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Abundance and environmental drivers of anthropogenic litter on 5 Lake Michigan beaches: A study facilitated by citizen science data collection

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ABSTRACT

The abundance and environmental drivers of anthropogenic litter (i.e., trash; AL) in marine habitats is well studied, but less AL research has been conducted in freshwaters. The long-running Adopt-a-Beach™ (AAB) program, administered by the Alliance for the Great Lakes, has directed volunteer litter collection on Great Lakes beaches since 2003. We analyzed all AAB records for 5 Lake Michigan beaches that span a population gradient to quantify total AL density, infer primary sources of AL, characterize seasonal patterns, and compare data to marine beaches. Human population density was positively related to AL density across the 5 sites, and > 72% of AL was smoking and food-related. Results indicated that most AL originated from activities occurring on or near the beaches, while other potential sources were minor (i.e., fishing, illicit dumping, sewage, or waterway activities). At all sites, AL was more abundant in the fall, which suggested that municipal beach cleaning might be effective at reducing abundance in summer. Finally, AL density was low relative to marine beaches, which we attributed to lack of AL from offshore, removal via beach cleaning, and the methodological artifacts and inherent variation within the large, citizen science data set. Future studies of AL dynamics on Great Lakes beaches will benefit from quantifying AL removal via cleaning, AL movement and decomposition, its effects on beach organisms, and additional comparisons to well-studied habitats worldwide.

Introduction

Accumulation of anthropogenic litter (i.e., trash; AL) in the ocean has received increased attention from scientists and the general public in recent years (Abu-Hilal and Al-Najjar, 2009; Hammer et al., 2012; Ivar do Sul and Costa, 2007). Sources of marine AL include direct inputs from boats and anglers and land-based inputs from terrestrial and riverine habitats (Ryan et al., 2009). Marine AL has several fates, including surface accumulation of buoyant material, sinking of heavy items, accumulation on beaches and other coastal habitats, decomposition into smaller pieces, and ingestion by marine organisms (Cole et al., 2011; Cooper and Corcoran, 2010; van Sebille et al., 2012).

Despite the growing body of literature on the abundance, fate, and ecosystem effects of AL in the ocean (Law et al., 2010; Moore, 2008), the study of AL in freshwaters lags far behind (Hoellein et al., 2014). River and lake ecosystems share many of the same sources of AL as marine environments and, because they have less water volume for dilution, AL abundance in freshwaters is likely to be high. The few studies completed in freshwaters have focused on plastic and AL in rivers (Hoellein et al., 2014; Rech et al., 2014) and plastic in the Laurentian Great Lakes. Eriksen et al. (2013) found microplastic densities in surface waters from Lakes Superior, Huron, and Erie were highly variable and in the same range as marine environments. In addition, microplastic abundance on Lake Huron beaches ranged from 0 to 408 items/m^2, depending upon proximity to industrial sources (Zbyszewski and Corcoran, 2011). To our knowledge, only two studies of AL in the Great Lakes report the density of plastic AL >5 mm or on the entire suite of anthropogenic litter (Hoellein et al., 2014; Zbyszewski et al., 2014). Both studies suggest that AL density is affected by adjacent land use, lake currents, and weathering, and note that research is needed to quantify environmental controls on AL density, movement, and breakdown in freshwaters.

Volunteer organizations that collect and record AL have made significant contributions to research on AL dynamics for marine beaches. Recent examples include citizen scientist-generated data sets for AL collected on beaches in California (Rosevelt et al., 2013) and Chile (Bravo et al., 2009; Hidalgo-Ruz and Thiel, 2013). This type of public participation in scientific research is defined as ‘contributory,’ in which members of the public contribute data which is then analyzed by scientists (Bonney et al., 2009; Miller-Rushing et al., 2012). Citizen science databases for AL in freshwater ecosystems are also available, but these data have yet to be analyzed and published in the scientific literature.

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The Alliance for the Great Lakes (AGL) Adopt-a-Beach™ program (AAB) has facilitated the collection of AL by volunteers since 2003. This program has strong potential to contribute citizen science data for research because of their consistency in data collection and reporting. Volunteer leaders receive training from AAB personnel, volunteers complete an identical litter collection form, and results are entered into an online database. The AAB database is publicly available, which makes the dataset well-positioned for detailed analyses. However, AAB data have not yet been used for scientific assessments of AL abundance on Great Lakes beaches.

Our objectives were to 1) quantify the spatial and temporal variation in AL abundance across 5 Lake Michigan beaches that span a gradient of population density, 2) determine the sources of and predictors of AL at the study sites, 3) compare AL densities on Lake Michigan beaches with published values for ocean beaches, and 4) to better understand the nature of citizen scientist AL data and science questions to which they can be turned. We predicted that most AL on the study beaches would be from beach visitors, so expected AL density would be highest at the most populated sites and in the summer. To address objective 2, we categorized AL according to common activities to infer its sources (e.g., food- and smoking-related AL). We predicted AL would be dominated by items originating from beachgoers, rather than other types of AL common on ocean beaches including those related to fishing, sewage, shipping, and illegal dumping. We also predicted that AL would be unrelated to recent storms or indicators of fecal contamination, as beachgoers, rather than river or sewer overflows were likely to be the primary factor. For objective 3, we predicted that AL density would be variable, but in the same range as published values from ocean beaches. These predictions were based on our years of participation in AAB beach events throughout Lake Michigan, and on the recent publications of AL density measurements on Great Lakes beaches (Hoellein et al., 2014; Zbyszewski et al., 2014).

Methods

Study sites

We selected 5 Lake Michigan beaches from the AAB web site for this study (Table 1). Lake Michigan is the third largest of the Laurentian Great Lakes by surface area (58,000 km^2), with an average depth of 85 m. The total coastline of Lake Michigan is approximately 2675 km and there are sandy beaches throughout all its shoreline. The southern portion of Lake Michigan is more urbanized and industrial, with rural areas to the north (Han et al., 2011).

Collection of AL by the AAB program is volunteer driven and is not completed on a regular schedule (i.e., weekly or monthly) so the dataset is variable among seasons, years, and sites. We selected study sites by first narrowing the field to those beaches that had the largest number of AAB collection dates, including ≥3 measurements within each season (spring, summer, and fall). Of approximately 400 Lake Michigan beaches with AL collection records, <25% had 9 or more total AL collection dates. Of those, few had replicate AL collection dates in each of the 3 seasons and were in separate counties. Thus, we were left with 5 individual beaches from separate counties that contained the appropriate replication and represented the largest possible population gradient. From highest to lowest population density, the study sites were North Avenue beach (Chicago, Illinois), Marquette Park beach (Gary, Indiana), West Side County Park (Fennville, Michigan), Sand Bay Beach #1 (near Sturgeon Bay, Wisconsin), and Sleeping Bear Dunes (near Empire, Michigan; Fig. 1). All 5 study sites are public land and maintained to varying degrees by city, county, or federal management agencies (Table 1).

Volunteer litter collection

AL collection for AAB is completed by teams of volunteers and a volunteer team leader. Prior to the collection date, team leaders were

Table 1
Site descriptors at each study beach and details of the Adopt-a-Beach (AAB) records.

	North Avenue	Marquette Park	West Side County Park	Sand Bay #1	Sleeping Bear Dunes
State	Illinois	Indiana	Michigan	Wisconsin	Michigan
County	Cook	Lake	Allegan	Door	Benzie
County population	5,194,675	496,005	111,408	27,785	17,525
Pop. density (no. km^{-2})	2,122	384	52	22	21
EPA beach ID	IL666876	IN924097	MI001151	WI176829	N/A
Length (km)	1.691	3.669	1.225	0.473	7.081
Width (km)	0.064	0.036	0.02	0.039	0.018
Beach area (km^2)	0.109	0.132	0.025	0.018	0.127
Catchment area (km^2)	1.21	11.55	1.26	25.25	3.05
Impervious surface (%)	30.0	19.3	0.5	1.3	2.1
Flickr (user-days)	122.75	0.75	0.88	1.38	28.88
GDP tour/rec. (million $)	3,520	37.5	29.1	85.1	4.6
Municipal beach cleaning					
Management agency	Chicago Parks District	City of Gary	Allegan County	Door County	Nat. Park Service
Cleaning method	Machine	Machine	Manual	(No data)	Manual
Cleaning period	Summer	Summer	Summer	(No data)	Volunteer
Cleaning schedule	Daily	Monday–Friday	Occasional	(No data)	Periodic
Adopt-a-Beach records					
Months included in records at each site	Mar–Nov	Apr–Sep	May–Sep	Apr–Sep	May–Nov
Total number of records	54	23	24	12	54
*Records w/ volunteer h	41	15	17	9	51
*Records w/ weather	39	16	14	7	3
*Records w/ coliform	18	10	10	6	0
Number of volunteers	1,817	1,065	60	56	100
*Total volunteer h	2,984	5,677	98	39	267
Total pieces	172,257	21,869	3,234	681	8,014
*Total mass (kg)	2,497	574	42	(no data)	501

County population and GDP tour/rec (gross domestic product of tourism and recreation by county) are from 2010. Flickr score is annual mean from 2005 to 2010. Abbreviations: Pop = population, EPA = Environmental Protection Agency, Nat Park Service = National Park Service.
* Not reported for all sampling events

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