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Plastic pollution in the South Pacific subtropical gyre

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ABSTRACT

Plastic marine pollution in the open ocean of the southern hemisphere is largely undocumented. Here, we report the result of a (4489 km) 2424 nautical mile transect through the South Pacific subtropical gyre, carried out in March–April 2011. Neuston samples were collected at 48 sites, averaging 50 nautical miles apart, using a manta trawl lined with a 333 μm mesh. The transect bisected a predicted accumulation zone associated with the convergence of surface currents, driven by local winds. The results show an increase in surface abundance of plastic pollution as we neared the center and decrease as we moved away, verifying the presence of a garbage patch. The average abundance and mass was 26,898 particles km^{-2} and 70.96 g km^{-2}, respectively. 88.8% of the plastic pollution was found in the middle third of the samples with the highest value of 396,342 particles km^{-2} occurring near the center of the predicted accumulation zone.

1. Introduction

Plastic pollution is the dominant type of anthropogenic debris ubiquitous throughout the marine environment (Barnes et al., 2009; Derraik, 2002; Gregory and Ryan, 1997). Floating plastic fragments have been reported in the Northern Hemisphere subtropical gyres since the early 1970s in the North Atlantic (Carpenter and Smith, 1972; Colton et al., 1974; Law et al., 2010), and North Pacific (Day et al., 1990; Moore et al., 2001; Hidalgo-Ruz et al., 2012). Few data exist describing plastic pollution in the Southern Hemisphere subtropical gyres (Morris, 1980; Thiel et al., 2003), although 81% of the earth's surface south of the equator is seawater.

Plastic pollution, originating from sea- and land-based sources, migrates into subtropical gyres (Maximenko et al., 2012; Lebreton et al., 2012) where it forms accumulation zones of microplastic particles distinct from surrounding waters relatively free of plastic pollution. These gyres are formed by surface currents that are primarily a combination of Ekman currents driven by local wind and geostrophic currents maintained by the balance between sea level gradients and the Coriolis force. These surface currents are detectable from the paths taken by satellite-tracked drifting buoys of the Global Drifter Program[7] (GDP). Drifters and other objects, floating at the sea surface, are also subject to direct wind force, impact of breaking waves and Stokes drift. Computer models, tuned to simulate trajectories of drifters, predict that plastic pollution and other marine debris will likely form accumulation zones within the five subtropical gyres (Maximenko et al., 2012). To our knowledge, no quantitative data existed for the open-ocean South Pacific Subtropical Gyre (SPSG) prior to this study.

Plastic pollution enters the marine environment via rivers, beaches, maritime activities, and illegal dumping at sea (Derraik, 2002; Ryan et al., 2009). Under the effects of UV degradation and hydrolysis, plastic loses its elasticity, and powered by wind and waves, gradually breaks into smaller particles (Andrady, 2003; Thompson et al., 2004; Cole et al., 2011). In other studies of marine debris, primarily from coastal assessments, 60–80% of marine debris is petroleum-based plastic (Derraik, 2002). Petroleum in any form entering the marine environment by anthropogenic means is a pollutant. A wide range of marine life, including marine mammals, reptiles and birds, is impacted by plastic pollution through

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[7] http://www.aoml.noaa.gov/phod/dac/gdp_information.php.

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entanglement or ingestion (Laist, 1987; van Franeker et al., 2011), and the persistent organic pollutants that sorb onto plastic (Mato et al., 2001; Teuten et al., 2007; Teuten et al., 2009; Rios et al., 2010). Plastic pollution also has the potential to transport non-native species to other regions (Astudillo et al., 2009; Barnes and Fraser, 2003; Bravo et al., 2011; Gregory, 2009; Webb et al., 2009).

The coastal margins of the South Pacific Ocean, and the Southern Ocean, are main contributors to plastic pollution in the SPSG (Lebreton et al., 2012). In the western region of the SPSG plastic pollution is an emerging contaminant on island shorelines and adjacent coastal and oceanic waters, impacting fisheries, creating navigational hazards, and affecting tourism by its negative aesthetic appeal (Gregory, 1999a). In the southeastern South Pacific Ocean, surveys of plastic pollution near the coast, including fragments of foamed polystyrene, plastic bags, and food sacks from salmon farms identified aquaculture as the most significant contributor (Hinojosa and Thiel, 2009). Along the Chilean coast, large amounts of plastics also come directly from beach and shore activities (Thiel et al., 2011). Other types of marine debris, including pumice and wood, are injected into the ocean near Patagonian Fjords, with their abundance corresponding to river runoff after spring snowmelt (Hinojosa et al., 2011). Plastic pollution has also been detected in the surface waters of the Southern Ocean (Barnes and Milner, 2005). In a survey of waters near Antarctica, plastic pollution was the only type of marine debris found south of 63°S (Barnes et al., 2010).

While large pieces of plastic pollution have been documented in the southern ocean and in the South Pacific, the presence and abundance of microplastics has not yet been confirmed. In particular, the area of the SPSG remains unstudied. Therefore, in this study we examined the abundance and composition of microplastics along a transect that crosses directly through the SPSG.

2. Materials and methods

To explore the presence and distribution of plastic pollution in the eastern South Pacific, an expedition on the sailing vessel *Sea Dragon* was organized and carried out by the 5 Gyres Institute.[8] The expedition started on March 23rd, 2011 from Valdivia, Chile and sailed to Pitcairn Island, which it reached on April 21, 2011. The weather during the entire voyage can be described as mild, with only one rain event during the second week of sample collection, when the sea state on the Beaufort Scale rose to five during one station. 48 neuston samples, described in this paper, were collected along a single transect from Robinson Crusoe Island to Pitcairn Island in the South Pacific Ocean, shown in Fig. 1. The first sample was taken at 33°05′S, 81°08′W, subsequent samples were collected approximately every 50 nautical miles until reaching Easter Island, and then again every 60 miles along the same transect in the direction of Pitcairn Island to 24°49′S, 126°61′W (Fig. 1).

The transect length and direction was determined by using a computer model developed at the University of Hawaii (Maximenko et al., 2012) to estimate the accumulation zone for plastic pollution in the SPSG. In the model, the entire ocean surface is divided into two-dimensional boxes of a half-degree in size. The probability for a drifter to move between pairs of boxes in 5 days is calculated, using nearly 15,000 trajectories of real GDP drifters. This probability density function can then be used to simulate propagation of floating tracers from various sources. Five-day model steps can be repeated infinitely to study the dynamics of plastic pollution over long time scales. Accurate data of sources of plastic pollution in the ocean are not available which creates a serious problem for modeling. However, plastic debris survives in the ocean many years – time that is sufficient to move across the entire ocean basin making it complicated to retrace plastics to their possible sources. For such tracer studies, the pattern of plastic concentration is determined by ocean currents and winds; given the long run periods of the model, it is not very sensitive to the location of sources and sinks. Model experiments, starting with tracers that are released uniformly over the entire Global Ocean, predict the formation of garbage patches in the five subtropical gyres. This model solution adequately describes the observed distribution of plastic, collected in the accumulation zones of the North Pacific and the North Atlantic subtropical gyres (Law et al., 2010). Note that in reality the maximum values of particle density in Fig. 1 are determined by the unknown amount of plastic dumped in different oceans, which may not be accurately reflected in model simulations. Other models have attempted to predict the abundance of plastic pollution in the subtropical gyres, seas, gulfs and bays, by considering contributions from river mouths, shipping lanes, and densely populated watersheds (Lebreton et al., 2012).

Samples were collected using a manta trawl with a rectangular opening of 16 cm high by 61 cm wide, and a 3 m long 333 μm net with a $30 \times 10\ cm^2$ collecting bag. The net was towed along the surface on the starboard side using a spinnaker pole to position the towline outside the wake of the vessel. The trawl speed, though kept constant throughout each individual trawl, ranged between 0.5 and $1.5\ m\ s^{-1}$, as measured by the onboard knotmeter. The duration of the trawl was kept to 60 min using a stopwatch. Samples were fixed in 5% formalin.

The samples were later rinsed in salt water, which floated most of the plastic to the surface for removal. Using a dissecting microscope, plastic was removed from preserved natural material, and then sorted by rinsing through Tyler sieves into six size classes: 0.355–0.499 mm, 0.500–0.709 mm, 0.710–0.999 mm, 1.00–2.79 mm, 2.80–4.749 mm, >4.75 mm. Individual pieces of plastic were divided into categories; fragment, polystyrene fragment, pellet, polypropylene/monofilament line, film; and then counted.

The area sampled was calculated by using onboard knotmeter data to measure the actual length of sea surface trawled in the 60-min period. The tow length multiplied by the width of the trawl provided the area sampled, allowing particle weight and abundance per km^2 to be calculated.

Using the Beaufort Scale (Beer, 1996), the sea state was calculated using wave height observed by three crewmembers and decided by consensus.

3. Results

Forty six out of 48 net tows (96%) contained plastic marine pollution, with no plastic found in two of the eastern-most samples (Fig. 1). Fig. 1 shows excellent correspondence between tracer distribution assessed by the model (shaded gray areas) and the observed count of plastic particles (color dots). For the comparisons in Figs. 2 and 3, the model has been scaled using the integral values, summed over all stations. Visual evaluation shows good correspondence between the observations (bars in Figs. 2 and 3) and the model (solid lines), all demonstrating bell-shape distributions along the transect. Correlation coefficients were found equal to 0.45 and 0.44, respectively. Somewhat wider model "bells" and their southeastern shift by a few stations may be due the difference between the multi-year mean, assessed by the model, and quasi-instantaneous state of the system, sampled during the 2 months of the expedition.

The average abundance was 26,898 pieces km^{-2}, and the average weight was 70.96 g km^{-2}. 85.6% of the total count and 88.8% of the total weight were collected between 97°09′W (sample 17) and 111°91′W (sample 32), representing the center third of the sampling transect (Figs. 2 and 3).

[8] http://www.5gyres.org.