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Note

Characterization of microplastic and mesoplastic debris in sediments from Kamilo Beach and Kahuku Beach, Hawai'i

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ABSTRACT

Sediment samples were collected from two Hawai'ian beaches, Kahuku Beach on O'ahu and Kamilo Beach on the Big Island of Hawai'i. A total of 48,988 large microplastic and small mesoplastic (0.5–8 mm) particles were handpicked from the samples and sorted into four size classes (0.5–1 mm, 1–2 mm, 2–4 mm, 4–8 mm) and nine color categories. For all sizes combined the most common plastic fragment color was white/transparent (71.8%) followed by blue (8.5%), green (7.5%), black/grey (7.3%), red/pink (2.6%), yellow (1.2%), orange (0.6%), brown (0.3%) and purple (0.2%). Color frequency distribution based on both numbers and mass of particles was not significantly different among the various size classes nor between the two beaches. White and black/grey resin pellets accounted for 11.3% of the particles collected from Kahuku Beach and 4.2% of the particles from Kamilo Beach. Plastic type based on Raman Spectrometer analysis of a small representative subsample indicated that most of the fragments were polyethylene and a few were polypropylene.

1. Introduction

It is estimated that in 2010 between 4.8 and 12.7 million metric tons of plastic trash ended up in the oceans from coastal countries (Jambeck et al., 2015). Some relatively large plastic debris such as plastic bottles remains relatively intact for many months or years and may be attacked by sharks and other fish (Carson, 2013); the term "sharkastics" has been coined to describe plastic objects found washed up on beaches with obvious bite marks (www.sharkastics.org). Numerous studies have documented various plastic objects found in the stomachs of dead seabirds and marine mammals (eg. Laist, 1997; Derraik, 2002; Lusher, 2015), and plastic bags are often swallowed by sea turtles who confuse them with jellyfish (Lutcavage et al., 1997; Barreiros and Barcelos, 2001). Prolonged exposure to ultraviolet radiation results in degradation rendering the plastic more brittle (Pegram and Andrady, 1989; Andrady et al., 1996). Surface cracks develop (Cooper and Corcoran, 2010) and mechanical forces such as wind, waves, and animal biting cause the larger objects to slowly fragment into smaller pieces (Qayyum and White, 1993; Yakimets et al., 2004; GESAMP, 2015) while still maintaining chemical integrity. Andrady and Neal (2009) state that it is likely that nearly all of the plastic that has ever entered the environment still exists and very little if any plastic fully degrades in the marine environment. A recent study based on collections from 24 expeditions between 2007 and 2013 estimates that >5 trillion plastic pieces weighing 268,940 tons are currently afloat in the world's oceans, with particles <5 mm in diameter accounting for 92.4% of the total (Eriksen et al., 2014). Fragments derived from a plastic that is denser than seawater (>1.02 mg/cm^3) eventually sink and contribute to deposition on the sea floor (Woodall et al., 2016). These include materials made of solid polystyrene (1.04–1.07) polyethylene terephthalate (1.38–1.39) and vinyl or polyvinyl chloride (1.35–1.45). Fragments derived from lighter plastics such as polypropylene (0.90–0.91), polyethylene (0.91–0.97) and expanded polystyrene foam (<0.05) remain in the water column near the surface for long periods of time, although some PP and PE microplastics may sink due to other factors including biofouling (eg. Zettler et al., 2013; McCormick et al., 2014) and presence of minerals as fillers added during manufacture or through adsorption (Corcoran et al., 2015; Ballent et al., 2016). Little is known about the rate of plastic fragmentation in seawater (GESAMP, 2015) but once plastics break down into tiny pieces they often are consumed by indiscriminate filter feeders and may be mistaken for plankton by larger planktivores (see Wright et al., 2013 for a review of the impacts of microplastics on marine organisms; Tanaka et al., 2013). Ultimately much of this suspended material washes ashore due to waves, storms and high tides where fragmentation proceeds faster and the tiny pieces become incorporated among beach sand grains. Some of this material may be consumed by various benthic invertebrate deposit feeders such as mussels, lugworms, and sea cucumbers (Graham and Thompson, 2009; Van Cauwenberghe et al., 2015a). While the indigestible plastics create serious and often fatal mechanical problems for

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organisms, plastics are known to adsorb many toxic chemicals from the surrounding water (eg. Frias et al., 2010) which may have even more significant consequences for those organisms that ingest them as well as organisms higher up the food chain.

At present there is no universally agreed nomenclature for the various sizes of plastic particles (Cole et al., 2011; Hidalgo-Ruz et al., 2012; GESAMP, 2015). Although the term microplastics is often used generically to refer to any small pieces of plastic, it is becoming more common to restrict this term to those particles smaller than 5 mm in diameter (GESAMP, 2015; Nel and Froneman, 2015; NOAA http://wwwmarinedebris.noaa.gov). Various researchers (Van Cauwenberghe et al., 2015b) have proposed dividing microplastics into small microplastics (0.1–1 mm) and large microplastics (1–5 mm) creating practical categories that more accurately reflect the ability to collect and sort such material. The term macroplastics generally refers to larger plastic objects (2.5 cm–1 m) that are still recognizable products, such as bottles, containers, toys and buoys. Particles that are larger than 5 mm but smaller than 2.5 cm may reasonably be termed mesoplastics.

In addition to the secondary microplastics resulting from the breakdown of macroplastic and mesoplastic debris there may be primary microplastics present, those particles manufactured to be that size (GESAMP, 2015). Such primary small microplastics include tiny microbead scrubbers used in cosmetics and other cleaners, and nanoparticles used in industrial processes. Virgin resin pellets, also called nurdles (Moore, 2011), used to manufacture plastic products, are generally around 2–5 mm in diameter (Shiber, 1979), so they fall under the category of large microplastics.

Studies involving micro- and mesoplastic debris particles have proliferated in recent years; Van Cauwenberghe et al. (2015b) found that, of the 122 papers identified through literature searches, the first reports of microplastics in marine sediments were published in the late 1970′s and early 1980′s (Gregory, 1977, 1978, 1983; Shiber, 1979, 1982), 90% were published since 2004 and 75% were published between 2010 and 2015. These studies have all examined occurrence and/or abundance of such particles on various beaches throughout the world. A number of papers dealing with microplastic debris mention color but most report color as incidental data only and do not discuss the various colors found for plastic pellets in sediments (eg., Nigam, 1982; Gregory, 1983; Khordagui and Abu-Hilal, 1994; Heo et al., 2013; Frias et al., 2016), microfibers (Nel and Froneman, 2015; Wessel et al., 2016; Woodall et al., 2016), and neuston plastic particles (Desforges et al., 2014). A few studies have attempted to correlate color with composition (Shiber, 1979, 1982), degree of erosion (Karapanagioti and Klontza, 2007; Turner and Holmes, 2011; Veerasingam et al., 2016), size (Shaw and Day, 1994) or potential for ingestion by marine biota (Day et al., 1990; Nor and Obbard, 2014). Corcoran et al., 2015 compared pellet color proportions from riverbank and lake sediments, concluding that the river may be a pathway for plastics to enter the lake. As far as the authors are aware the present study is the first to determine a frequency distribution of colors of plastic fragments collected from marine beach sediments.

The large-scale circulation patterns of the North Pacific consist of two gyres, the North Pacific Subpolar Gyre and the North Pacific Subtropical Gyre, with the North Pacific Subtropical Convergence Zone between them (Howell et al., 2012). At either end of the Subtropical Convergence Zone are two accumulation areas, the so-called Western and Eastern Garbage Patches, where large amounts of floating marine debris accumulate. The Hawai'ian Island chain lies near the western boundary of the Eastern Garbage Patch and the gyre currents in this area together with the Coriolis Effect tend to move material toward the eastern shores of the islands (McDermid and McMullen, 2004; Corcoran et al., 2009).

The objective of this study was to characterize in terms of size and color large microplastic and small mesoplastic (0.05–8 mm) beach debris found on two widely separated Hawai'ian beaches.

2. Methods

Perhaps the beach most famous for accumulating marine debris is Kamilo Beach on the southeastern tip of the Big Island of Hawai'i (see Fig. 1). Kamilo Beach is a narrow (3 m wide) strip of sand between an intertidal lava bench and an upland vegetation barrier stretching some 700 m south from a rocky headland known as Kamilo Point. The area is accessible from the nearest paved road by a 12 km drive in a four-wheel drive vehicle over a rough “road” across a lava field. It is visited only by some locals for camping and by Hawai'i Wildlife Fund (www.wildhawaii.org) volunteers for organized beach cleanups. Truckloads of derelict fishing nets and other large debris as well as large “plastiglomerates” (Corcoran et al., 2014) have been removed by HWF but significant quantities of micro- and mesoplastic “confetti” remain in the sand. Megan Lamson and Bill Gilpatrick of Hawai'i Wildlife Fund graciously provided one of us (AY) transportation to Kamilo Beach.

Another somewhat less remote beach is Kahuku Beach on the northeast tip of O′ahu (see Fig. 1). The 600 m long section that accumulates large amounts of debris is a 15 m wide strip of sand between the subtidal lava bench and the upland vegetation. It is only a third of a kilometer from the nearest paved road but is bordered by the Kahuku Golf Course, a property that must be traversed to gain access to the beach. The result is that few people visit the beach other than schoolchildren and volunteers participating in beach cleanups organized by Sustainable Coastlines Hawai'i. Kahi Paccaro of Sustainable Coastlines Hawaii provided transportation and access to Kahuku Beach.

Samples from three quadrats were collected from each beach in October 2014 (Kahuku Beach) and November 2014 (Kamilo Beach). At Kamilo Beach (18° 51′ 25″ N, 155° 35′ 59″ W) the top 5–10 cm of sediment within one-meter square quadrats above the wrack line was sieved through a wood-frame screen (1 cm × 1 cm wire mesh) into a tub of seawater. Carson et al. (2011) found that over half of the total plastic fragments recovered from Hawai'ian beaches was located in the top 5 cm of sediment and nearly 95% was found in the top 15 cm. Any macroplastic debris caught in the sieve was disposed of. The water in the tub was stirred up several times and all floating material was skimmed off the water surface using an ordinary kitchen strainer and placed in plastic bags for later analysis. At Kahuku Beach (21° 41′ 1″ N, 157° 56′ 41″ W) the top 10–15 cm of sediment within one-meter square quadrats was sieved through a wood-frame screen (3 mm × 3 mm wire mesh) and everything retained in the sieve except macrodebris was collected for further sorting and analysis. Despite the size of the screen mesh a considerable amount of plastic debris <3 mm was collected due to smaller particles adhering to larger plastic particles or being trapped among the wood and other material. Sampling method varied between the two beaches because sampling equipment borrowed from the Hawai'i Wildlife Fund for Kamilo Beach and Sustainable Coastlines Hawai'i for Kahuku Beach was not identical.

All samples were dried and sieved through a series of 8″ Tyler brass sieves (8 mm, 4 mm, 2 mm, 1 mm, 0.5 mm) to create four size classes (0.5–1 mm, 1–2 mm, 2–4 mm, 4–8 mm). Each size fraction was sorted by hand under a dissecting microscope (Olympus SZ61) to separate all plastic particles from other low-density material such as seeds and pieces of wood. The plastic particles were then further sorted into nine color categories; white/transparent (hereafter referred to as white), black/grey (hereafter referred to as black), red/pink (hereafter referred to as red), and all shades of blue, green, yellow, orange, brown, and purple. The number of particles in each color category within each size fraction was counted by hand and weighed to the nearest 0.01 g on an analytical balance (Mettler AE163). Percentages of the total plastic collected were calculated for each color and size fraction and used in comparison analyses. White and black plastic pellets were counted separately but added to the other plastic fragments for calculations of percentages. Tiny fibers, pieces of rope and string and polystyrene foam were excluded from the counts.

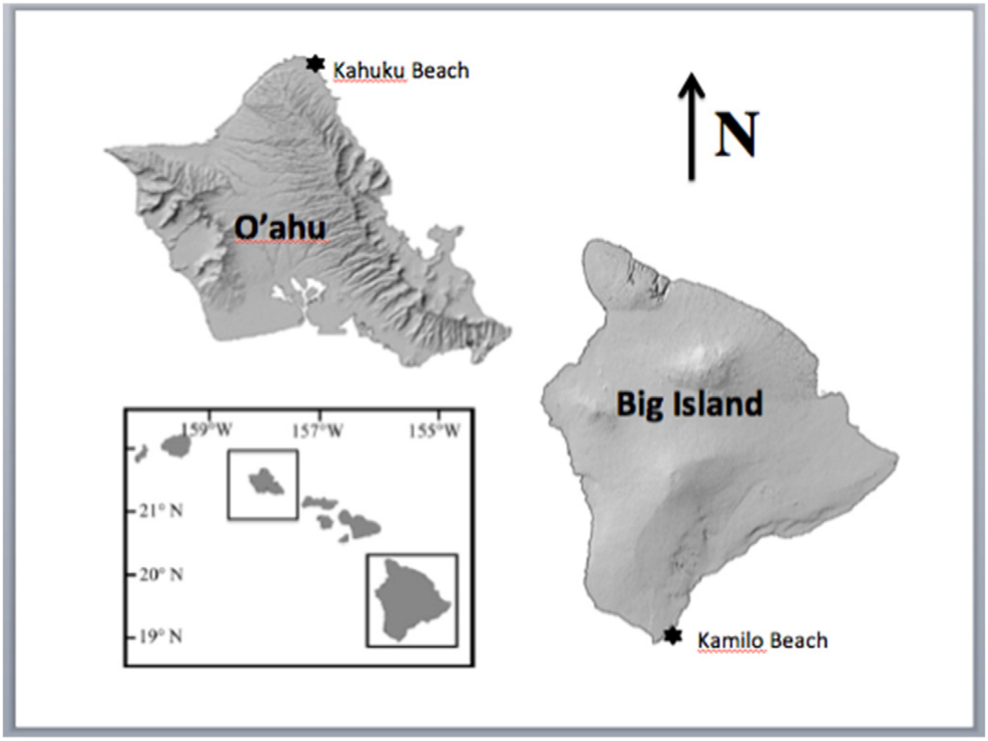

Fig. 1. Map of Hawai'ian Islands showing study sites.

A small number of representative plastic particles (75 fragments and 5 plastic pellets) were analyzed via Raman Spectroscopy (Agiltron Desktop L-PeakSeeker™ Raman Spectrometer) to identify the plastic polymer composition of the material. Resulting spectra were internally computer compared to a known polymer spectra library to identify the composition of the particle.

Statistical tests were performed using JMP Statistical Software Version 12.1.0 (SAS Institute, Inc., http://www.jmp.com). The majority of the data sets were compared via nonparametric tests due to the absence of normality (Shapiro–Wilk test for normality) in some of the groups with low sample sizes relative to the total amount of plastics collected. For the comparison of mean color percentages among each of the size classes, variability in color percentages among triplicate samples, and variation in color percentages between the two beaches, Kruskal-Wallis tests were performed. A Steel-Dwass test for multiple comparisons indicated which pairs of sizes were significantly different. Because only the percentages of black plastics from Kahuku Beach were observed to be significantly different among size classes, and a Shapiro-Wilk test indicated normality, a Student's t-test was performed to determine how size classes of black plastic differed.

3. Results

In total, 44,988 plastic particles between 0.5 mm and 8 mm were recovered from the two beaches combined (28,782 from Kamilo Beach samples and 16,206 from Kahuku Beach samples). Of these, 41,946 (93.2%) were fragments of larger plastic debris and 3040 (6.8%) were plastic pellets (1212, representing 4.2% of the plastics collected from Kamilo Beach and 1828, representing 11.3% from Kahuku Beach) (see Table 1). Most of these plastic pellets (93.1%) were round or disc-shaped whereas 6.9% were cylindrical. The vast majority (95.9%) fell in the 2–4 mm size class. In addition, most (87.7%) were white whereas 12.2% were black and only 2 were other colors (1 blue, 1 brown). Many of the pellets showed considerable weathering, being faded, crazed and pitted. The few pellets (5) analyzed by Raman Spectroscopy were all composed of polyethylene.

By far the most common color in all size classes and from both beaches was white, ranging from 66.0 to 75.6% of the total number of plastic fragments (65.5–80.1% by weight). The next most common color throughout all size classes was either blue, green or black, with percentages of each ranging from 1.3 to 12.1, followed by red, yellow, orange, brown and purple (percentages ranging from 0.2 to 0.6). For both beaches the color distribution was consistent within each of the size categories (0.5–1 mm, 1–2 mm, 2–4 mm, 4–8 mm) ($p = 0.01$, Kruskal-Wallis test) with only one exception. The proportion of the number of black particles in each size category was significantly different from each other ($p < 0.05$, Student's t-test after Shapiro-Wilk test to confirm normality); at $p < 0.01$, there were significant differences in percentages of black particles between the 0.5–1 mm size class and all three of the other size classes and between the 1–2 mm and 2–4 mm size classes. There were no significant differences between any size classes for each color when percentages based on mass were analyzed. For each beach, when the data from all three samples were combined, the mean percentages for color categories across all size classes were not significantly different between Kamilo Beach and Kahuku Beach ($p < 0.01$, Wilcoxon test) except for the colors orange, brown and

Table 1
Number of plastic pellets of each color in each size class from each beach.

Collection site (size class)	White	Black	Other	Total
Kamilo Beach				
(1–2 mm)	3	0	0	3
(2–4 mm)	988	150	1 blue, 1 brown	1140
(4–8 mm)	37	32	0	69
Total	1028	182	2	1212
Kahuku Beach				
(1–2 mm)	0	0	0	0
(2–4 mm)	1603	171	0	1774
(4–8 mm)	35	19	0	54
Total	1638	190	0	1828
Combined total	2666	372	2	3040

Three samples were collected from each beach.
No pellets were found in the 0.5–1 mm size class.

purple. Far fewer particles of these three colors were collected (<0.7% of each) so there is much greater variability in the mean percentage values. In only three cases out of 18 pairs were there a percentage of a color difference >1% between the two beaches (1.6% for numbers of white particles, 2.2% for numbers of green particles, and 2.1% for mass of blue particles); all other percentage differences ranged from 0.1–0.8% (see Table 2). Therefore, the data for the two beaches were combined to provide ranking of color as follows: based on numbers of particles, white (71.8%), blue (8.5%), green (7.5%), black (7.3%), red (2.6%), yellow (1.2%), orange (0.6%), brown (0.3%) and purple (0.2%); based on mass of particles, white (68.3%), blue (10.9%), black (8.9%), green (7.5%), red (2.3%), yellow (1.6%), orange (0.4%), brown (0.3%) and purple (0.2%) (see Table 2). Results of a Steel-Dwass test for multiple comparisons suggested 5 proportion categories: (1) white, (2) blue, black, green, (3) red, (4) yellow, (5) orange, brown, purple. A parametric Tukey-Kramer test for multiple comparisons yielded the same ranking.

Of the 75 representative fragments analyzed for composition using Raman Spectroscopy, 63 were polyethylene, 6 were polypropylene, and the identity of 6 could not be determined due either to the sample having excessive fouling or pitting or being a dark color (black, blue, grey). Raman Spectroscopy cannot distinguish between Low Density and High Density Polyethylene (LDPE and HDPE) and often cannot analyze dark colors (black, blue, grey) because the laser beam energy is absorbed by the sample, resulting in burning or melting.

4. Discussion

McDermid and McMullen (2004) found that 11.5% of the plastic (excluding line, film and foam) collected from sediments on nine remote locations throughout the Hawai'ian Islands were plastic pellets, a value comparable to the 6.8% average reported here from two Hawaiian beaches (4.2% from Kamilo Beach and 11.3% from Kahuku Beach). In the present study, 87.7% of the plastic pellets collected were white (including off-white and transparent or clear), a finding in agreement with other studies that have reported that most plastic pellets found in sediments are white/transparent (Shiber, 1979, 1982; Nigam, 1982; Gregory, 1983; Khordagui and Abu-Hilal, 1994; Karapanagioti and Klontza, 2007; Turner and Holmes, 2011; Heo et al., 2013; Corcoran et al., 2015; Veerasingam et al., 2016). This finding is not surprising because white plastic pellets are the most common color manufactured (Redford et al., 1997). Some studies have reported a high frequency of yellow plastic pellets (20 ± 12% in Karapanagioti and Klontza, 2007; second most abundant in Turner and Holmes, 2011, and Veerasingam et al., 2016) a result that was not found in this study. The difference might be due to those researchers counting discolored plastic pellets as "yellow" whereas in the present study they were counted as white/clear if that could be determined to have been the original color. Other studies found relatively few black/grey plastic pellets whereas they were fairly common (12.2%) in the present study. Only one blue and no red or green plastic pellets were found in the present study whereas such colors were reported from other studies, albeit in small quantities; Turner and Holmes (2011) indicate that such colors did not exceed 2% whereas Shiber (1979), Gregory (1983), Khordagui and Abu-Hilal (1994), Heo et al. (2013) and Veerasingam et al. (2016) either rank those colors well below white or simply say that some colored plastic pellets were found. The few pellets analyzed by Raman Spectroscopy were all identified as polyethylene, the same result found by Turner and Holmes (2011) and Corcoran et al. (2015), not surprising because PE is the most widely used class of plastics in the world (Andrady, 2003).

The collection method used at Kahuku Beach (material retained on a 3 mm × 3 mm screen) differed from the method used on Kamilo Beach (material that passed through a 1 cm × 1 cm screen). Therefore only small particles (<2 mm) that adhered to other larger fragments or were trapped among other debris were collected from Kahuku Beach, representing just 8% of the total, compared to 65% of the Kamilo Beach samples. It is assumed that the proportions derived from the Kamilo Beach samples (40% 0.5–1 mm, 25% 1–2 mm, 27% 2–4 mm, 8% 4–8 mm) more accurately reflect the actual size distribution of plastic particles in beach sediments because none of the smaller particles were lost whereas many were lost from the Kahuku Beach samples.

It is interesting that the frequencies of microplastic and mesoplastic colors in Kamilo and Kahuku beach sediments were consistent across all four size classes. Shaw and Day (1994) found that the abundance of blue neuston plastic increased with decreasing size, from 6.1% in the largest to 30.3% in the smallest size class (0.053–0.250 mm) whereas the abundance of white decreased with decreasing size, from 45.9% to 8.3%. The abundance of transparent plastic increased with decreasing size down to 0.250 mm and then decreased in the smallest size class. These trends were not observed in the present study but Shaw and Day (1994) examined much smaller sizes (down to 0.053 mm) of microplastics than were considered in this study (down to 0.5 mm). It is even more interesting that the frequencies of microplastic and mesoplastic colors were very similar between two beaches that are separated by nearly 400 km. If the color frequencies of pelagic plastics in the ocean vary one would not expect the color frequencies of material washed up on widely separated beaches to be so similar. Perhaps future neuston studies will reveal if the color frequencies of pelagic micro- and mesoplastics are fairly uniform throughout the waters around the Hawai'ian Islands.

Day et al. (1990) found that white and transparent particles combined comprised 79.8% of the neuston plastic (≥0.5 mm) that they collected in the North Pacific Ocean, Bering Sea and Japan Sea between 1985 and 1988. Blue particles comprised 7.3%, black/grey 4.2%, green 3.5%, tan 2.6%, brown 1.0%, red/pink 0.7%, yellow 0.5%, and orange 0.3%. Shaw and Day (1994) found that white and transparent particles combined comprised 74.2% of the neuston plastic (>0.053 mm) that they collected in the North Pacific Ocean in 1987. Blue particles comprised 16.9%, black/grey 5.2%, green 1.8%, yellow 0.5%, and both

Table 2
Color distribution (%) of plastic particles collected from each beach.

Collection site	White	Blue	Green	Black	Red	Yellow	Orange	Brown	Purple
Based on number of particles									
Kamilo Beach (*N* = 28.782)	72.4	8.3	7.4	6.5	2.9	1.1	0.8	0.4	0.2
Kahuku Beach (*N* = 16.206)	70.8	9.0	7.6	8.7	2.3	1.4	0.2	0.03	0.1
Combined	71.8	8.5	7.5	7.3	2.6	1.2	0.6	0.3	0.2
Based on mass of particles									
Kamilo Beach (*N* = 302.0 g)	68.3	8.5	7.1	8.5	2.4	1.1	0.4	0.5	0.2
Kahuku Beach (*N* = 435.3 g)	68.2	10.6	7.7	8.9	2.3	1.9	0.3	0.1	0.1
Combined	68.3	10.9	7.5	8.9	2.3	1.6	0.4	0.3	0.2

Three samples were collected from each beach.

red/pink and brown 0.1% each. Boerger et al. (2010) found that white/clear plastic made up 74% of the plastic collected in neuston trawls in the North Pacific Central Gyre, whereas blue/green made up 15%, black/grey 10.6%, yellow 1%, and red/pink and orange combined for 1%. While there is some variation in the proportions of colors in those studies versus this one, there are similarities in the results. White/transparent neuston plastic is by far the most common in all of the studies discussed above (79.8%, 74.2%, and 74% in the neuston versus 71.6% in sediments) and the rank of most to the least abundant colors is very similar with the next three most common colors being blue, green and black in the present sediments study versus blue, black and green in the Day et al. (1990) and Shaw and Day (1994) neuston studies and blue, green and black in the Boerger et al. (2010) neuston study. Considerably more green plastic was found in the present sediments study (8.0%) compared to the Day et al. (1990) and Shaw and Day (1994) neuston studies (3.5% and 1.8% respectively). Blue particles were much more abundant in the Shaw and Day (1994) neuston study (16.9%) than in the Day et al. (1990) neuston study (7.3%) or the present sediments study (8.6%). Green and blue were combined in the Boerger et al. (2010) neuston study data. Of the remaining colors, none exceeded 1.5% in any of the studies except red that accounted for 3.0% of the plastic in the present sediment study (versus 0.7%, 0.1% and <1% in the neuston studies).

Although filter feeders indiscriminately ingest microplastics from the water column, Shaw and Day (1994) note that visual predatory planktivorous fish may mistakenly feed on microplastics that most closely resemble their zooplankton prey. Wright et al. (2013) suggest that prey item resemblance of microplastics as a result of color may contribute to the likelihood of ingestion. An examination of stomach contents in mesopelagic fish (mostly myctophids) revealed microplastic (1–2.79 mm) color frequencies of 74.9% white/clear, 11.9% blue, 5.2% green, 4.5% black/grey, 1.0% yellow, 1.4% red/pink and 0.6% orange (Boerger et al., 2010). Greene (1985) suggests that microplastic ingestion due to food resemblance may also apply to pelagic invertebrate planktivores that are visual raptorial predators. Selective removal of certain colors from the water column by visual predators could result in different proportions of colors of microplastics in beach sediments than what was in the water column initially. Unfortunately, there are no data available on the amount of each plastic color produced or what enters the marine environment, so it is not possible to determine if differential removal of plastic colors is occurring in the wild. It would be of interest to maintain some visual predatory planktivorous species in an aquarium with known color frequencies of pelagic microplastics to determine if there is any differential removal of certain colors by feeding in a controlled laboratory experiment.

Disclosure statements

Neither author has any past, current or potential conflicts of interest relating to this work.

This work and associated data have not been published elsewhere and are not in consideration for publication elsewhere. The study was presented on October 22, 2016 at the New England Estuarine Research Society (NEERS) Conference on Block Island, Rhode Island, USA.

Roles of authors

Alan M. Young designed the study, carried out field sampling and laboratory sorting and analysis of samples, and drafted the manuscript.

James A. Elliott performed statistical analysis of the data and edited the manuscript.

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