Marine Pollution Bulletin xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Plastic in surface waters of the Inside Passage and beaches of the Salish Sea in Washington State

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A R T I C L E I N F O

Article history:
Received 21 January 2015
Revised 5 June 2015
Accepted 8 June 2015
Available online xxxx

Keywords:
Citizen science
Microplastic
Sandy beaches
Surface water
Salish Sea
Inside Passage

A B S T R A C T

We summarize results of two independent studies on plastic pollution in the marine environment that overlap in time and space. One study evaluated the abundance of anthropogenic debris on 37 sandy beaches bordering the Salish Sea in Washington State while the other characterized plastic debris in surface waters of the Salish Sea and the Inside Passage to Skagway, Alaska. Both studies concluded that foam, primarily expanded polystyrene was the dominant pollutant. Plastic was found in surface waters the full length of the Inside Passage but was concentrated near harbors. At the wrack line, an average square meter of Washington's 1180 km of sandy beaches in the Salish Sea had 61 pieces of anthropogenic debris weighing approximately 5 g. The total loading for the entire 1 m wide band is estimated to be 72,000,000 pieces and 5.8 metric tons. Most anthropogenic debris on beaches is generated within the region.

1. Introduction

Many studies have documented consumption of plastics by marine organisms, particularly birds, but also invertebrates, fishes, and indirectly by seals through consumption of fish with plastic in their system. (e.g. Browne et al., 2008; Eriksson and Burton, 2003; Gregory, 1977, 1978, 1991; Laist, 1997; Lindborg et al., 2012; Mato et al., 2001; Oehlmann et al., 2009; Shomura and Yoshida, 1985; Teuten et al., 2009). Boerger et al. (2010) reported that 35% of plankton-feeding fish collected in the North Pacific had ingested plastic which was mostly in the size range of 1–2.79 mm. Cole et al. (2013) documented ingestion by 13 of 15 species of zooplankton that were exposed to small polystyrene beads. How many animals are killed as a result of environmental plastic is unknown, but Wallace (1985) estimated that as many as 100,000 marine mammals may die annually as a result of entanglement.

Anthropogenic debris in the environment ranges in size from only a few microns to many square meters. We generally follow Arthur et al. (2009) who defined microplastic/microdebris as being anything less than 5 mm in diameter tempered with the practicality that, because of the use of plankton nets, 0.333 mm is usually the lower limit. In this paper we refer to anything larger than 5 mm in diameter as macroplastic/macrodebris and anything smaller than 0.333 mm as nanoplastic/nanodebris. A particular ecological problem with micro and nanoplastic is the ease with which it may be mistaken as food or passively ingested by organisms at the lower end of the food chain.

While an extensive literature documents the presence around the world of plastic in marine waters (e.g. Arthur et al., 2009; Cózar et al., 2014; Law et al., 2010, 2014; Eriksen et al., 2013; Ryan et al., 2009) and beaches (e.g. Bravo et al., 2009; Kusui and Noda, 2003; Thompson et al., 2004), no previous studies have broadly documented plastic in enclosed waters of western North America with substantial urbanization such as the Salish Sea[1] or the transboundary waters of the Inside Passage of Washington, British Columbia, and Alaska. In this article we report on two independent studies that were conducted in these areas at approximately the same time. Together they provide a better picture of regional plastic pollution than either does alone.

The task of implementing a study to quantify the amount of plastics on Washington's Salish Sea sandy beaches was possible because it was supported by a large number of volunteers. Use of

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[1] The term "Salish Sea" refers to a large estuarine system shared by British Columbia and Washington State. It includes the Strait of Juan de Fuca, the Strait of Georgia, Puget Sound, and connecting channels, passes and straits. The word "Salish" comes from the name linguists use when referring to the indigenous people of the region and the language they spoke. The term Salish Sea has been officially accepted by both British Columbia (GeoBC, 2014) and the state of Washington (State Board on Geographic Names, 2009).

http://dx.doi.org/10.1016/j.marpolbul.2015.06.019
0025-326X/

Please cite this article in press as: Davis III, W., Murphy, A.G. Plastic in surface waters of the Inside Passage and beaches of the Salish Sea in Washington State. Mar. Pollut. Bull. (2015), http://dx.doi.org/10.1016/j.marpolbul.2015.06.019

citizen scientists to assist in large scale projects has become increasingly important as researchers understand the valuable contributions these individuals can make, from collecting accurate data to advocating for science-based decision making (e.g. Bravo et al., 2009). It is now recognized that citizens who participate in environmental monitoring gain valuable insights into ecological and management issues and are often motivated to engage at a deeper level as partners in research and conservation in their communities (Danielsen et al., 2005).

2. Materials and methods

2.1. Beach sampling

Port Townsend Marine Science Center (PTMSC) staff, supported by more than 600 volunteer citizen scientists from sixteen partnering community groups representing all twelve Washington State Salish Sea counties, sampled sandy beaches twice a year from fall 2008 to spring 2011. The goal was to learn what types and quantities of micro debris were accumulating on beaches and to establish a baseline for future studies. The project started in seven counties and grew to include all twelve counties bordering the Salish Sea (Table 1, Fig. 1). All sampling occurred in daylight hours during pre-determined weeks in October and March. Sampling was not restricted to low tide windows since all plots were located in the high tide zone. PTMSC recruited and trained volunteers from all twelve Salish Sea counties so that "locals" would be sampling their own beaches. This provided an added benefit in that community members often initiated localized conservation efforts such as peer to peer education and waste reduction programs for single use plastics.

Sampling sites were selected to ensure easy access across a wide geographic range of sandy beaches; most had public access. Sampling methods, using sieves, were developed for use on sandy beaches. A different set of methods and tools would be necessary for sampling on other beach types such as cobble, rock and mud. Thirteen sites were heavily sampled and designated as core sites (Table 1, Fig. 1); twenty-four supplemental sites were sampled at a reduced frequency. At each beach three 1 m square quadrats were laid out approximately 10 m apart in the highest wrack line: That area high up on the beach where debris is deposited from tidal and wind action. At each beach an immovable landmark was selected to serve as a reference point for the entire study period. Using the reference point, the sampling teams would visually draw a straight line from it to the water and place the middle of the three quadrats where the line crossed the highest wrack line. Since

Table 1
Salish Sea beach sample stations. Shaded areas indicate when (spring or fall) samples were collected.

STATION NUMBER	BEACH	NUMBER OF DATES	NUMBER OF QUADRATS	LATITUDE (NORTH)	LONGITUDE (WEST)	2008 F	2009 S	2009 F	2010 S	2010 F	2011 S	2011 F
Core Sample Stations												
1	Adelma Beach	6	18	48°03.1'	122°50.4'							
2	Bowman Bay	5	15	48°25.1'	122°39.2'							
3	Cabana Beach	6	18	48°29.5'	122°41.3'							
4	Clayton Beach	6	18	48°38.4'	122°28.9'							
5	Double Bluff	6	18	47°58.8'	122°30.9'							
6	Dungeness Spit	6	18	48°09.1'	123°10.9'							
7	Fay Bainbridge State Park	6	18	47°42.3'	122°30.4'							
8	Fort Casey	5	15	48°09.5'	122°40.9'							
9	Fort Worden	6	18	48°08.2'	122° 45.7'							
10	Gooseberry Point	6	18	48°43.9'	122°40.1'							
11	Hollywood Beach	6	18	48°07.2'	123°25.8'							
12	Howarth Park	5	15	47°57.8'	122°14.5'							
13	Mukilteo Lighthouse State Park	5	15	47°56.8'	122°18.5'							
Supplemental Sample Stations												
14	Belfair State Park	4	12	47°25.8'	122°52.5'							
15	Crescent Beach	2	6	48°41.7'	122°53.8'							
16	Discovery Park	3	9	47°39.6'	122°26.0'							
17	Fort Flagler	4	12	48°05.9'	122°41.4'							
18	Indian Island Beach	3	9	48°41.7'	122°54.5'							
19	Jack Hyde Beach	2	6	47°16.5'	122°27.8'							
20	Jackson's Beach	1	3	48°31.1'	122°41.7'							
21	Jetty Island	3	9	48°00.2'	122°13.8'							
22	Johnson Point	4	12	47°10.1'	122°49.5'							
23	Kayak Point	3	9	48°08.1'	122°22.1'							
24	Lincoln Park	3	9	47°31.6'	122°23.7'							
25	Odlin Park	1	3	48°33.4'	122°53.5'							
26	Owen's Beach	2	6	47°18.8'	122°31.8'							
27	Point No Point	3	9	47°54.7'	122°31.7'							
28	Potlatch State Park	2	6	47°21.7'	123°09.4'							
29	Protection Island	4	12	48°07.6'	122°54.8'							
30	Richmond Beach	1	3	47°45.8'	122°23.2'							
31	Rotary Park	1	3	48°30.8'	122°36.1'							
32	Salt Creek	4	12	48°09.7'	123°42.4'							
33	Silverdale Waterfront Park	4	12	47°38.6'	122°41.7'							
34	South Beach	1	3	48°27.4'	123°00.1'							
35	Tawana State Park	1	3	47°22.7'	122°58.3'							
36	Tolmie State Park	2	6	47°07.3'	122°46.6'							
37	Walker County Park	2	6	47°12.1'	123°03.7'							
	TOTAL	**134**	**402**									

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