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

Timothy J. Hoellein [a,*], Meagan Westhoven [a], Olga Lyandres [b], Jamie Cross [c]

[a] Department of Biology, Loyola University Chicago, 1032 W Sheridan Rd., Chicago, IL 60660, USA
[b] Alliance for the Great Lakes, 150 N. Michigan Avenue, Suite 700, Chicago, IL 60601, USA
[c] Alliance for the Great Lakes, 41 Washington Avenue, Harborfront Place Suite 280D, Grand Haven, MI 49417, USA

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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.

* Corresponding author. Tel.: +1 773 508 8859.
E-mail address: thoellein@luc.edu (T.J. Hoellein).

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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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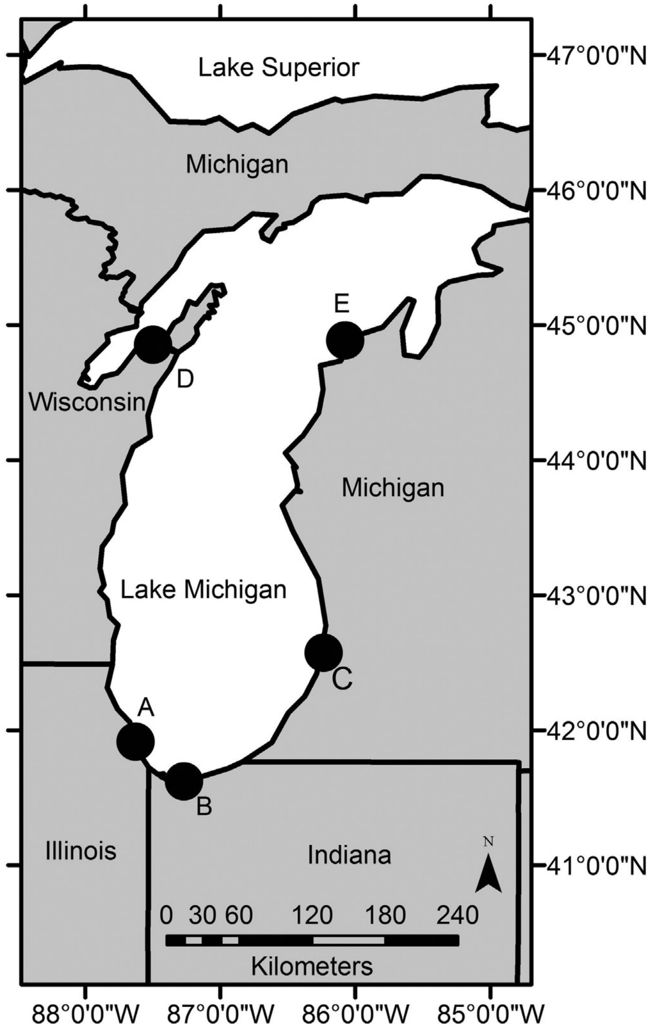

Fig. 1. Lake Michigan study sites include beaches at A) North Avenue, B) Marquette Park, C) West Side County Park, D) Sand Bay #1, and E) Sleeping Bear Dunes.

strongly encouraged to attend an interactive 2 h training event conducted by Alliance for the Great Lakes staff or to view instructional videos online. Each team leader received a kit with detailed instructions on data collection, safety instructions, equipment (i.e., water test kit), collection forms, and directions for entering data on the AAB web site. The program has a high retention rate for team leaders, who represent a diversity of interested adults, including teachers, community members, and representatives of local businesses. On the date of collection, directions and search area dimensions were given to the volunteers by the leader. Volunteers spread out in small groups to walk the area and collect AL. For every item collected, volunteers tally abundance in predetermined categories on the standard collection form (Appendix A). The minimum size of AL collected is limited by material visible to the naked eye, approximately 0.5–1 cm, so no microplastics were collected. Leaders were asked to weigh the total AL collected. To maintain data quality, Alliance for the Great Lakes staff reviewed and provided final approval to entered data.

In addition to directing AL collection, leaders were asked to complete a routine beach monitoring form aligned to the U.S. Environmental Protection Agency's Beach Sanitary Survey, which describes the conditions on the beach, records recent precipitation patterns, and collects water samples for measurement of water column bacteria. Assessing the relationship between weather and fecal coliform counts with AL density allowed us to infer the potential for storms and sewage to affect AL on the study beaches. Weather was recorded as the timing (<24 h ago, <48 h ago, <72 h ago, >72 h ago) and intensity of the most recent rain event (misting, light rain, steady rain, heavy rain, none, or 'not sure'). Fecal coliform and *Escherichia coli* colony-forming units (CFU) were measured using Petrifilm™ (3 M, St. Paul, MN, USA). Petrifilm has been used elsewhere to provide estimates of fecal coliform and *E. coli* (Senini et al., 1997; Stepenuck et al., 2011). Volunteers wade to a depth of 0.5 m and collect surface water in a sterile whirl-pak (Nasco, Ft. Atksinson, WI, USA) while wearing nitrile gloves. With a sterile plastic pipette, 1 mL of water is placed on Petrifilm media and a plastic cover applied. The media are incubated at room temperature or slightly above (~20–22 °C) for 48 h. Fecal coliform colonies turn red, *E. coli* colonies turn blue. Volunteers report the CFU number of each type on two replicate Petrifilms (CFU/mL). We note that not all sampling dates have records for coliform, weather, volunteer hours, total AL mass, and beach area (Table 1). This variation in volunteer reporting among sampling dates has important implications for data analysis and interpretation (see Discussion).

Beach descriptors

Few AAB records included a description of the search area boundaries for each sampling date, so we used maps to calculate beach area. The north and south ends of North Avenue and Sand Bay beaches were clearly delineated by non-beach boundaries (e.g., sea walls, sidewalks). Marquette Park beach has a clear west end and the midpoint was described in search records. We calculated the east end as the equivalent distance from the midpoint to the west end. The beach at West Side Park blends into neighboring beaches. The beaches north and south have a described midpoint, and we calculated the north and south ends of the beach as the equal distance between midpoints. Finally, we used road name boundaries to determine the north and south ends of the beach at Sleeping Bear Dunes National Lakeshore. For each site, we measured beach length on a map, and calculated the mean width from 10 equally spaced measurements (i.e., from the water line to vegetation or sidewalk). We quantified area as the length times mean width (Table 1).

We compiled additional metrics of beach descriptors through multiple sources (Table 1). We used 2010 US census data to find county population size and density for each beach. The Alliance for the Great Lakes maintains Geographic Information Systems (GIS) files containing digital elevation models and impervious surface cover (Xian et al., 2011), which delineate catchment size and land use for Great Lakes Beaches (O. Lyandres, unpublished data). The Great Lakes Environmental Assessment and Mapping Project (GLEAM; http://greatlakesmapping.org) assembled a basin-wide spatial dataset of Great Lakes beaches, including gross domestic product (GDP) of the tourism and recreation sector for each county (National Oceanic and Atmospheric Administration, 2013), and a Flickr score (D. Allan, personal communication), which has been found to be a suitable proxy for beach visitation (Wood et al., 2013), the Flickr score represents the number of photo user-days, or the number of days per year that a unique user uploaded at least one photo within a 500 m radius of each beach location. Flickr scores were calculated using the InVEST model (Natural Capital Project; http://www.naturalcapitalproject.org/InVEST.html; Accessed December 2013, D. Allan, personal communication). Finally, we contacted management agencies directly to record the type (i.e.,machines or manual), seasonal extent, and daily interval for municipal beach cleaning at each site. The occurrence of municipal beach cleaning at Sand Bay beach is unknown (no response from management agency).

Data analysis

All AAB data, including AL and beach survey results, were downloaded from the AAB web site (http://www.greatlakesadopt.org/Home/HistoricalData; accessed September 2013).We used simple linear regression to quantify the relationship between the total number of volunteer hours and the number of AL items collected on each date. We expressed AL abundance as the number of items collected per beach area (density). We used these values to compare AL abundance across all 5 sites and 3 seasons (spring, summer, and fall). We considered spring to include collection dates March–May, summer as June–August, and fall as September–November. There were no collection dates for December–February.

To compare among seasons and sites, we used a 2-way classification approach with the non-parametric Friedman test, where data are converted to ranks after blocking by either season or site (Zar, 1999). This approach was used because the Kolmogorov–Smirnov test for uniform distribution failed, both with raw data and following transformation via all conventional techniques (e.g., log, square root, inverse). The Friedman test was conducted for AL density for total AL and for 5 AL categories. The Friedman test does not assess significant interactions between season and site, and there is no post hoc test for pairwise comparisons.

The AL collection form used by the AAB groups items according to their function. The categories were first developed by the Ocean Conservancy to quantify the activities that contribute to AL accumulation. The AAB program used the same categories to facilitate comparison of data between Great Lakes and ocean beaches. The categories included shoreline and recreational activities, smoking-related, waterway activities, medical/personal hygiene, and dumping-related material. We made one modification, which was to separate the shoreline and recreational activity category into food-related and miscellaneous categories. The food-related category includes paper and plastic bags, utensils, plates, beverage containers (glass, aluminum, and plastic), pull tabs, 6-pack holders, caps/lids, and straws/stirrers. Smoking-related AL includes cigarette butts, lighters, cigar tips, and tobacco packaging. AL from waterway activities includes fishing-related items (i.e., bait containers, fishing line and nets, traps, and lures) and boating-related AL (i.e., cleaning bottles, buoys, floats, light bulbs, oil bottles, pallets, crates, plastic sheeting, tarps, rope, and strapping bands). We combined floats with boating-related AL; however, we acknowledge that floats may originate from fishing activities. Future research may benefit from more careful identification of the type of floats found during AL collection. Diapers, condoms, tampons/tampon applicators, and syringes are in the medical/personal hygiene category. Dumping activities include appliances, batteries, building materials, car parts, 55 gallon drums, and tires. Miscellaneous AL is classified as recreational material and 'other' (i.e., fireworks, drug paraphernalia, clothing, shoes, balloons, shotgun shells, toys, and charcoal).

We used simple linear regression to quantify relationships between AL density and beach descriptors including county population density, catchment area, impervious surface cover, Flickr score, GDP of tourism and recreation by county, and *E. coli* and coliform abundance. AL density values required log transformation for all regressions. We compared AL density according to recent precipitation patterns (time and intensity) using a 1-way ANOVA. Finally, we compared AL density on Lake Michigan beaches to published values for ocean beaches. We searched literature for reports of mean, minimum, and maximum density as number of items per area, to compare data from ocean studies which used a minimum AL collection size of 0.5 cm ($N = 11$) to mean values for Lake Michigan beaches using a *t*-test (log transformed). For all statistics, we set a p value of ≤ 0.05 to indicate a significant difference.

Results

Relative proportion of AL across 5 beaches

The entire data set for the 5 study beaches represented 167 individual collection events, where 3,098 volunteers collected a total of 206,055 individual AL items (Table 1). The most common categories of AL collected were smoking- and food-related items (Fig. 2).

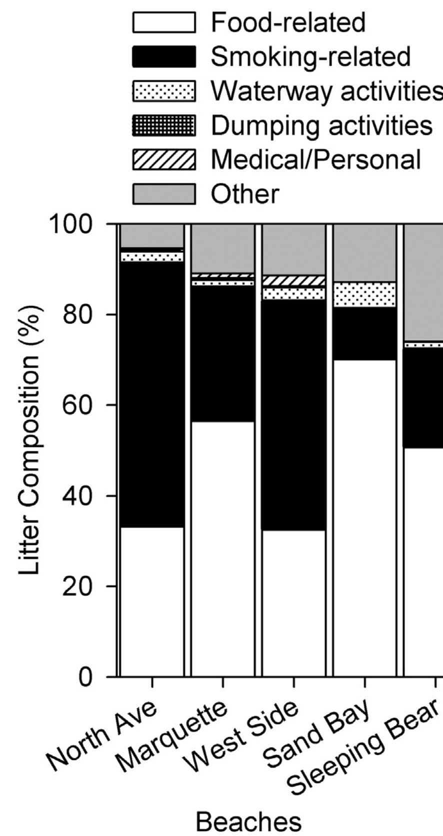

Fig. 2. Relative proportion of anthropogenic litter collected at 5 Lake Michigan beaches.

Cigarette butts were >95% of the items in the smoking-related category. Among food-related items, the most common materials were screw caps (for plastic bottles), snap-on lids (for food containers), food wrappers/containers, and straws. Sand Bay had the greatest proportion of AL from waterway activities at 5.7% of the total AL, where waterway AL consisted of ropes and strapping bands. Medical and personal hygiene items were found at each site except Sand Bay, but represented <2.3% of total AL at the most abundant location (West Side). AL from dumping was also a minor component of total abundance, <0.6% of AL across all 5 sites. Finally, 'other' AL represented 5–26% of litter. Sleeping Bear had the greatest proportion of AL in this category (26%), which was made up mostly of charcoal briquettes from beach campfires.

Relationship between number of items and volunteer hours

The number of volunteer hours was significantly and linearly related to the number of AL items collected across all sampling events ($R^2 = 0.553$, $p < 0.001$; Fig. 3). Considered for each beach independently, there was also a significant relationship at Marquette Park ($R^2 = 0.671$, $p < 0.001$) and Sleeping Bear ($R^2 = 0.136$, $p = 0.008$), but the relationship was not significant at North Avenue ($R^2 = 0.017$, $p = 0.412$), West Side ($R^2 = 0.105$, $p = 0.202$), or Sand Bay ($R^2 = 0.399$, $p = 0.068$).

Spatial and temporal variation of AL

The density of the total AL collected was significantly different among sites (Friedman test $p = 0.015$) and seasons (Friedman test $p = 0.043$; Fig. 4A). Among sites, North Avenue had the highest density while Sand Bay and Sleeping Bear had the lowest. Among seasons, total AL density was highest in fall and lowest in spring. Smoking-related, food-related, and waterway activity AL showed the same patterns as total density (Figs. 4B, C, and D); however the patterns were only significant for food-related items (Friedman $p = 0.048$; Fig. 4C). We did not

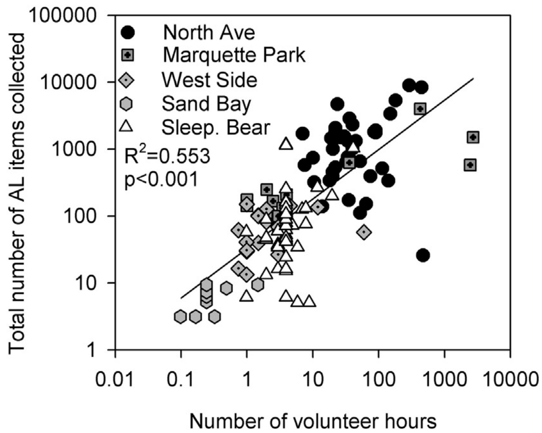

Fig. 3. Simple linear regression between the total number of anthropogenic litter (AL) items found on each sampling date and the number of volunteer hours on each date. Sites are shaded according to county population density, where darker = greater population.

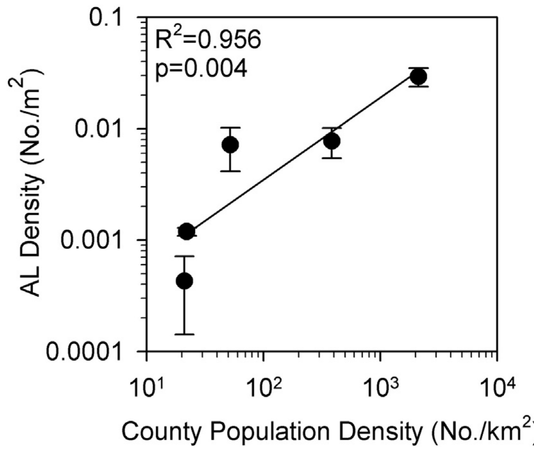

Fig. 5. Simple linear regression between county population density and mean (±SE) anthropogenic litter (AL) density.

examine spatial and temporal patterns of dumping and medical/personal hygiene AL as they were a minor portion of total AL density.

Correlations between AL abundance and environmental factors

We quantified the relationship between AL density and multiple descriptors of beach visitation using simple linear regression. AL density was significantly related to county population density ($R^2 = 0.956$, $p = 0.004$; Fig. 5) but was unrelated to catchment size ($R^2 = 0.023$, $p = 0.807$), impervious surface cover ($R^2 = 0.308$, $p = 0.332$), tourism and recreation GDP ($R^2 = 0.603$, $p = 0.123$), or Flickr score ($R^2 = 0.013$, $p = 0.857$). At North Avenue beach, AL density was unrelated to time elapsed since recent rain (ANOVA $p = 0.285$) and intensity of recent rain (ANOVA $p = 0.574$; Fig. 6). For the other 4 sites, there was not enough replication across categories to complete the weather analysis. Finally, there was no significant relationship between *E. coli* or coliform bacteria counts and AL density; and only at Sand Beach were coliform and AL density weakly related.

AL density and composition relative to literature values

Density of AL at the 5 Lake Michigan beaches was on the low end of the range of published values for ocean beaches (Fig. 7). The average values at our 5 study sites, 0.0092 items/m^2, was significantly lower than the average of density from 11 marine beach studies, 1.82 items/m^2 (t-test, $p < 0.001$). However, densities span several

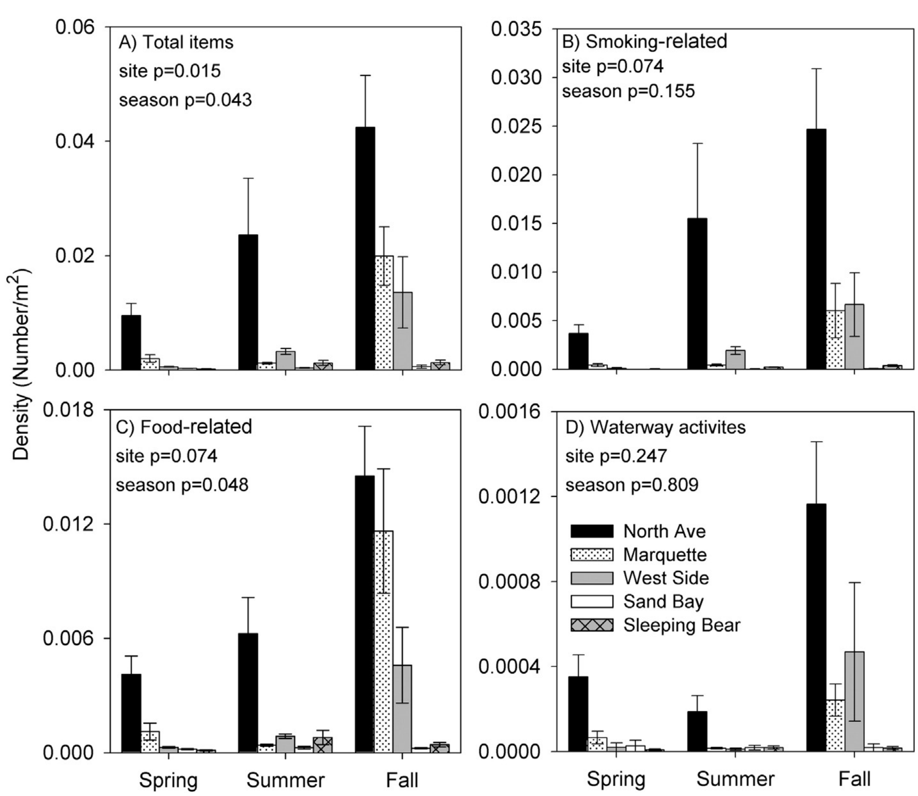

Fig. 4. Seasonal analysis of mean (±SE) anthropogenic litter (AL) density on each beach for (A) total AL, (B) smoking-related (C) food-related, and (D) AL from waterway activities. *p*-values are from Friedman's test for 2-way classification of non-parametric data, where the values are ranked and blocked by site and season.

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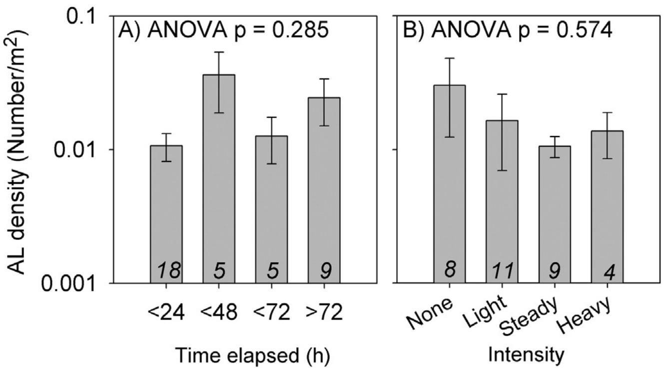

Fig. 6. Mean (±SE) density of anthropogenic litter (AL) on North Avenue beach according to characteristics of the most recent rain event reported by volunteers, in terms of (A) time elapsed and (B) intensity. Numbers in italics indicate number of measurements for each mean. There was not enough replication across categories to complete the analysis for the other 4 study sites.

orders of magnitude for most studies (Fig. 7), and the range of values at the Lake Michigan beaches clearly overlaps with the range reported for ocean beaches. In addition, AL density measured in this study was in the same range as those reported for Hartigan Beach, another Lake Michigan beach in Chicago (Hoellein et al., 2014).

Discussion

Primary source of AL was direct littering from beach visitors

Multiple lines of evidence indicate AL at the study sites originated largely from activities occurring directly on or adjacent to the beaches. Smoking- and food-related items were the most abundant category at all sites. In addition, AL from fishing, illicit dumping, sewage, or waterway activities were minor components of AL composition, suggesting that only a minor amount of AL is transported onto beaches from offshore sources. Finally, the positive relationship between county population density and AL density also suggests that local AL sources were dominant. We acknowledge county population and other descriptors (e.g., tourism GDP and Flickr score)

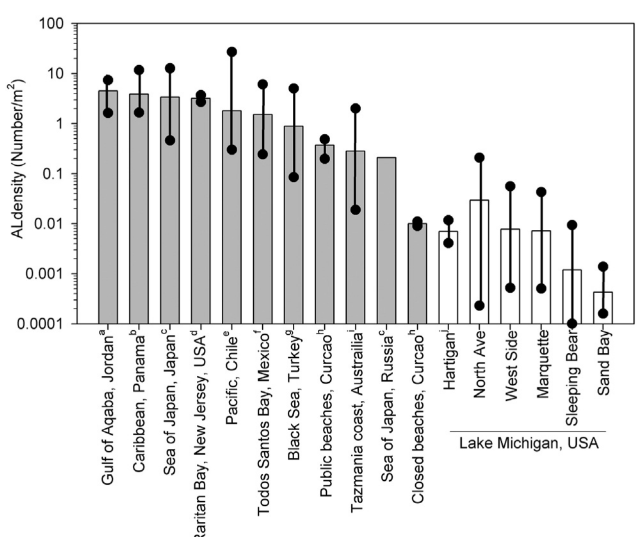

Fig. 7. Mean (± range) of anthropogenic litter (AL) density on marine and Lake Michigan beaches, a) Abu-Hilal and Al-Najjar (2004) b) Garrity and Levings (1993), c) Kusui and Noda (2003), d) Thornton and Jackson (1998), e) Bravo et al. (2009), f) Silva-Iñiguez and Fischer (2003), g) Topçu et al. (2013), h) Nagelkerken et al. (2001), i) Slavin et al. (2012), and j) Hoellein et al. (2014). Minimum size reported for AL collection was 'visible' for all studies, except for a and g (minimum size = 2 cm), and i (minimum size = 0.5 cm).

served only as proxies for measurements of beach visitor abundance, which were unavailable. We also note that some of these items may have moved from neighborhoods and streets onto beaches (Seco Pon and Becherucci, 2012), and smoking- and food-related items can come from offshore onto the beaches (Bowman et al., 1998; Rosevelt et al., 2013). We recommend future AL studies generate assessments of the number, activity, and attitudes of visitors on Lake Michigan beaches about littering, which has been useful for studies seeking to identify best practices to reduce AL accumulations on marine beaches (i.e., educational tools; Santos et al., 2005; Slavin et al., 2012).

Our results are consistent with research showing that beach users are a primary source of AL on well-studied tourist beaches in South America (Araújo and Costa, 2006; Bravo et al., 2009; Thiel et al., 2013; Wetzel et al., 2004), Mexico (Silva-Iñiguez and Fischer, 2003), and the Caribbean (Nagelkerken et al., 2001). For example, Santos et al. (2009) found that AL generated by beach users accounted for 70% of AL on developed beaches, but only 10% of AL on undeveloped beaches. Marine beaches situated away from tourist sites or population centers have a larger proportion of AL generated from offshore activities such as fishing, aquaculture, and shipping (Hinojosa and Thiel, 2009; Kusui and Noda, 2003; Nagelkerken et al., 2001; Santos et al., 2009; Thiel et al., 2013). In our study, all 5 sites were parks that served as destinations for visitors, and sources from smoking and food-related activities represented >72% of the litter (Fig. 2). Undeveloped beaches in the Great Lakes may show similar values as undeveloped ocean beaches. However, a recent study showed an undeveloped shoreline in Lake St. Clair had high AL density, attributed to lake currents and shoreline characteristics (i.e., a depositional zone; Zbyszewski et al., 2014).

Beach grooming and the influence of seasonality on visitor abundance may drive AL dynamics on the study beaches. For example, beach cleaning at North Avenue, Marquette Park, and West Side County stops after the first Monday in September (coincident with the US holiday Labor Day), and AL densities were higher for beaches in fall. Warm weather can attract beach visitors well into the fall, and AL generated by fall beachgoers, combined with a lack of regular grooming, could lead to this pattern. In spring, water temperatures in Lake Michigan remain quite cold. Low beach visitation in spring, combined with winter weather scouring AL from beaches, likely contribute to low density. Topçu et al. (2013) also found higher AL density in fall but attributed the pattern to currents and fishing activity. In contrast, Thornton and Jackson (1998) found higher density of AL in summer due to beach visitors. To further explore seasonal patterns for Great Lakes beaches, more data are required to measure seasonal visitor attendance, the amount of AL removed during beach cleaning, and rates of AL movement from beaches by season. This could be accomplished by regular sampling of the same sites throughout a year, partnership with municipal cleaning agencies, and marking and tracking AL to measure fluxes on and off beaches (Bowman et al., 1998).

Identifying AL sources is critical for crafting efficient strategies for AL prevention and management (Santos et al., 2005; Wetzel et al., 2004). Our results suggest that efforts should first be directed at the food consumption and tobacco use that occurs on the beaches. In addition to fines, preventive measures could include additional signs, abundant, well-maintained sites for garbage disposal and recycling (including ashtrays), use of sustainable packing material for beach vendors, and education at schools and volunteer events (Widmer and Reis, 2010). Permitting for events on beaches could require a waste management plan. Beach cleaning could potentially be improved to maximize efficiency. Reduction of the grate size on beach cleaning equipment could allow for collection of discarded cigarettes, although this presents an engineering challenge to avoid filling grates with small stones (Ariza et al., 2008). We observed high AL abundance around obstacles such as benches, garbage cans, and sidewalks (Hoellein et al., 2014). These areas represent challenging sites for AL collection via cleaning equipment, and may require a different strategy such as manual collection or smaller machinery.

AL abundance at the 5 Lake Michigan beaches was lower than ocean sites

The abundance of AL on the 5 Lake Michigan sites was on the low end of the range for published values on ocean beaches and was lower than reported for plastic AL on Lakes Huron, Erie, and St. Clair (Zbyszewski et al., 2014). We can attribute the lower density to multiple factors, including the lack of fishing-related AL, the absence of rivers near the sampling locations, beach cleaning, the homogenous nature of beach habitat at the study sites, land use and lake currents, and methodological artifacts from the citizen–scientist data set, including size of collected AL. Below, we consider each factor's influence on AL abundance at our study sites.

A major component of marine AL is the amount of fishing-related garbage found on beaches. Across the 5 Lake Michigan beaches, however, fishing-related items comprised only 0.19% of total AL even though commercial and recreational fishing occurs in the lake. This could be attributed to the lower levels of commercial fishing in the Great Lakes relative to the oceans and orientation of the study sites towards beach activities other than recreational fishing. Other studies have found that tourist-oriented beaches have low fishing AL (Araújo and Costa, 2006; Topçu et al., 2013), or that fishing-related items are more likely to be found at habitats directly adjacent to fishing areas (Abu-Hilal and Al-Najjar, 2009; Claereboudt, 2004). However, nets, monofilament, and buoys from fishing implements are widely dispersed by currents, and can be found in oceans worldwide (Hammer et al., 2012; Jones, 1995). Anecdotally, we do not often observe fishing on Chicago beaches, but anglers can be found near piers, marinas, and boats. Therefore, while fishing activity appears to be a minor source of AL at the study sites, fishing-derived AL could accumulate in Lake Michigan open waters or in non-beach shoreline habitats more frequently visited by anglers (e.g., marinas, rocky shorelines, and fishing piers).

Rivers that deliver storm water runoff or material from combined sewer overflows can be a major source of AL on adjacent beaches (Araújo and Costa, 2006; Rech et al., 2014; Rosevelt et al., 2013). For example, two large AL 'rafts' (i.e., loosely connected, large masses of floating AL) washed onshore at Lake Michigan's east coast in 2008 and 2010, and were attributed to combined sewer overflows and spills from recycling centers in the urbanized areas around Milwaukee and Chicago (United States Coast Guard, 2011). These large episodes are rare and generate government investigations and public attention. Aside from these events, attributing the source of individual AL items to a river rather than a beach visitor is often not possible. Santos et al. (2009) found freshwater organisms colonizing AL on river-adjacent ocean beaches, and concluded that rivers were a significant source of AL to those sites. Determining riverine sources at Great Lakes beaches using this method would be more challenging as many AL colonizing organisms are similar between rivers and lakes, but it has not yet been attempted.

The abundance of *E. coli* and coliform bacteria can serve as an indicator of contamination by sewage, which can originate from rivers, combined sewer overflows (CSO), or dogs and birds (Haack et al., 2003). *E. coli* and coliform bacteria CFU were unrelated to AL density, suggesting that there is no link between the two components. Sand Bay beach showed the strongest relationship between AL and bacteria among the sites (Table 2). This site was also near a river outlet (Table 1) although total AL density was low. While riverine sources or combined sewer overflows did not appear to be a major source of AL at our study sites, they could be more significant at other locations in the Great Lakes near river and CSO sites.

Table 2
R^2 (*p*-value) from simple linear regression between bacteria counts (as colony-forming units) and anthropogenic litter (AL) density (number/m^2) at 4 study beaches in Lake Michigan.

	AL density	
	E. coli	Coliform
North Avenue	0.094 (0.216)	0.028 (0.508)
Marquette	0.011 (0.350)	0.008 (0.803)
West Side	0.037 (0.570)	0.102 (0.338)
Sand Bay	0.126 (0.260)	0.413 (0.169)

Beach cleaning likely contributed to the seasonal variation in AL abundance we observed, and may also partially explain low overall densities relative to ocean beaches. For example, large tractors from the Chicago Parks District remove AL early each morning in summer, which represents some portion of AL accumulation that is not included in volunteer AL collection records. Studies of marine beaches in Chile support this possibility (Bravo et al., 2009). However, other research on the effect of beach cleaning on AL abundance for ocean beaches shows limited effectiveness. For example, Santos et al. (2009) found that tourist beaches with regular cleaning reduced the relative size of AL compared to other beaches, but not overall abundance. Santos et al. (2005) also suggested cleaning on tourist-oriented beaches was ineffective for AL reduction and more proactive approaches were required.

Our study sites were relatively uniform sandy beaches that are used and maintained for recreation, and they are likely to have a different abundance and composition of AL relative to non-beach habitats around the Great Lakes (Zbyszewski et al., 2014). In a similar fashion, AL abundance on ocean beaches are well-studied, but other marine habitats such as rocky coastlines, marshes, and mangroves are less frequently examined and can have considerable AL accumulations (Abu-Hilal and Al-Najjar, 2009; Debrot et al., 2013; Viehman et al., 2011). AL abundance on non-beach habitats such as upland grasses, marshes, or rocky shorelines have rarely been measured in the Great Lakes (but see Zbyszewski et al., 2014).

We found no evidence that catchment size or land use (i.e., impervious surface cover) affected AL density at our study sites, but land use patterns have been shown to affect plastic AL density elsewhere in the Great Lakes (Zbyszewski et al., 2014). Plastic AL was abundant on beaches on the southern shoreline of Lake Huron, and densities were driven by distance from industry and prevailing lake currents (Zbyszewski and Corcoran, 2011). Recent evidence also suggests that microplastic is abundant in Great Lakes surface waters and that lake currents redistribute microplastic, as occurs in open oceans (Law et al., 2010). Eriksen et al. (2013) showed that microplastic was more abundant at downstream lakes (Lakes Erie and Huron) relative to lakes upstream (Lake Superior). Macroscopic AL items are probably also affected by land-use patterns (Browne et al., 2010) and lake currents (Zbyszewski et al., 2014), but documenting these patterns will require analyses using different analytical approaches than used in this study, such as tracing movement of individual AL items (Bowman et al., 1998).

The nature of citizen scientists AL data sets: implications for data interpretation

The final explanation for relatively low AL density on Lake Michigan beaches relative to marine beaches relates to methodological artifacts and inherent variation of the citizen science data set, including caveats for AL size range, beach area reporting, and search time. No minimum size threshold for AL collection is specified by AAB protocols, so volunteers pick up what catches their eye as they walk the beaches. Therefore, AL in the microplastic size range (<0.5 cm) are not collected. This is potentially significant, as density of microplastic on 7 Lake Huron beaches ranged from 0 to 408 items/m^2 (Zbyszewski and Corcoran, 2011), and surface water microplastic concentrations across 21 sites in Lakes Superior, Huron, and Erie ranged from 0 to 0.466 items/m^2 (Eriksen et al., 2013). Both maximum values from those studies are above our maximum measured density of macroscopic AL, 0.204 items/m^2 at North Avenue beach (Fig. 6). Future studies will benefit from simultaneous measurements of microplastic and macroscopic AL on Great Lakes beaches to determine their relative abundance, if there

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is a relationship between the two categories, and if they share environmental drivers (Browne et al., 2010).

The second important caveat for interpretation of this data set is variation in reporting of beach area cleaned. Specific dimensions for search area were rarely reported by volunteers. We also suspect the number of volunteer hours included on many sampling dates was smaller than needed to ensure that volunteers covered the entire beach. We view the AL density measurements for the 5 beaches in this study as conservative, because we used the entire beach area in our calculations for AL density on each sampling date. The AL density at the 5 study sites was similar to an independent assessment of abundance on Hartigan Beach in Lake Michigan (Hoellein et al., 2014) where the search area was carefully defined during collection. However, AL density reported from volunteer data was lower than density of plastic on shorelines in Lakes Huron, Erie, and St. Clair (0–34 items/m^2) (Zbyszewski et al., 2014). Like marine beaches, AL density on Great Lakes beaches appears highly variable and requires more study including integration of data from citizen science (this study; Hidalgo-Ruz and Thiel, 2013).

Volunteers for AL collection often commit to a given amount of time to participate, and this has important implications for data interpretation. Our results indicate that the greater number of volunteer hours, the more AL is collected (Fig. 3). This pattern has several possible explanations, including 1) there is so much AL that volunteers are not ‘saturated’ and do not reduce the amount on the beach, 2) volunteers search with greater intensity and find more AL when given more time, and 3) volunteers stop collecting AL once the beach is cleaned. Any and all of these may affect our results, but our experience suggests the latter two are more likely. We observe AL collector groups repeatedly cover the same ground, sometimes finding items that were initially overlooked. In addition, AL collection is a social activity. When all AL is collected, we observe volunteers often stop searching and socialize for the remaining time. Thus, the total time spent by volunteers at the site may not reflect AL search time, but the AL collected by volunteers accurately captures the AL density on the beach.

The use of citizen science data sets comes with complementary benefits and limitations (Miller-Rushing et al., 2012). For example, AL density is highly variable among sites and dates when measured according to rigorous scientific methods (Abu-Hilal and Al-Najjar, 2009; Santos et al., 2009). This natural variation in AL distribution is compounded by variation in the citizen-science collected data sets including the number of participants, time dedicated to AL collection, and attention to detail for collection and reporting. Despite the variation inherent to citizen science data, important benefits include the high number of measurements and direct application of results. This study is only a subset of the AAB data, but it includes the combined efforts of thousands of volunteers who removed hundreds of thousands of AL items over a period of 11 years. Academic or government researchers are unlikely to maintain a funded research program that could generate a volume of measurements this high. An additional benefit of using this citizen science data is that results can be directly applied towards revising the methods and refining the goals of the AAB program as it grows. These results will form a basis for testing new hypotheses on additional portions of the AAB data set. For example, results from this project and others motivated the AAB program to modify the AL collection form in 2014 so volunteers could document small items (<5 mm). In addition, we will study changes in the abundance of cigarettes following the passage of recent smoking bans at Chicago beaches. Overall, these data contribute to the growing body of research, which analyzes results from volunteer AL collection programs in the Great Lakes and beaches elsewhere.

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References

Abu-Hilal, A.H., Al-Najjar, T., 2004. Litter pollution on the Jordanian shores of the Gulf of Aqaba (Red Sea). Mar. Environ. Res. 58, 39–63.

Abu-Hilal, A., Al-Najjar, T., 2009. Marine litter in coral reef areas along the Jordan Gulf of Aqaba, Red Sea. J. Environ. Manag. 90, 1043–1049.

Araújo, M.C.B., Costa, M.F., 2006. The significance of solid wastes with land-based sources for a tourist beach: Pernambuco, Brazil. Pan-Am. J. Aquat. Sci. 1, 28–34.

Ariza, E., Jimenez, J.A., Sarda, R., 2008. Seasonal evolution of beach waste and litter during the bathing season on the Catalan coast. Waste Manag. 28, 2604–2613.

Bonney, R., Cooper, C.B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K.V., Shirk, J., 2009. Citizen science: a developing tool for expanding science knowledge and scientific literacy. Bioscience 59, 977–984.

Bowman, D., Manor-Samsonov, N., Golik, A., 1998. Dynamics of litter pollution on Israeli Mediterranean beaches: a budgetary, litter flux approach. J. Coast. Res. 14, 418–432.

Bravo, M., Gallardo, M.D., Luna-Jorquera, G., Nunez, P., Vasquez, N., Thiel, M., 2009. Anthropogenic debris on beaches in the SE Pacific (Chile): results from a national survey supported by volunteers. Mar. Pollut. Bull. 58, 1718–1726.

Browne, M.A., Galloway, T.S., Thompson, R.C., 2010. Spatial patterns of plastic debris along estuarine shorelines. Environ. Sci. Technol. 44, 3404–3409.

Claereboudt, M.R., 2004. Shore litter along sandy beaches of the Gulf of Oman. Mar. Pollut. Bull. 49, 770–777.

Cole, M., Lindeque, P., Halsband, C., Galloway, T.S., 2011. Microplastics as contaminants in the marine environment: a review. Mar. Pollut. Bull. 62, 2588–2597.

Cooper, D.A., Corcoran, P.L., 2010. Effects of mechanical and chemical processes on the degradation of plastic beach debris on the island of Kauai, Hawaii. Mar. Pollut. Bull. 60, 650–654.

Debrot, A.O., Meesters, H.W.G., Bron, P.S., de Leon, R., 2013. Marine debris in mangroves and on the seabed: largely-neglected litter problems. Mar. Pollut. Bull. 72 (1-1).

Eriksen, M., Mason, S., Wilson, S., Box, C., Zellers, A., Edwards, W., Farley, H., Amato, S., 2013. Microplastic pollution in the surface waters of the Laurentian Great Lakes. Mar. Pollut. Bull. 77, 177–182.

Garrity, S.D., Levings, S.C., 1993. Marine debris along the Caribbean coast of Panama. Mar. Pollut. Bull. 26, 317–324.

Haack, S.K., Fogarty, L.R., Wright, C., 2003. *Escherichia coli* and Enterococci at beaches in the Grand Traverse Bay, Lake Michigan: sources, characteristics, and environmental pathways. Environ. Sci. Technol. 37, 3275–3282.

Hammer, J., Kraak, M.H.S., Parsons, J.R., 2012. Plastics in the marine environment: the dark side of a modern gift. Rev. Environ. Contam. Toxicol. 220, 1–44.

Han, H., Bosch, N., Allan, J.D., 2011. Spatial and temporal variation in phosphorus budgets for 24 watersheds in the Lake Erie and Lake Michigan basins. Biogeochemistry 102, 45–58.

Hidalgo-Ruz, V., Thiel, M., 2013. Distribution and abundance of small plastic debris on beaches in the SE Pacific (Chile): a study supported by a citizen science project. Mar. Environ. Res. 87–88, 12–18.

Hinojosa, I.A., Thiel, M., 2009. Floating marine debris in fjords, gulfs and channels of southern Chile. Mar. Pollut. Bull. 58, 341–350.

Hoellein, T.J., Rojas, M., Pink, A., Gasior, J., Kelly, J.J., 2014. Anthropogenic litter in urban freshwater ecosystems: distribution and microbial interactions. PLos One 9, e98485.

Ivar do Sul, J.A., Costa, M.F., 2007. Marine debris review for Latin America and the Wider Caribbean Region: from the 1970s until now, and where do we go from here? Mar. Pollut. Bull. 54, 1087–1104.

Jones, M.M., 1995. Fishing debris in the Australian marine environment. Mar. Pollut. Bull. 30, 25–33.

Kusui, T., Noda, M., 2003. International survey on the distribution of stranded and buried litter on beaches along the Sea of Japan. Mar. Pollut. Bull. 47, 175–179.

Law, K.L., Moret-Ferguson, S., Maximenko, N.A., Proskurowski, G., Peacock, E.E., Hafner, J., Reddy, C.M., 2010. Plastic accumulation in the North Atlantic subtropical gyre. Science 329, 1185–1188.

Miller-Rushing, A., Primack, R., Bonney, R., 2012. The history of public participation in ecological research. Front. Ecol. Environ. 10, 285–290.

Moore, C.J., 2008. Synthetic polymers in the marine environment: a rapidly increasing, long-term threat. Environ. Res. 108, 131–139.

Nagelkerken, I., Wiltjer, G., Debrot, A.O., Pors, L., 2001. Baseline study of submerged marine debris at beaches in Curacao, West Indies. Mar. Pollut. Bull. 42, 786–789.

National Oceanic and Atmospheric Administration, 2013. Economics: National Ocean Watch (ENOW) Data, Based on Data from the Bureau of Labor Statistics and the Bureau of Economic Analysis. NOAA Coastal Services Center, Charleston, SC.

Rech, S., Macaya-Caquilpán, V., Pantoja, J., Rivadeneira, M., Jofre Madariaga, D., Thiel, M., 2014. Rivers as a source of marine litter—a study from the SE Pacific. Mar. Pollut. Bull. 82, 66–75.

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Rosevelt, C., Los Huertos, M., Garza, C., Nevins, H.M., 2013. Marine debris in central California: quantifying type and abundance of beach litter in Monterey Bay, CA. Mar. Pollut. Bull. 71, 299–306.
Ryan, P.G., Moore, C.J., van Franeker, J.A., Moloney, C.L., 2009. Monitoring the abundance of plastic debris in the marine environment. Philos. Trans. R. Soc. B 364, 1999–2012.
Santos, I.R., Friedrich, A.C., Wallner-Kersanach, M., Fillmann, G., 2005. Influence of socio-economic characteristics of beach users on litter generation. Ocean Coast. Manag. 48, 742–752.
Santos, I.R., Friedrich, A.C., Ivar do Sul, J.A., 2009. Marine debris contamination along undeveloped tropical beaches from northeast Brazil. Environ. Monit. Assess. 148, 455–462.
Seco Pon, J.P., Becherucci, E.M., 2012. Spatial and temporal variations of urban litter in Mar del Plata, the major coastal city of Argentina. Waste Manag. 32, 343–348.
Senini, L., Parisi, M.G., Tabusso, E., Bottazzi, V., Cocconcelli, P.S., 1997. Efficacy of petrifilm for the enumeration of the aerobic flora, coliforms and *E. coli* in typical Italian products. Ind. Aliment. 36, 1498–1502.
Silva-Iñiguez, L., Fischer, D.W., 2003. Quantification and classification of marine litter on the municipal beach of Ensenada, Baja California, Mexico. Mar. Pollut. Bull. 46, 132–138.
Slavin, C., Grage, A., Campbell, M.L., 2012. Linking social drivers of marine debris with actual marine debris on beaches. Mar. Pollut. Bull. 64, 1580–1588.
Stepenuck, K.F., Wolfson, L.G., Liukkonen, B.W., Iles, J.M., Grant, T.S., 2011. Volunteer monitoring of *E. coli* in streams of the upper Midwestern United States: a comparison of methods. Environ. Monit. Assess. 174, 625–633.
Thiel, M., Hinojosa, I.A., Miranda, L., Pantoja, J.F., Rivadeneira, M.M., Vasquez, N., 2013. Anthropogenic marine debris in the coastal environment: a multi-year comparison between coastal waters and local shores. Mar. Pollut. Bull. 71, 307–316.
Thornton, L., Jackson, N.L., 1998. Spatial and temporal variations in debris accumulation and composition on an estuarine shoreline, Cliffwood Beach, New Jersey, USA. Mar. Pollut. Bull. 36, 705–711.
Topçu, E.N., Tonay, A.M., Dede, A., Öztürk, A.A., Öztürk, B., 2013. Origin and abundance of marine litter along sandy beaches of the Turkish Western Black Sea Coast. Mar. Environ. Res. 85, 21–28.
United States Coast Guard, 2011. National Response Center Report #877186. Coast Guard Investigative Service, Chicago, IL, p. 4.
van Sebille, E., England, M.H., Froyland, G., 2012. Origin, dynamics and evolution of ocean garbage patches from observed surface drifters. Environ. Res. Lett. 7.
Viehman, S., Pluym, J.L.V., Schellinger, J., 2011. Characterization of marine debris in North Carolina salt marshes. Mar. Pollut. Bull. 62, 2771–2779.
Wetzel, L., Fillmann, G., Niencheski, L.F.H., 2004. Litter contamination processes and management perspectives on the southern Brazilian coast. Int. J. Environ. Pollut. 21, 153–165.
Widmer, W.A., Reis, R.A., 2010. An experimental evaluation of the effectiveness of beach ashtrays in preventing marine contamination. Braz. Arch. Biol. Technol. 53, 1205–1216.
Wood, S.A., Guerry, A.D., Silver, J.M., Lacayo, M., 2013. Using social media to quantify nature-based tourism and recreation. Sci. Rep. 3.
Xian, G., Homer, C., Demitz, J., Fry, J., Hossain, N., Wickham, J., 2011. Change of impervious surface area between 2001 and 2006 in the conterminous United States. Photogramm. Eng. Remote Sens. 77, 758–762.
Zar, J.H., 1999. Biostatistical Analysis. 4th edition. Prentice-Hall, Inc., Upper Saddle River, New Jersey.
Zbyszewski, M., Corcoran, P.L., 2011. Distribution and degradation of fresh water plastic particles along the beaches of Lake Huron, Canada. Water Air Soil Pollut. 220, 365–372.
Zbyszewski, M., Corcoran, P.L., Hockin, A., 2014. Comparison of the distribution and degradation of plastic debris along shorelines of the Great Lakes, North America. J. Great Lakes Res. 40, 288–299.

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