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The generation and cost of litter resulting from the curbside collection of recycling

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ABSTRACT

This study examined the generation of litter, defined as spillage and uncollected residue, from a curbside collection system for residential recycling. The primary recycling containers used in the study were 18-gal (68 L), open-top bins. The study, conducted over a seven-week period, was comprised of both an urban and suburban area. Six litter characterizations were conducted in which all new litter larger than 1 in.^{2} was collected, segregated, counted, and weighed. We found that each week the open-top recycling bins contributed approximately 20,590 pieces of litter over 1 in. in size per every 1000 households, which resulted in the generation of 3.74 tons of litter per 1000 households per year. In addition to the bins having no top, the primary root causes of the litter were constantly overflowing recycling bins, the method of collection, and material scavenging. Based on an estimated cost of litter cleanup ranging from $0.17 to $0.79 per piece of litter, the direct economic costs from the collection of litter and loss in recycling revenues were estimated at US$3920 to US$19,250 per 1000 households per year. Other notable impacts from the litter, such as increased risk of flood damage from storm drain impairment and marine ecosystem damages exist, but were not monetized. The results strongly suggest that modification of the curbside collection system would decrease the amount and associated cost of litter by replacing existing curbside collection containers with larger volume containers with covers and by modifying the task-based incentive system to emphasize litter prevention rather than the current aim of completing the task most quickly.

1. Introduction

The curbside collection of residential recyclables has been shown to significantly increase a municipality's recycling rate (see for example Folz, 1991; Everett and Peirce, 1993; and Jenkins et al., 2003). The added convenience with curbside recycling increases resident participation and thus the amount collected (Wagner, 2013). In 2011, the US had more than 9800 residential curbside collection programs serving 73% of the U.S. population (US EPA, 2013). Many types of curbside recycling containers are available, varied by volume, color, style, cost, messaging, use of Radio Frequency Identification (RFID) technology, which permits recycling data collection at the household level, and durability. Because recycling collection is managed at the municipal level and various types of collection containers are available, there is wide variety in the recycling containers used throughout the US (Lane and Wagner, 2013). The 18-gallon (68 L) plastic open-top bin (17″ w × 22″ l × 16″ h) is one of the more popular containers, due principally to it being the cheapest available option at approximately $10 each. In contrast, at $50 each, 64-gallon carts can necessitate a relatively major capital investment for a mid-size city. For example, a mid-sized city with 50,000 households considering the adoption of a cart program would face a cost of some $2.5 million. Based on a study by Lane and Wagner (2013) on the use of recycling containers in the US, of the 782 responses, 178 municipalities (with a combined population of 17.184 million) used open top bins with a capacity of 18 gallons or less. From this data, the prevalence of the use of this type of collection container is clear.

Although the capital cost of purchasing small open-top bins is substantially less than that of rolling carts, it is important to assess direct and indirect costs associated with their use (to be sure, there likely are other capital costs to the collection trucks depending on whether carts will be collected automatically, semi-automatically, or manually). One such cost comes from their contribution to litter from the open-top design, which more easily transforms recyclable

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materials to litter through overflow, spillage, and uncollected residue. As defined by Huffman et al. (1995), litter is any piece of misplaced solid waste that can be individually handheld. While open-top containers are broadly recognized to contribute to wind-blown litter, there is a paucity of data as to the exact contribution. A 2008 pilot program for cart-based recycling collection in Clark County, Washington, while not explicitly focusing on the connection between open-top recycling bins and litter, highlighted the connection in participating neighborhoods between the shift from open-top bins to covered rolling carts and a notable decline in windborne litter (Green Solutions, 2008). Where eight neighborhoods took part in the pilot, an average of 65% of residents noticed a decrease in litter in their neighborhood with cart-based collection, with as low as 35% of residents noticing a reduction in litter in the least windy neighborhoods and as many as 85% of residents noticing a reduction in litter in the windiest neighborhoods participating in the pilot study (Green Solutions, 2008).

This study focused on quantifying the contribution and economic cost of collecting litter generated from a municipal curbside recycling collection system that used open-top recycling bins.

1.1. Generating curbside recycling related litter

Litter generated during the curbside collection of recycling is caused primarily by four factors: curbside collection container design, weather (especially wind), the method of transferring the contents of curbside collection containers to collection vehicles, and scavenging of the containers by humans and animals.

Open-top recycling bins are themselves potential sources of litter, as wind can blow lighter materials (e.g., small pieces of paper, plastic food containers, etc.) out of the bin. Wind has been found to be the primary factor in the generation of marine litter, as litter on coastal lands is blown into the ocean or to an area where it can be conveyed to the ocean (Owens et al., 2011). The potential of any container to generate litter is a function of the presence of a lid, the relation between the volume of the container and the volume of recyclables contained within a collection container, the mean velocity of steady winds and gusts, the length of time the container is on the curb prior to removal of its contents, and how the container is emptied (e.g., manual or automatic). According to Lapp (1983), the key factors regarding the generation of wind-blown litter from trash include the strength and turbulence of wind in addition to the compaction and moisture content of the waste and the type of waste. Lapp's (1983) modeling showed that a 10–15 mph (16–21 km/h) wind or gust can blow an envelope or lightly crumpled piece of paper 20 feet (6 m) unless trapped by vegetation or a fixed object, and can be carried 120 feet in a 50 mph (80 km/h) wind. (It should be noted that since Lapp's 1985 research, there has been a considerable reduction in weight per volume of materials ("lightweighting") especially packaging made of plastic, metals, and paper (see for example Timpane, 2015) suggesting that litter could travel further than found in 1985.) In addition, ground-level obstructions can create a sudden horizontal and/or vertical shift in wind, thus creating turbulence, a key factor in the creation and transportation of wind-blown litter (Lapp, 1983). Lighter materials not compacted prior to collection, such as those placed loosely in curbside collection bins, are especially susceptible to wind (Lapp, 1983). Recycling materials that become wet from precipitation are less likely to become litter. For urban areas in northern climates, litter is a component of snow removed for subsequent disposal, with the amount of litter increasing the longer the snow remains prior to removal (Johnston, 1985). Snow removed from urban areas is generally deposited on land in snow dumps, but in some jurisdictions may be discharged directly into freshwater or the ocean. In land-based snow dumps, melting snow infiltrates to ground water or is discharged to storm drains or the sewer system. Following the completion of the melting of snow during warmer periods, the residual is a mix of contaminants, grit, and refuse necessitating collection and disposal (Vanier, 1985; Scott and Wylie, 1980). In the US state of Maine, for example, all post-melt litter at land-based snow dumps must be removed and disposed of by July 15th or by the complete melting of the snow in the dump, whichever is earliest.

Spillage of material during the curbside collection of recycling is another source of litter. Materials in recycling containers can become litter during the manual or automatic transfer of materials from the curb to the collection truck, especially when open-top containers are used. If materials remain in the collection container after the container's contents have been dumped into the truck, those materials can become litter, especially if the container is not returned to a proper upright position. In a pre- and post-litter study, Schert (2000) attributed a 71% increase in litter to automated collection (although in his study he found that collection of trash was a larger source of litter than recycling collection). The recycling containers in the study were 18-gallon, open-top containers. Regarding the litter characterized in the study (which was limited to large pieces, defined as equal or larger than 4 in.^{2}), paper packaging made up the largest percentage (Schert, 2000). Additionally, one Florida study (FCSHWM, 2003) found that overflowing and uncovered dumpsters were prominent factors in collection-generated litter. Another potential factor related to the contribution of curbside recycling to litter is the collection method employed by workers. For example, Portland, Maine uses a task-based incentive system in which workers are paid for a full shift regardless of when the daily assigned tasks are completed. This incentivizes the hurried collection of recyclables by work crews, with a high potential for health and safety risks as well as spilled materials (KCI, 2015). In Portland, the recycling collection crew returns emptied recycling bins back to the curbside upside down in order to prevent the collection of precipitation in the bins. As a consequence, if any materials remain in the emptied bin (e.g., large or wet items), they can easily become dislodged and thus become a potential source of litter unless immediately collected by the bin owner. Under a task-based incentive system, there is a disincentive to slowing the collection process down to prevent the generation of litter or to clean up litter if it is created.

Although it is known to occur, there is little in the literature regarding human scavenging of refundable containers in bottle bill states (states with beverage container deposit and refund laws). One of the impediments to accurate measurement is that scavenging is generally illegal and is practiced informally and covertly by individuals with limited economic means. Ashenmiller (2011) found that, among households participating in a Santa Barbara, California study, beverage deposit scavenging is a significant source of income for those in the lowest income bracket. In New York City, individuals scavenge recycling containers to collect revenues from aluminum, scrap metal, and other commodities, which include redeemable containers (Lange, 2012). With small, open-top recycling containers, visual inspection and removal of materials is more convenient for scavengers than with other types of collection containers, especially since the depth of the 18-gal bins is only about 24 in. (61 cm). When scavengers sort through collection containers, it is often with limited regard to the impact of such behavior on the generation of curbside litter. Thus, the act of scavenging has the potential to dislodge and transfer non-target materials out from the recycling container.

Animal scavenging also is a potential factor. Broad anecdotal evidence and eyewitness accounts exist of animals (e.g., squirrels, crows, gulls, etc.) ripping open trash bags in the city of Portland, Maine to access their contents. Little research has been conducted regarding scavenging from curbside trash bags by animals. However, one limited study showed that the introduction of transparent garbage bags coincided with an increase in scavenging of waste by crows (Kurosawa et al., 2003). Similarly, Sazima (2007) reported that black vultures had learned to tear into plastic bags in search of food on Brazilian beaches. With unwashed food containers and other items potentially attractive to animals present in recycling, it is highly likely that the findings applicable to trash would be equally applicable to recycling.

1.2. Impacts of litter

The direct economic impacts of litter are the costs to collect, remove, and dispose of or recycle the litter. Other direct impacts from litter include the impairment of storm collection drains. Indirect impacts include reduced aesthetics, property values, and tourism and increased marine litter. Other impacts are widely studied but it is much more difficult to attach a monetary value to the increased risk of flood damage from storm drain impairment and marine ecosystem damage.

1.2.1. Litter cleanup costs

Regarding the estimated costs to clean up litter, governments generally do not apportion litter costs based on individual pieces of litter, but on the time spent cleaning up litter. There are some examples of annual per capita costs for litter collection, but these data are not helpful in determining the marginal cost of a specific source of litter such as that generated from recycling containers. The majority of cost information comes primarily from litter collection programs along roadsides (KAB, 2009). There are limitations to applying roadside litter cleanup costs to litter cleanup costs from recycling collection. Cost is a function of litter deposition rates and density, cost of labor, surface conditions, and cost of necessary equipment. According to Stein (2005), who draws on a 2004 litter study commissioned by the state of New Jersey (GBBI, 2005), the cost of litter cleanup by paid public employees is \$1.29 (2005 dollars) per piece of litter and \$0.18 cents (2005 dollars) per item based on the use of voluntary labor under Adopt-a-Highway litter cleanup programs. Another approach is to extrapolate per item costs using mean litter density compared to per road mile cost. According to KAB (2009), the mean prevalence of litter in the US is 7784 items per mile in urban areas, which is based on visible litter surveys that include litter to a depth of 15 feet (4.57 m) from the edge of the road. A Michigan study (CRI, 2015) estimated that the per-road mile cost of litter clean up by public employees was \$1666.67 while relying on voluntary programs cost an average of \$365.92. Using the mean count of 7784 items per mile equates to a per item cost of \$0.21 when using paid public employees and \$0.047 when using volunteer labor.

1.2.2. Impairment of storm drains

Studies on the impact of litter on storm drains are limited. One of the most detailed studies is the 2009 National Visible Litter Survey and Litter Cost Study (KAB, 2009). In its assessment of litter found around storm drains, KAB found 191 pieces of litter per 1000 ft^2 of surface area. These results, however, were not for the storm drain catch basins, but for the area surrounding each storm drain; instead, the litter was deemed likely to enter the storm drain from wind or water action. Of these pieces, 32% were tobacco products, 20% were plastic, 16% confectionary products, 16% paper, 9% glass, 4% metal, and 3% unclassified (KAB, 2009). Studies of materials found inside of storm drain catch basins are also minimal. A 2008 study of the Chesapeake Bay Basin region found significant variation in the percentage of material removed from catchment basins constituted by litter, with as low as 0.3% in one residential area and as high as 15.4% in another (Law et al., 2008). In Portland, Maine, which has 6000 storm drains throughout the city, the average cost of storm drain cleaning is between \$111.95 and \$167.91 per storm drain per year (Curran, 2012). A common approach to preventing or reducing litter impairment of storm drains is street sweeping and manual litter cleanup. Thus, litter can add further costs if more frequent sweeping is necessary to collect litter to prevent storm drain blockage.[1]

1.2.3. Indirect impacts

The indirect costs of litter are more challenging to assess than litter's direct costs, but they have the potential to be significant. Litter's impact on property values is widely recognized. The National Association of Home Builders pricing model estimates that litter reduces property values of an affected neighborhood by more than 7% (KAB, 2009). The effect of litter on the aesthetic value of an area can have costs beyond a reduction of property values. Reduced aesthetic value and increased public perception of an unhealthy environment can negatively impact the tourism economy (WHO, 2003; Silva-Cavalcanti et al., 2009). The blockage of storm drain flow control devices is problematic, as it can cause flooding, but it also can reduce the efficacy of sewage treatment and control (Armitage, 2007).

Land-based litter originating from storm events, wind, and solid waste management practices is a major contributor to marine litter (Owens et al., 2011). Marine litter can alter and damage benthic habitats, upset benthic organisms, and can convey invasive species (Galgani et al., 2013). Some 700 marine species are affected by marine debris primarily through entanglement and ingestion (Wilcox et al., 2016). Plastic is especially problematic because of its persistence and longevity in the environment, coupled with the action of wind, waves, and currents resulting in its breakdown to smaller pieces – microplastics (Gold et al., 2014). Plastics generally constitute the largest portion of beach litter (Schulz et al., 2015). In 2012, plastics constituted of 12.6% by weight of the total quantity of MSW generated in the US compared to 8% in 1990 (US EPA, 2014). This data, however, can be misleading because it is reported by weight as opposed to volume, which is significant due to the documented occurrence of light weighting (Timpane, 2015) and since packaging constitutes the largest source of plastic resins (Jambeck et al., 2015).

2. Background of study

The population of the city of Portland, Maine was 66,318 in 2013. The city is located in the northeastern corner of the US on the Atlantic coast. Portland has a humid continental climate, extreme winters, no dry season, warm summers and pronounced seasonal variation (Pidwirny, 2011). Average daily sustained winds range from 10 mph in spring to 7 mph in fall, with average gusts of 17 mph and 13 mph during those two seasons respectively (Weather Spark). The annual precipitation is 47.33 in. (120.2 cm) per year (U.S. Climate Data, 2015).

Portland provides weekly curbside trash and recycling collection to residences with fewer than four units and some municipal buildings. Each workday, the city deploys 3 two-person crews to service a collection area, which is serviced once per week. The city collects recycling and trash once per week (52 weeks per year), both on the same day within the designated collection zone. In total, the city has 15,860 stops for weekly collection (14,200 single family stops and 1660 stops at multi-family and municipal buildings).

In 1999, the city provided 18-gallon open-top bins to all residents for the initiation of its curbside recycling program and still offers these bins for sale. By providing free containers, the goal

[1] Emerson, J., 2015. Utility Coordinator, City of Portland, Maine. Personal Interview (N. Broaddus, Interviewer), Portland, Maine, June 2015.

was to increase participation in curbside recycling collection. This is supported by Noehammer and Byer (1997), who found that providing free containers significantly increases participation in voluntary recycling programs. The capacity of the bins has remained the same even though the city adopted pay-as-you-throw pricing for trash disposal (city residents must purchase city trash bags) in 1999 and switched to single stream (or "no sort") curbside recycling collection in 2007. Portland's residential recycling rate was 7.0% in 1998, but by 2014 had climbed to 36.6%. Since 1978, Maine has had bottle bill legislation in place, passed specifically to control litter, not to increase the state's recycling rate (Criner et al., 1991). The state's bottle bill has since been expanded and is one of the most comprehensive beverage container deposit/refund programs in the US, covering liquor, wine, beer, water, soda, and fruit juice containers made of metal, plastic, and glass. The recovery rate of beverage containers covered by the legislation is estimated at 90% statewide.

3. Methods

Two study areas were selected within Portland: an urban area and a suburban area. The study areas were selected because they are two separate, delineated service routes on different collection days. These two different study areas also represent the diversity of the city's population and collection system.

- Suburban Area – This area has a relative low urban density with 1179 collection stops. The area is dominated by single-family homes (94%) and has a housing density of 2046 households/mi^2. There are 93,580 total feet of street in this study area.
- Urban Area – This area has a relatively high urban density with 862 collection stops. The area has a housing density of 5016 households/mi^2 and contains a diverse mixture of multi-family and single units: 9.7% of buildings contain 4 or more units, 18% contain 3 units, 23.1% contain 2 units, and 48.9% are single-family dwellings. There are 46,790 total feet of street in this study area.

Data was collected separately for each study area over a seven-week period between June 10, 2015, and July 22, 2015. For this study, two different data sets were collected: the prevalence of overflowing recycling containers on each route during the study period and the characterization of litter attributable to the recycling containers set out for collection.

The city recycling crews started collection at approximately 6:30 am. In order to collect accurate data, researchers began collecting data at 6:15 am in order to stay ahead of the collection trucks. (The city requires residents to set out trash and recycling by 6:00 am on the collection day.) The data collection process ended at approximately 11:30 am, always before the collection crew completed the route.

During the study period, a visual assessment was made of every recycling container set out during the week. For each container, regardless of its size or type, a single researcher assessed the volume of recyclable materials as to the degree to which they overflowed or had been placed adjacent to the container. Where the volume of recyclable materials exceeded the capacity of the container, volumes were reported as a percentage of the capacity of the container.

Litter was collected on six different days over the study period, with three discrete collection events for each study area. The weather conditions for the day and time period of each litter collection are presented in Table 1. As shown, there was no precipitation recorded during any of the litter collection days so the condition of collected litter was as it was placed into the bins by residents. Researchers conducted litter collection between the hours of 11:00 am and 3:00 pm, which was after city employees had completed curbside collection. By collecting and removing the litter, fresh litter counts were conducted as opposed to accumulated litter counts. All litter equal to or larger than 1 in.^{2} and attributable to a recycling container was collected. Litter not likely to have been in the recycling bin (such as bagged pet waste, cigarette butts, weatherworn litter, food waste, and broken bottles) was ignored. Litter within 20 feet of the sidewalk (or set-out location) of each container was collected (10 feet into the street and 10 feet toward the dwelling). Following collection, all litter was segregated and characterized by size, weight, and material type. Having been collected in plastic bags, labeled and stored for up to one week, the litter was subsequently sorted on a sorting table by four research assistants. The litter was sorted into the following categories and subcategories:

- Mixed Paper
  - Packaging (wrappers, etc.)
  - News/magazine/office
  - Paperboard
  - Other paper
  - Cardboard
- Mixed Plastic, #1–#7
  - Packaging
  - Beverage containers
  - Straws
  - Other plastic
- Metal
  - Packaging/Aluminum
  - Aluminum beverage containers
  - Other metal (e.g., ferrous pieces, cans)
- Glass
- Other

Within each category, litter was counted, weighed (wet weight), and sorted by size: small (1–3 in.), medium (3–6 in.), and large (6+ in.).

4. Results

The results of the prevalence of container overflow over the study period are presented in Table 2. As noted above, although 18-gallon recycling containers bins were provided to residents, there are no restrictions on the type, volume, or number of recycling bins. Thus, as noted below, 26% of residents used multiple bins. Nonetheless, on average, 15.2% of the bins were overflowing each week with the mean overflow volume of 66.9%, which is defined as the volume of material overflowing the capacity of the collection bin.

Table 3 shows the results of the six litter characterizations. The means are presented for each study area for litter count and weight for the total, per linear curb foot (i.e., the length of curb eligible for curbside collection, where street length is counted for both sides of the street where collection occurs on both sides, and for one side of the street where one side of the street lacks of buildings eligible for curbside collection), and per collection stop (dwelling). Determining the weekly set-out rate is difficult because RFID technology is not used in Portland. RFID technology allows for the collection of real-time data including set-outs, participation, and compliance and can also be used to support unit-based pricing schemes. However, because RFID is not used, researchers had to collect data visually by street address, remaining sufficiently ahead of the

Table 1
Weather conditions during litter collection days.

Collection day	Precipitation (mm)	Mean wind speed	Temperature
10 June 2015	0	20.2 km/h (18.2 mph)	20.4 °C (68.6 °F)
11 June 2015	0	23.6 km/h (14.7 mph)	18.8 °C (65.9 °F)
17 June 2015	0	12.7 km/h (7.9 mph)	26.0 °C (72.1 °F)
18 June 2015	0	31.5 km/h (19.6 mph)	22.3 °C (78.7 °F)
9 July 2015	0	9.9 km/h (6.2 mph)	20.6 °C (69.0 °F)
22 July 2015	0	18.3 km/h (11.4 mph)	24.7 °C (76.4 °F)

Except for precipitation, all data is based on the mean hourly recordings from 6:51 to 15:51 collected by the National Centers for Environmental Information (NCEI) of the National Oceanic and Atmospheric Administration (NCEI, 2016), at the Portland International Jetport (14764/PWM), which is located approximately 5 km from the study sites.

Table 2
Prevalence of recycling container overflow.

	Urban area	Suburban area	Combined mean
Mean number of bins per collection stop	2.04	1.34	1.69
Percent of recyclers with more than 1 bin	36.2%	15.8%	26.0%
Weekly mean percent of recycling bins with overflow	16.9%	13.4%	15.2%
Weekly mean volume percent overflow of bins with overflow	77.3%	56.6%	66.9%

Table 3
Results of the litter collection and characterization for Portland, Maine.

	Urban area (N = 733)	Suburban area (N = 1050)	Combined mean
Mean total weekly count (pieces >1 in.)	486 pieces	292 pieces	389 pieces
Mean total weekly weight	218.6 oz	74.5 oz	146.5 oz
Count per 1000 curb feet	5.2 pieces	2.7 pieces	3.87 pieces
Weight per 1000 curb feet	2.33 oz	0.69 oz	1.46 oz
Mean weekly item count per collection stop	0.66 pieces	0.28 pieces	0.44 pieces
Mean weekly item weight per collection stop	0.3 oz	0.07 oz	0.16 oz

collection crew so as to avoid interfering with their operation. Although residents are required to set out their trash and recycling bins by 6:00 am, researchers witnessed the placement of trash and recycling much later, though still before the collection trucks arrived. Because of this, for some addresses where researchers had previously determined that no recycling container was set out at the time of data collection, containers were later observed to have been set out. In addition, collection crews would periodically alter their collection route. These combined factors hampered our ability to determine an accurate set-out rate. A consultant to the city had previously estimated the weekly recycling participation rate/set-out to be 90% (KCI, 2015), which seems reasonable. Thus, to estimate citywide litter generation, only 90% of the city's collection stops are used in the extrapolation of study area values. Based on GIS analysis of the streets where recycling containers were set out and litter was collected, there are 93,580 curb feet in the urban area and 107,390 curb feet in the suburban area. Because litter was collected within a 10-foot radius of each likely container location, the measured litter count is likely to be a low estimate of the number of pieces of litter attributable to the collection container. It is highly likely that some pieces of recyclable material that became litter were blown more than 10 feet away from the collection container by wind or gusts created by passing vehicles during the period of time between 6:00 am, the time residents are requested to set out their recycling bins, and the time of the litter count, which occurred between 11:00 am and 3:00 pm.

The results of the litter categorization are presented in Fig. 1, which compares the mean prevalence of litter of each material type (the number of pieces collected of each type of recyclable material) in the urban and suburban study areas. The data is reported as mean pieces per household per week. As noted above, individual pieces of litter were assigned one of three size categories: small (1–3 in.), medium (3–6 in.), and large (6+ in.). In the urban area, the litter collected was composed 11.2% of small pieces, 47% of medium pieces, and 41.9% of large pieces, while in suburban areas the composition was 14.3% small, 36.7% medium, and 49% large. As to be expected, there was more litter in the urban area than in the suburban area (which is supported by the data in Table 2 above) due to urban dwellers having, on average, more bins per collection stop, more recycling bins with an overflow of materials, and a greater volume of overflow from the bins. Coupled with these factors are the greater density of households and associated bins and a higher prevalence of scavenging in part due to the higher density of recycling bins.

Combining results from both study areas, the mean amount of litter generated weekly from each curbside recycling bin was 0.44 pieces weighing 0.16 oz. If these values are extrapolated to apply to all 15,860 collection stops in Portland, assuming a 90% participation/set-out rate, open-top curbside recycling bins contribute approximately 6280 pieces of litter over 1 in. in size each week, weighing 2284 pounds in total. Per year, this equates to 326,560 pieces of litter weighing 118,768 lbs (59.38 tons).

When material designated for recycling becomes litter, there is a loss in material value, which is a function of the commodity value of the material. As shown in Table 4, the likely lost recycling revenue was estimated by aggregating weights of the segregated collected litter into their respective commodity categories. The commodity values used in Table 3 are based on mean revenues received for each short ton of material from July 2010 to May 2015.[2] The estimated annual tonnage citywide is the amount estimated to be generated yearly for the entire city from all collections stops, which is based on the mean weight of litter generated per collection stop during the study period.

Because litter becomes trash, it would necessitate disposal at the nearby waste-to-energy facility, which charges a tipping fee of $70.50 per ton. Thus, the trash tipping fees for 2.25 tons of litter per year is $158.60. This fee does not include hauling charges

To estimate the economic cost of the marginal increase of litter from recycling bins on city streets, a per-piece litter collection cost range was determined based on the researcher's actual time spent collecting the litter. Regarding labor cost, at the low end of the range, the current federal minimum wage is $7.25 per hour.[3] Fringe benefits (e.g., sick leave, vacation, insurance, etc.) are not required to be paid to employees. At the upper range, the mean 2015 hourly wage for service workers employed by state and local governments $34.02 per hour, which include fringe benefits (US BLS, 2015). Although this is used as the upper end of the range, this figure is more realistic because litter collection on city streets is more likely to be conducted by service workers employed by the city government. The average person-hours spent per litter collection event

[2] The revenues are based on what ecomaine received, which is the municipally-owned regional solid waste facility that manages residential recyclables collected in Portland.

[3] The City of Portland has established a minimum wage of $10.10 per hour, but the federal minimum wage was used for a broader application of costs.

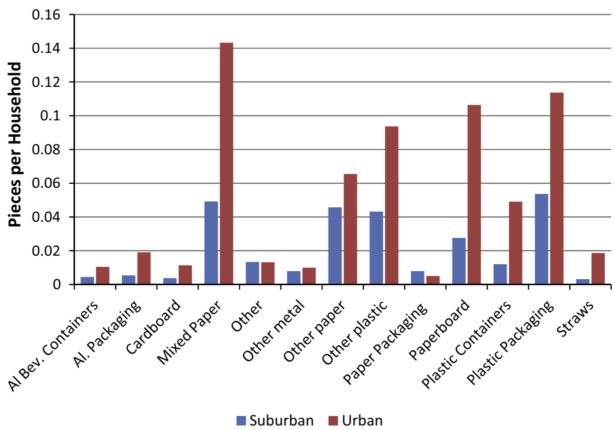

Fig. 1. Prevalence of the categories of litter based on item counts.

Table 4
Estimated economic value of lost revenues due to recycling becoming litter.

	Value of materials per ton[a]	Estimated annual tonnage citywide	Estimated lost revenues
Mixed Paper	Mean $74.83	0.86	$64.35
Cardboard	Mean $123.54	0.28	$34.60
Ferrous	Mean $180.78	0.03	$5.40
Aluminum	Mean $441.48	0.15	$66.25
Plastic, #1–#7, mixed	Mean $100.00	0.87	$87.00
Glass	$0	0.06	$0
Total		2.25	$257.50

[a] Glass has had $0 market value over the past 5 years.

during the study period was 9 h. Using the range of hourly labor rates of $7.25–$34.02, using the mean of 389 pieces of litter per collection event, and the person-hours to collect the litter, we estimate the litter cleanup cost to range from $0.17 to $0.79 per piece of litter.

Using the estimated range of per-piece litter collection costs of $0.17–$0.79 and the 326,560 pieces of litter per year, the marginal cost of the collection costs of litter cost associated with the recycling containers would be $55,515–$257,980. While the 326,560 pieces of litter will not be entirely collected by the city, individuals and businesses share in the collection effort and their opportunity costs must be considered; thus, the $55,515–$257,980 should be viewed as a direct economic impact.

The total annual estimated cost to the city of collecting and disposing of litter and the lost recycling revenue from the recycling containers is shown in Table 5. The cost from storm drain impairment by litter and the resultant risk of flood damage was not included because of the inability to directly assign cost to the litter, but there are clearly both direct and indirect costs.

Table 5
Estimated annual direct cost of litter from curbside recycling collection.

Item	Annual cost
Litter collection	$55,515–$257,980
Lost recycling value	$258
Trash disposal	$158
Total	$55,931–$258,396

5. Discussion

The benefits of curbside recycling collection are well-understood and are encouraged by many municipalities, organizations, and individuals. The results of this study do not challenge this notion. The results of the study do, however, call attention to litter as an issue and highlight the potential for two major factors to reduce the generation and associated of costs of litter from curbside recycling collection.

As demonstrated by the results, the direct and indirect costs are significant for a small city. Litter impairs the ability of storm drains to properly function, which can cause or exacerbate flooding. The presence of litter in storm drains necessitates more frequent cleaning, which is an added cost. Litter also is an aesthetic problem. Though the costs of decreased aesthetic value are difficult to measure accurately, fielding citizen complaints becomes a direct cost to the city, while degraded aesthetics can negatively impact property values and tourism. Furthermore, in a coastal city like Portland, which is sited on a sheltered harbor, litter generated on land often becomes marine litter due to wind and storm water run-off. The costs of marine litter can also be substantial, both in terms of beach cleanup efforts and in terms of damage to marine ecosystems and industries that can impact fisheries and the working waterfront.

To reduce these negative impacts, litter must be collected and removed. As shown in this study, the estimated total annual cost of the litter citywide is $55,931–$258,396, or $3.52–$16.29 per collection stop per year. This study shows that, given the source of litter, it is more cost-effective to prevent or reduce the generation of litter than to constantly engage in litter cleanup efforts, which should be done through a careful assessment when selecting the appropriate size and type of recycling container for curbside collection. Because of the high capital costs involved in the provision of collection containers, assessment of total program costs should include potential future modifications to the program in addition to the containers' capacity and convenience and, as this study highlighted, their potential to create litter.

This study also found that the primary causes of litter were the prevalence of open-top recycling bins, the task-based collection system, the return of recycling bins upside down, and scavenging. The use of small, open-top recycling bins were found to be susceptible to overflowing materials, wind, and scavenging. Consequently, replacing these bins with covered bins with a larger capacity would address these specific factors. At the same time, the impacts of scavenging would be reduced due to the greater unused volume in the bin and the height of the container becoming a physical barrier to scavenging activities. The task-based incentive system for recycling (and trash) collection should be reconsidered with regards to preventing or reducing litter caused by the speed of recycling collection. If the careful collection of materials is incentivized rather than the speed at which collection occurs, this too would reduce the generation of litter from curbside collection.

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