig. 2). The spatial distribution of surface water temperature showed characteristics of a typical temperate sea, whereas the surface salinity distribution pattern differed before and after the rainy season associated with precipitation (Figs. 2, 3). Relatively low salinity was observed at stations close to the Nakdong River mouth in 2012. Low salinity also was found at stations J1, J2, J3, and J10 located on the northern coast of Jinhae Bay in 2013.

Abundance and Composition of Plastic Particles and Epineuston

Floating microplastic and epineuston occurred at almost all stations during the study period. Total microplastic abundances were 1.92 ± 1.84 and 5.51 ± 11.24 particles/m³ before and after the 2012 rainy season, respectively (Table 1). Total epineuston abundances were 22 ± 30 and 251 ± 173 inds.m³ before and after the 2012 rainy season, respectively (Table 1). Total microplastic abundances were 1.68 ± 0.81 and 1.07 ± 0.34 particles/m³ before and after the 2013 rainy season, respectively (Table 1). Total epineuston abundances were 102 ± 110 and 281 ± 297 inds.m³ before and after the 2013 rainy season, respectively (Table 1).

Epineuston predominated in all samples compared to microplastics during the study (Fig. 4). The relative abundance of microplastics decreased from 7.9 to 2.2 % after the rainy season, whereas that of epineuston increased

Fig. 2 Daily precipitation in Geoje and Jinhae Bays during 2012 and 2013. Dotted box official rainy season according to the Korean Meteorological Administration. Arrows sampling times



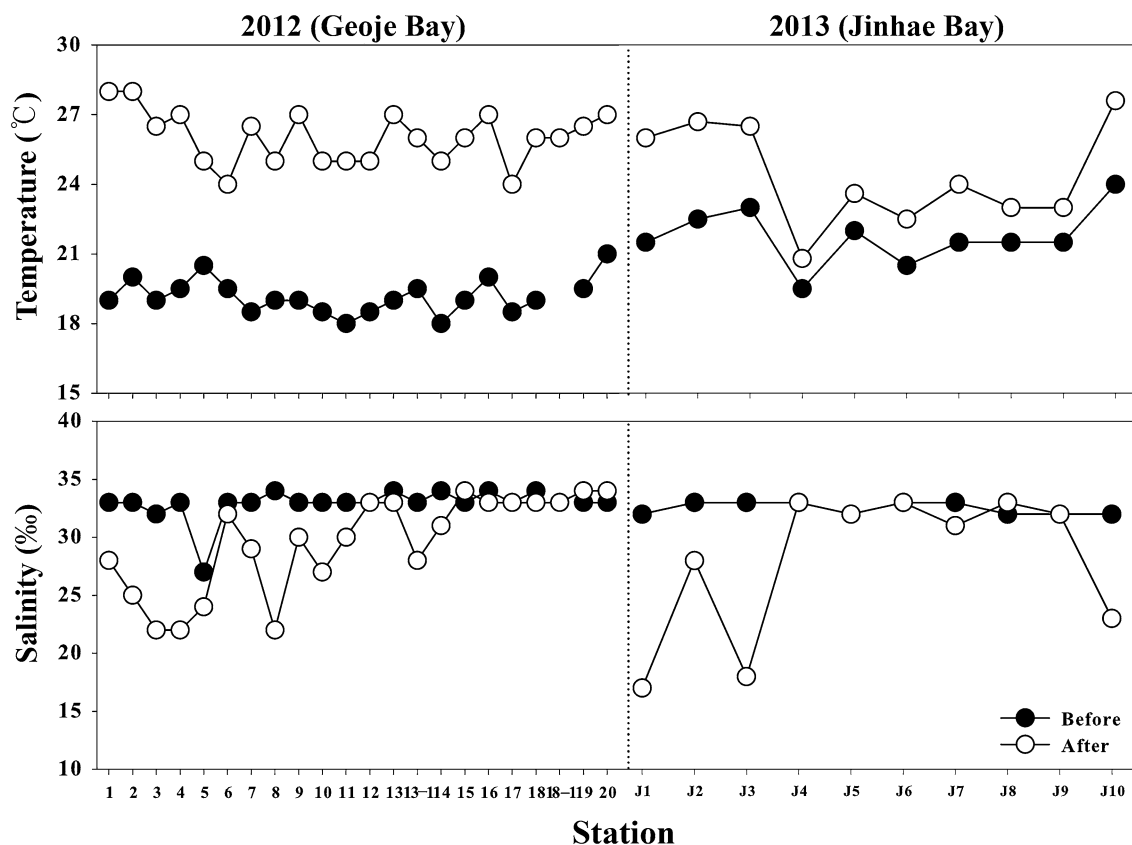


Fig. 3 Spatial variations in surface temperature and salinity in Geoje and Jinhae Bays before and after the 2012 and 2013 rainy seasons

from 92.1 to 97.9 % after the rainy season in 2012 (Fig. 4). The relative abundance of microplastics decreased from 1.6 to 0.4 % after the rainy season, whereas that of epineuston increased from 98.4 to 99.6 % after the rainy season in 2013 (Fig. 4).

Neustonic microplastic consisted of fiber, hard plastic, paint particles, Styrofoam, and others (sphere, film, and other polymers) (Fig. 5; Table 1). Hard plastic, paint particles, fiber, and Styrofoam dominated total microplastic abundance in this study (Fig. 5; Table 1). Paint particles and Styrofoam as the most dominant microplastics showed opposite patterns of relative abundance before and after the 2012 rainy season in Geoje Bay. The relative abundance of paint particles decreased from 49.0 % before the rainy season to 19.2 % after the rainy season, whereas that of Styrofoam increased from 16.6 % before the rainy season to 51.7 % after the rainy season in Geoje Bay in 2012. However, the relative abundances of Styrofoam and paint particles collected from Jinhae Bay before and after the 2013 rainy season showed an opposite trend to those in 2012 (Fig. 5).

Epineuston was mostly composed of the heterotrophic dinoflagellate *N. scintillans*, cladocerans, adult and immature copepods, meroplankton of macrobenthos (polychetes,

gastropods, bivalves, and cirripedians), euphausiid eggs, appendicularians, fish eggs, and other rare groups in Geoje and Jinhae Bays in 2012 and 2013 (Fig. 6; Table 1). Fish eggs (anchovy) predominated, followed by cladocerans and immature copepods before the 2012 rainy season (Fig. 6; Table 1). Fish eggs decreased in number, but cladocerans largely increased after the 2012 rainy season. *Noctiluca scintillans* drastically decreased but cladocerans and fish eggs increased significantly after the 2013 rainy season in Jinhae Bay (Fig. 6; Table 1).

Microplastic to Epineuston Ratio

The total mean ratio of microplastic to epineuston was 0.086 ± 0.061 in May before the rainy season and 0.022 ± 0.065 in July after the rainy season in 2012 (Fig. 7; Table 1). The total mean ratio was 0.016 ± 0.007 in June before the rainy season and 0.004 ± 0.001 in July after the rainy season in 2013 (Fig. 7). The ratios of microplastics to epineuston in May were higher than those in Geoje Bay in July 2012. The highest ratios before the 2012 rainy season (May) were observed at stations 4, 10, 13-1, and 14, which are close to a shipyard and a beach

Table 1 Mean \pm standard deviation (mean \pm SD), sizes, and abundance of microplastic and epineuston (330 μm –2 mm) collected with a Manta trawl around Geoje and Jinhae Bays, Korea in 2012 and 2013

Items	Size (μm) mean \pm SD		2012		2013		F value	Before Mean \pm SD	After Mean \pm SD	F value
	Before (Mean \pm SD)	After (Mean \pm SD)	Before (Mean \pm SD)	After (Mean \pm SD)	Before (Mean \pm SD)	After (Mean \pm SD)				
Microplastics (particles/ m^3)										
Fiber	1439.9 \pm 438.2	0.34 \pm 0.13	0.62 \pm 0.34	13.92**	0.25 \pm 0.09	0.15 \pm 0.07	8.30*			
Hard plastic	997.9 \pm 457.8	0.24 \pm 0.22	0.98 \pm 1.49	1.47*	0.33 \pm 0.27	0.18 \pm 0.09	2.85			
Paint particles	435.0 \pm 363.5	0.94 \pm 0.96	1.05 \pm 0.94	0.30	0.25 \pm 0.24	0.28 \pm 0.18	0.14			
Styrofoam	944.0 \pm 564.5	0.38 \pm 1.23	2.85 \pm 10.01	1.34	0.81 \pm 0.78	0.45 \pm 0.39	1.66			
Film	1386.0 \pm 478.6	0.01 \pm 0.04	0.00 \pm 0.01	1.28	0.25 \pm 0.09	0.01 \pm 0.01	1.45			
Other polymer	293.8 \pm 154.6	N.D.	N.D.	–	0.00 \pm 0.01	N.D.	–			
Sphere	328.0 \pm 69.8	0.01 \pm 0.02	0.00 \pm 0.01	1.47	0.01 \pm 0.02	N.D.	–			
Sub total	–	1.92 \pm 1.84	5.51 \pm 11.24	2.28	1.68 \pm 0.81	1.07 \pm 0.34	4.85*			
Epineuston (Individuals/ m^3)										
<i>Noctiluca scintillans</i>	361.8 \pm 25.8	0 \pm 2	23 \pm 29	12.38**	61 \pm 98	N.D.	–			
Cladocerans	770.2 \pm 65.0	2 \pm 7	124 \pm 150	13.81**	17 \pm 45	193 \pm 240	5.16*			
Adult copepods	1122.5 \pm 166.3	0 \pm 1	1 \pm 1	2.48	2 \pm 3	2 \pm 2	0.17			
Immature copepods	503.2 \pm 67.9	2 \pm 4	7 \pm 15	2.25	1 \pm 1	4 \pm 5	4.65*			
Meroplankton	387.5 \pm 14.4	0 \pm 1	6 \pm 9	9.07**	10 \pm 10	14 \pm 14	0.54			
Euphausiid egg	679.6 \pm 49.3	N.D.	11 \pm 46	–	N.D.	11 \pm 35	–			
Appendicularians	1086.3 \pm 397.2	N.D.	2 \pm 3	–	9 \pm 10	3 \pm 3	2.20			
Fish egg	623.5 \pm 60.7	16 \pm 30	75 \pm 77	10.61**	3 \pm 3	53 \pm 64	5.99*			
Subtotal	–	22 \pm 30	251 \pm 173	37.56**	102 \pm 110	281 \pm 297	3.19			
Total	–	23.92 \pm 31.84	256.51 \pm 184.24	36.82**	103.68 \pm 110.81	282.07 \pm 296.34	3.17			
Ratio of microplastic to epineuston for total average density	–	0.086 \pm 0.061	0.022 \pm 0.065	4.81*	0.016 \pm 0.007	0.004 \pm 0.001	2.74			

N.D. not detected

* $p < 0.05$; ** $p < 0.005$

Fig. 4 Relative abundance of total microplastics and epineuston from samples collected using a Manta trawl in Geoje and Jinhae Bays before and after the 2012 and 2013 rainy seasons

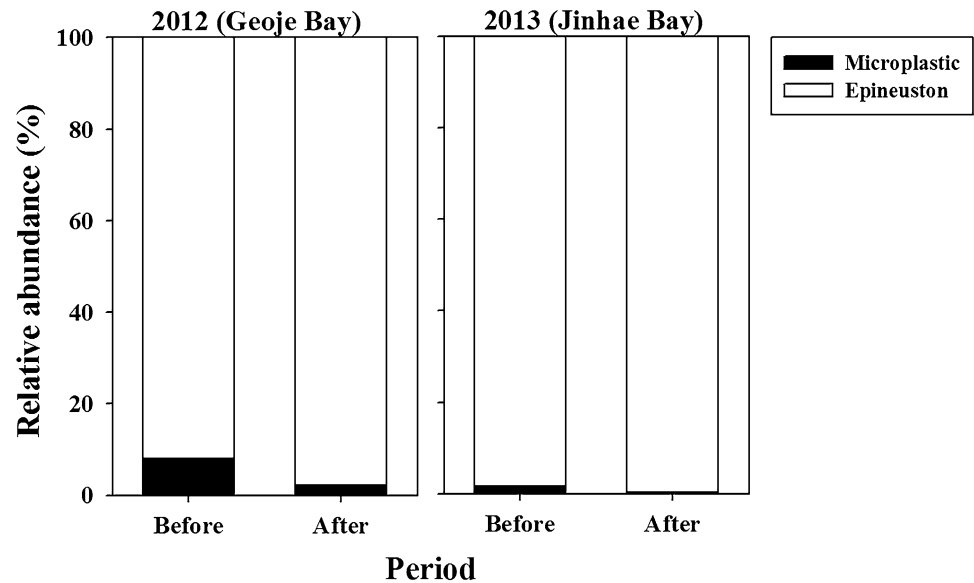
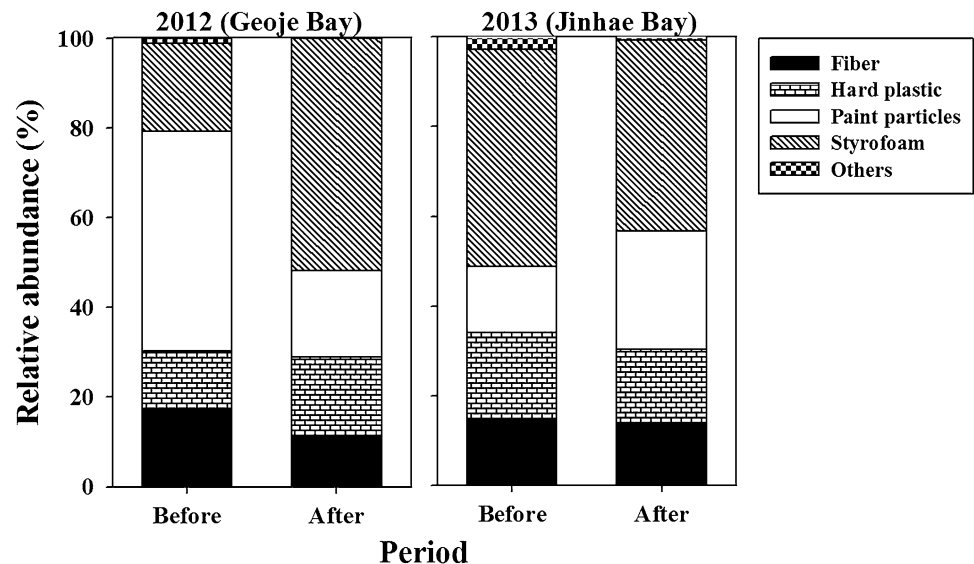


Fig. 5 Relative abundances of type-specific microplastics from total microplastics (330 μm –2 mm) collected by a Manta trawl in Geoje and Jinhae Bays before and after the 2012 and 2013 rainy seasons



resort; high ratios also were found at stations 7, 15, and 18-1 after the rainy season in July 2012, which is far from the Nakdong River mouth (Fig. 7). The total mean ratios of microplastic to epineuston in June 2013 were higher than those in Jinhae Bay in July 2013 (Fig. 7). The highest ratios before the rainy season (June) were observed at stations 1, 2, 8, and 10, which were close to a municipal wastewater treatment plant with outlets toward sea and semi-enclosed bays surrounded by urbanized areas or aquaculture farms (Figs. 1, 7). High ratios also were found at stations 8 and 9 in Jinhae Bay after the 2013 rainy season (Fig. 7). Except stations 15 in 2012 and J9 in 2013, most of the mean total microplastics to epineuston ratios before the rainy season decreased after the rainy season in Geoje and

Jinhae Bays in 2012 and 2013 (Table 1). The decreases in the ratios after the 2012 rainy season stemmed from slightly increased abundance of microplastics and increased epineuston, whereas the decreases in the ratios after the 2013 rainy season were caused by a increase in epineuston abundance, particularly cladocerans, but slight decrease of microplastics (Table 1). When results from Geoje and Jinhae Bays during the study are merged, relatively high ratios of total microplastic to taxonomical groups of epineuston were cladocerans, immature copepods and meroplankton before the rainy season, whereas those were *N. scintillans*, adult copepods, euphausiid eggs, appendicularians, and fish eggs after the rainy season (Table 2).

Fig. 6 Relative abundances of taxonomic groups from total zooplankton (330 μm–2 mm) collected using a Manta trawl in Geoje and Jinhae Bays before and after the 2012 and 2013 rainy seasons

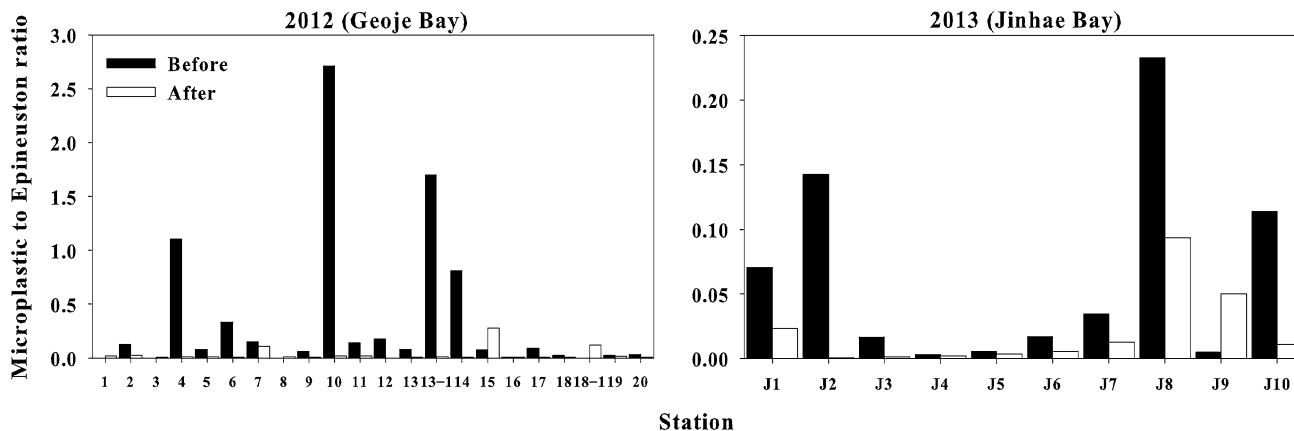
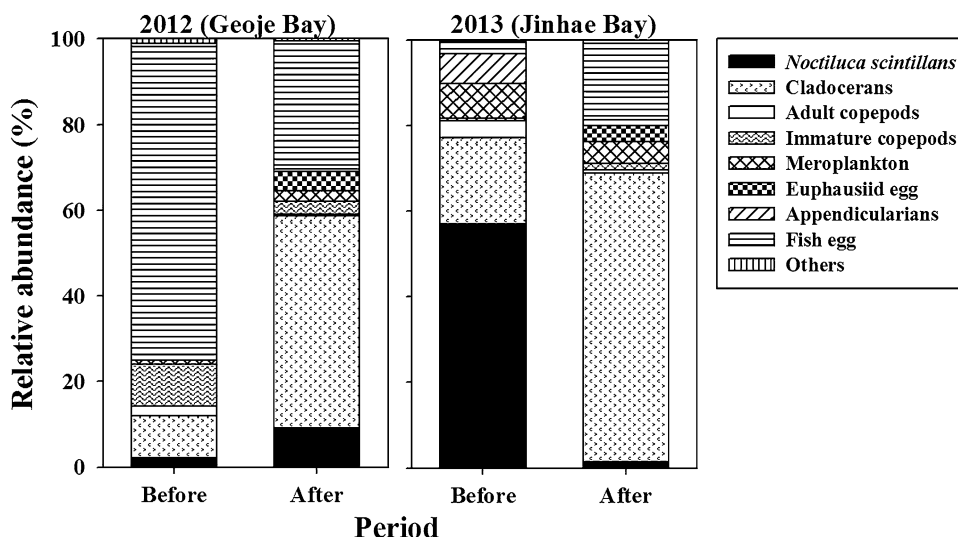


Fig. 7 Spatial distribution in the microplastic to epineuston ratios from neuston samples (330 μm–2 mm) collected in Geoje and Jinhae Bays before and after the 2012 and 2013 rainy seasons

Table 2 Ratio of total microplastic to epineuston by taxonomical groups before and after the rainy seasons during the study

Ratio of microplastic to epineuston			F value
Total MP/ <i>Noctiluca scintillans</i>	0.09 ± 0.03	0.26 ± 0.36	4.175*
Total MP/Cladocerans	0.27 ± 0.06	0.03 ± 0.05	2.068
Total MP/Adult copepods	2.07 ± 0.80	2.91 ± 5.90	0.065
Total MP/Immature copepods	1.12 ± 0.51	0.65 ± 0.76	1.112
Total MP/Meroplankton	0.55 ± 0.21	0.47 ± 0.83	0.964
Total MP/Euphausiid eggs	N.D.	0.37 ± 0.22	–
Total MP/Appendicularians	0.67 ± 0.23	1.93 ± 3.19	1.655
Total MP/Fish eggs	0.15 ± 0.03	0.66 ± 0.13	1.745

N.D. not detected, SD standard deviation, MP microplastic

* $p < 0.05$; $n = 31$

The relatively high ratios of total microplastic to epineuston before the 2012 rainy season were mostly explained by paint particles to meroplankton, and next by paint particles to *N. scintillans* and adult copepods in Geoje

Bay. Only the meroplankton showed higher ratios of dominant microplastics (fiber, hard plastic, paint particles, and Styrofoam) to epineuston compared to other taxonomical zooplankton (Fig. 8). Before the 2013 rainy

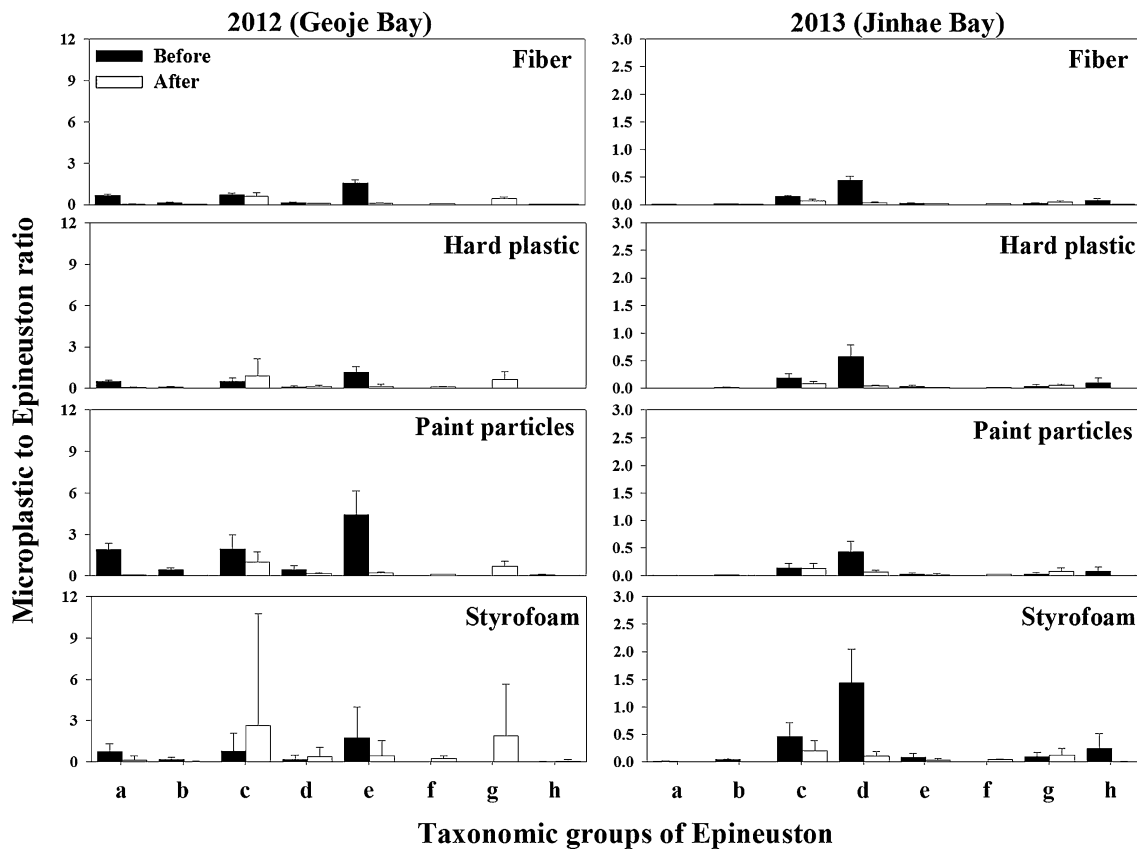


Fig. 8 Microplastics to epineuston (330 μm –2 mm) ratios by taxonomic group for total mean density in Geoje and Jinhae Bays before and after the 2012 and 2013 rainy seasons (*a* *Noctiluca scintillans*;

b cladocerans; *c* adult copepods; *d* immature copepods; *e* meroplankton; *f* euphausiid eggs; *g* appendicularians; *h* fish eggs)

season, the relatively high ratios were mainly characterized by Styrofoam to immature copepods, followed by Styrofoam to adult copepods in Jinhae Bay. Only immature and adult copepods represented higher ratios of dominant microplastics (fiber, hard plastic, paint particles, and Styrofoam) to epineuston compared with other taxonomical zooplankton (Fig. 8).

Discussion

Previous studies have assessed the potential for zooplanktivores to forage on microplastic fragments instead of prey items using ratios of microplastic to zooplankton in the North Pacific Gyre, Southern California's coastal waters, San Gabriel River, the North Western Mediterranean Sea, Bay of Calvi (Mediterranean-Corsica), and Portuguese coastal waters (Moore et al. 2001, 2002; Lattin et al. 2004; Doyle et al. 2011; Collignon et al. 2012, 2014; Frias et al. 2014).

Planktivorous organisms can have potential threat to experience the ingested microplastic-related physical (e.g.

clogging or blockage of digestive tract) and chemical (e.g. release of chemical additives) impacts depending on the presence and size of particles, encounter rates, and the selective feeding force by specific organisms in diverse physical environments (Lusher et al. 2013; Wright et al. 2013; Setälä et al. 2014). A gradual increase in the concentration of microplastics caused by continuous fragmentation in the entire ocean is surely predicted to occur; however, environmental discontinuities, such as river run-off due to heavy precipitation from coastal storms as well as convergence, gyres, fronts, eddies, and meanders at some offshore locations can enhance the opportunities for encounter between microplastics and zooplankton by retaining and accumulating the microplastics (Moore et al. 2001; Moore 2008; Doyle et al. 2011; Carson et al. 2013). Among a variety of environmental discontinuities, concentration of neuston plastics in the NPCG outweighed zooplankton by a ratio of 6 in 1999 (Moore et al. 2001) and the number of plastics increased dramatically in 2008, which can affect the ability of fish to distinguish between plastic and their natural food (Boerger et al. 2010).

The microplastic to epineuston ratios for total mean density varied spatially with different range before and after the rainy seasons in Geoje and Jinhae Bays in 2012 and 2013, indicating that vulnerability of zooplanktivores to microplastics changed before and after the 2012 and 2013 rainy seasons in both bays (Fig. 7). And, zooplanktivores in Geoje Bay could be more susceptible to microplastics compared to those in Jinhae Bay based on the mean ratios (Table 1; Fig. 7). The anchovy *Engraulis japonicus*, which is dominant planktivorous fish in the Southern Sea based on Korea Oceanographic Data Center of National Fisheries Research & Development Institute (kocd.nfrdi.re.kr), can be the most probable one among zooplanktivores which can eat microplastics in the study area. Most of the fish eggs found during the study corresponded to *E. japonicas*, indicating that this study area is also spawning and nursery habitat for the fish (Table 1) (Yoo et al. 1992; Kim et al. 1994; Park et al. 2004).

The decreases in the ratios after the 2012 and 2013 rainy seasons had different underlying causes between years (Fig. 7). The decreases in the ratios after the 2012 rainy season resulted from a significant increase in total epineuston after the rainy season, though the mean abundances of fiber and hard plastics increased significantly among microplastics (Table 1). However, the decrease in microplastics and the relatively strong increase in epineuston contributed to decrease the ratios after the 2013 rainy season in Jinhae Bay (Table 1). The increased abundances of epineuston after the 2012 and 2013 rainy seasons stemmed primarily from the remarkable increases in the numbers of cladocerans (*Evadne tergestina* and *Penilia avirostris*). Hwang et al. (2011) also found high numbers of cladocerans in Jangmok harbor of Jinhae Bay, corresponding to a similar rainy season period as our study (Fig. 3).

The mean ratio in the Bay of Calvi (Mediterranean-Corsica) was 0.002, which is relatively low compared to that of other regions, such as the North Pacific Subtropical Gyre, the San Gabriel River, Santa Monica Bay, and the North Western Mediterranean Sea (Table 3). Moreover, the low ratio could indicate that neustonic zooplankton rarely meet with microplastics (Collignon et al. 2014). In contrast, a ratio of 0.5, which occurs in the North Pacific Subtropical Gyre, the San Gabriel River, and Santa Monica Bay, can confuse zooplanktivores and they mistake microplastics for prey items (Collignon et al. 2012). The total mean ratios we observed in the study area suggest that zooplanktivores are likely intermediately to confuse microplastics with prey items (Table 3). In addition, the possibility of exposing zooplanktivores to microplastics was higher before the rainy season than after the rainy season during both years (Fig. 7; Table 1). Moreover, the distributional pattern of the microplastic to zooplankton ratios was very similar to

that of Moore et al. (2002), who reported high ratios before a storm and relatively low ratios after a storm in coastal waters, which was opposite to the offshore water pattern on the California coast. Moore et al. (2002) reported that the high abundance of inshore microplastics before a storm moves offshore after a storm. This phenomenon also occurred in the present study (Fig. 7). Extremely high microplastic to zooplankton ratios >0.5 were observed at a few Geoje Bay stations in 2012, and ratios >0.1 were recorded at three Jinhae Bay stations in 2013 (Fig. 7). These stations corresponded to active human activities in semi-enclosed bays, such as a shipyard, a beach resort, a municipal wastewater treatment plant with outlets toward sea, and an aquaculture facility (KIOST 2011; Kang et al. 2015). Especially, the Geoje Bay stations with remarkably high ratios in 2012 were coincident with moving path of the buoys as results of northeasterly wind and common sea surface currents flowing into the coast at sea (Jang et al. 2014). The extremely high ratios decreased at all stations after the 2012 and 2013 rainy seasons but a relatively high ratio was recorded at offshore stations 15 and 18-1 in 2012 and J9 in 2013 (Figs. 1, 7). In contrast, a relatively high microplastic to epineuston ratio was reported by Lattin et al. (2004) after a storm compared to that before a storm.

In particular, zooplanktivores have potential to mistake microplastics for prey items in terms of immature copepods, meroplankton, and cladocerans before the rainy season based on merged results around Geoje and Jinhae Bays during the study (Table 2). Among microplastics and epineuston before the rainy season, paint particles are the most probable confusion with meroplankton with a ratio of 4.413 in 2012, whereas Styrofoam could be mistaken as immature copepods by zooplanktivores with a ratio of 1.435 in 2013 (Fig. 8).

Practically, incidence of microplastics (mostly <2 mm) in the gut of studied fishes ranged from 9.2 to 36.5 % in the estuarine waters, English channel, and NPCG (Boerger et al. 2010; Davison and Asch 2011; Possatto et al. 2011; Lusher et al. 2013). A few studies suggested that the studied epi- and mesopelagic fishes probably ingested microplastics during normal feeding activity despite their visual sensation because of same color between prey items and microplastics (Boerger et al. 2010; Lusher et al. 2013). Ingested microplastics by the studied fishes consisted of Styrofoam, rubber, fibers, small fragment, film, beads, fishing line, and finally rope with the most common size class of <2 mm, corresponding to composition of dominant microplastics observed in the present study (Fig. 5). From the microplastics, fibers, which were dominant type in the gut (Lusher et al. 2013), are the most commonly prevalent form in the marine environment (Wright et al. 2013). The impacts of the ingested microplastics to the fishes cannot be fully understood until it can be investigated if fish can

Table 3 Comparison of the microplastic to epineuston ratios between present and previous studies

Study site	Ratio of plastic to plankton	Size range of plastics (mm)	Sampling design	References
North Pacific Gyre	0.3	0.33–4.75	Central pressure cell of the North Pacific sub-tropical high	Moore et al. (2001)
San Gabriel River	0.6	0.33–4.75	Before and after storm	Moore et al. (2002)
Santa Monica Bay	0.3	0.33–4.75	Before and after storm	Lattin et al. (2004)
North Western Mediterranean Sea	0.5	0.33–5	Before and after strong wind	Collignon et al. (2012)
Bay of Calvi (Mediterranean-Corsica)	0.002	0.2–2	Annual variation	Collignon et al. (2014)
Portuguese coastal waters	0.04–0.14	0.28	Regular monitoring	Frias et al. (2014)
Geoje bay	0.086 (before), 0.022 (after)	0.33–2	Before and after rainy season	Present study
Jinhae bay	0.016 (before), 0.004 (after)	0.33–2	Before and after rainy season	Present study

pass the microplastics through totally or some plastic remains in the gut (Boerger et al. 2010). However, recently, Carlos de Sá et al. (2015) reported that juveniles of common goby (*Pomatoschistus microps*) ingested microplastics by confusing microplastics with natural preys and showed significant reduction of the predatory performance and efficiency, implying that ontogenic developmental conditions may influence the prey selection capability. Long-time residence of the ingested microplastics in the gut of fishes can be led to malnutrition, eventual starvation and significant reductions in fish populations (Boerger et al. 2010; Cole et al. 2011). On the other hand, laboratory experiments have demonstrated that ingested nano- or microplastic fragments cause mortality, decreased growth rates, malformations, and decreased fecundity in marine zooplankton (Cole et al. 2013; Lee et al. 2013; Kaposi et al. 2014; Besseling et al. 2014; Setälä et al. 2014).

In summary, confusion of zooplanktivores to microplastics with prey organisms was relatively higher in Geoje and Jinhae Bays before the 2012 and 2013 rainy seasons compared with after rainy seasons based on the total mean ratios of microplastics to zooplankton in the neustonic samples. The greatest high ratios occurred in a semi-enclosed bay characterized by a shipyard and a beach resort in Geoje Bay before the 2012 rainy season, and relatively high ratios occurred at stations close to a municipal wastewater treatment plant with outlets toward sea and an aquaculture facility in Jinhae Bay before the 2013 rainy season. Before the rainy season, the relatively high ratios occurred between total microplastics (mainly fiber, hard plastic, paint particles, and Styrofoam) and epineuston (cladocerans, immature copepods, and mero-plankton) compared with after the rainy season throughout

the study period. Among the ratios before the rainy season, the highest ratios were paint particles to meroplankton in Geoje Bay in 2012 and Styrofoam to immature copepods in Jinhae Bay in 2013.

Acknowledgments This study was supported by research project titled “Environmental Risk Assessment of Microplastics in the Marine Environment” from the Ministry of Oceans and Fisheries, Korea.

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