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Abstract

Six tonnes of discards and recyclables from three waste districts in a New York suburb were sorted in 2012. The districts were chosen because one had a higher recycling percentage, one had median performance, and one was a low performing district. ASTM standards were followed for the waste composition sorting. The results showed, as expected, that the waste district with the highest recycling rate appeared to have the highest separation efficiencies, leading to greater amounts of recyclable materials being source separated. The waste districts also had different overall waste generation, both in terms of the amounts of wastes generated, and their composition. The better recycling district generated less waste, but had a higher percentage of recyclables in the waste stream. Therefore, in some sense, its waste stream was enriched in recyclables. Thus, although the residents of that district recovered materials at a higher rate, they also left large amounts of recyclables in their discards – as did the residents of the other districts. In fact, the districts only recycled between one quarter and less than half of all available recyclables, so that their discards were comprised of up to one third recyclable materials. This level of performance does not appear to be unique to this Town; therefore, we believe that additional recovery efforts through post-collection sorting for recyclables may be warranted.

Key words: curbside collection, waste sorts, paper, containers, household recycling rates, recycling percents, non-parametric statistics

1.0 Introduction

US national recycling rates have been relatively flat since the turn of the century (28.5% recycling in 2000, 34.7% recycling in 2011) (USEPA 2013). Recycling as used here is defined as the collection of material with the intention of using it to create new products; whether or not true recovery of the collected materials is achieved is not part of the measurement.

Recycling performance has been found to relate to three classes of recycling attributes: program characteristics; target population socio-demographic characteristics; and target population psychological characteristics. So, Pay-As-You-Throw (PAYT) programs have higher recycling rates to minimize participant disposal costs (Dahlen and Lagerkvist 2010; Skumatz 2008; Folz and Giles 2002; Linderhof et al. 2001; Salkie et al. 2001; Callen and Thomas 1999; Miranda and Aldy 1999), mandatory recycling programs have greater participation rates than voluntary programs (Viscusi et al. 2012; Nixon and Saphores 2009; Ferrara and Missios 2005), curbside collection has better performance than drop-off programs (Best 2009; Ebreo and Vining 2000) and public outreach increases recycling (Sidique et al. 2010; Nixon and Saphores 2009; Callen and Thomas 1999; Fransson and Garling 1999; Read 1999; Scott 1999; Daneshvary et al. 1998). Factors such as differences in age (Sidique et al. 2010; Diamantopoulos et al. 2003; Scott 1999), income (Jones et al. 2010; Ferrara and Missios 2005; Berger 1997), education (Nixon and Saphores 2009; Jenkins et al. 2003), socio-economic status (Mukherjee and Onel 2012), home-ownership (Oskamp 1995), political ideology (Fransson and Gärling 1999), race (Johnson et al. 2004), household size (Lebersorger and Beigl 2011), and employment (Bach et al. 2004) have been shown to affect recycling rates, although the strength or direction of the trends may not be consistent (for instance, opposite findings regarding age as a predictor by Stern and Dietz 1994 and Scott 1999). Also, note that most of those papers tracked participation rates not separation rates. Attitudes that have been related to environmentally conscious activity and behaviors, and recycling participation, include: concern for the community (Vincente and Reis 2008; Tonglet et al. 2004); convenience and effort (Barr and Gilg 2005; Peretz et al. 2005; Sterner and Bartlings 1999); positions regarding morality (Berglund 2006), the environment generally (Best and Kneip 2011), and government (Guerin et al. 2001); social norms (Halvorsen 2008) and social interactions (Shaw 2008); and, personality and past experience (Ajzen and Fishbein 1977). One explanation for psychological linkages to recycling participation is that highly visible curbside recyclables collection programs increase social pressure (Vining and Ebreo 1992).

Recycling performance is commonly measured in one of two ways. In survey-based studies, one common measure is based on self-reports of the recycling frequency (i.e., the number of events utilized by the participants for recycling as a function of the number of recycling events available to them). These "participation rates" can also be measured by counting the number of households setting out recyclables. Other studies measure the material or percent of material recycled. It is assumed that increased participation rates result in greater diversion rates, but there are no studies that document this. Therefore, most general recycling assessments (USEPA 2013; Greene et al. 2011; NYSDEC 2010; Johnstone and Labonne 2004) focus on recycling rates as reasonable means to compare recycling performance.

The composition of solid waste is different from nation to nation (Hoornweg and Bhada-Tata 2013), has been said to vary across the US as a whole (USEPA 2013; OTA 1989), and has been documented to be different from state-to-state (Staley and Barlaz 2009) and for communities across the rural-suburban-urban spectrum in one state (DSM Environmental Services Inc. and MSW Consultants 2013; NYSDEC 2010). Because waste streams vary, ability and success at recycling may be at least partially dependent on the amount of recyclables that are available to recycle -- the composition of the generated waste stream. Comparisons of recycling performance across varying programmatic, demographic, and psychological groupings appear to assume there is similar waste stream composition, and that differences in effort at recycling will therefore equate to differences in recycling performance. This assumption appears to be shared by those who link participation rates directly to recycling performance. Although recycling rates may very well vary due to programmatic, demographic, and psychological differences, the effects could be masked or accentuated by differences in the availability of materials to recycle.

Determining the composition of pre-source separation solid waste turns out to be more difficult, and undertaken fewer times, than might be supposed. USEPA uses its Franklin Associates model to determine waste composition for the nation as a whole before any management of those wastes is accomplished (USEPA 2013). The accuracy of this methodology has been questioned (Tonjes and Greene 2012). There are many site, locality, and state level waste composition studies, made by sorting collected wastes in a formalized fashion. ASTM (2006) has issued widely followed guidance for this. We have collected 107 examples of local and state waste composition studies. All begin with discarded wastes. We are not aware of any studies, save one (RW Beck 2005), that also included collected recyclables, and attempted to relate recycling and waste discard rates to subsets of the studied region. The sprawling RW Beck report to New York City Department of Sanitation never directly linked particular subset area waste generation with recycling, partly because there were mismatches between routes for waste collection and routes for recycling.

We report here on a waste composition study for the Town of Brookhaven, conducted with an eye on multiple objectives. We sought to quantify the capture rate for particular recyclable materials, and to relate those capture rates to three different levels of recycling performance in the Town. We sought to determine the composition of discards and recyclables for the three districts. We also sought to create a composite waste composition for each district, and to determine if there were meaningful differences in the overall waste compositions in the three districts, and if those differences related to any differences in recycling.

2.0 Materials and Methods

2.1 Study Location

The Town of Brookhaven (Long Island, New York) is located approximately 75 km east of Manhattan Island, New York City (Figure 1). The Town created a residential waste collection program in 1988. Mandatory curbside recycling was added in 1989. Separate collection of leaves and brush and a ban on grass clippings collection was instituted in 2002. Recycling switched from alternate week dual stream collection to single stream collection in 2014. Residents pay a fixed fee per household serviced, which is collected through property tax bills. Approximately 115,000 single, two, and three family housing are provided service. Multi-family, condominiums and cooperatives and other areas with private streets, and the nine incorporated villages in the Town are not included in the collection program.

Town government administers the program, but the physical collection of wastes is accomplished by contracted private companies. There are 35 geographically distinct districts in the Town waste collection program.

2.1.1 Waste Districts

We selected three districts that delivered discarded wastes to the Town Transfer Station on the Monday/Thursday collection cycle: District 1, District 18, and District 31. District 1 had the greatest curbside separation percentage of all 35 districts in 2011, District 18 ranked 15 (of 35), and District 31 ranked 33. Curbside separation rates were defined as the sum of paper and container recyclables divided by the sum of the collected recyclables plus collected discards. District 1 is smaller than the other two districts, contains a smaller percentage of minority residents, and its residents tend to be wealthier, and better educated (Table 1). Town waste administrators believed that the three carting companies for these districts have better than usual compliance with various collection rules, such as avoiding using the same truck to collect from two districts on the same day (doing this would confuse our analysis).

2.2 Waste Sorts

2.2.1 General Procedures

We assumed that the waste composition data would be normally distributed, and used ASTM (2006) assumptions regarding waste composition, selecting "mixed paper" as our key component, as it required many fewer samples than all other components under the guidelines. The ASTM algorithm for samples, with an allowable error of 10%, produced a value of 17 samples needed per district. We collected 18 discard samples per district, and five container samples from each district.

All discard samples were processed on Mondays and Thursdays in a paved, open area near the transfer station at the Town Waste management Facility. The first truck generally arrived by 10 am. All waste from the three samples was processed by 4 pm. No rain occurred on any of the 18 sampling days. Some materials were lost to wind and scavenging gulls, but the impact was minimal.

All recyclable samples were processed within the on-site Materials Recycling Facility (MRF) on Wednesdays. Only container loads were sampled, so at most two samples were processed each day. The first sample generally arrived after 10 am, and all materials were processed by 3 pm.

Although Districts 18 and 31 deliver wastes to the transfer station on the Monday/Thursday cycle, due to their large size they also deliver wastes on the Tuesday/Friday cycle as well. The second collection cycle on Tuesday/Friday was not sampled, although the delivery data were used to generate waste profiles. Sampling began August 20, 2012, and continued until November 15, 2012. Samples were not taken on Labor Day (September 3) and Columbus Day (October 8) as the Town does not offer service on these holidays. Because of the disruption of sampling associated with Superstorm Sandy (we did not sample October 25, the week of October 29, and the week of November 5) and the potential that storm debris would change the waste composition, the samples collected on November 15 were not included in the analysis. Therefore, the analyses that follow will report on 17 samples from each district (eight Monday samples, nine Thursday samples).

Recyclables sampling began August 22 and ended October 24. District 1 container recyclables were delivered August 22 and every two weeks thereafter. Districts 18 and 31 container recyclables were sampled August 29 and every two weeks thereafter, so that a total of five container samples from each district were sampled over 10 weeks.

Source separated paper recyclables were not sorted, as visual inspection and the history of sorting recyclables at the MRF created confidence that close to 100% of delivered paper loads would be sorted for resale. Thus, information regarding the composition of the paper recyclables was not gathered. Logistical difficulties prevented sorting of yard wastes; inappropriate material in yard waste collections has been noted but were assumed to be unimportant for this study, which focused on other materials.

Wastes were sorted into 14 categories (Table 2), including all general categories of recyclable materials managed by the Town. Materials were not disaggregated, except that garbage bags and other waste holders were emptied, and aggregations that were formed due to compaction in the truck were separated as was possible. Thus, containers and other packaging were counted in with food at times, and other packaging was contaminated by food. Containers were not drained of liquids. Multi-material pieces were sorted according to judgements of predominant material, although the broad categories of "organic" and "inorganic" removed some particular uncertainties associated with multi-materials. Bulk wastes were excluded because they did not fit into the bucket loader well, and very large objects were not encountered (such as garbage cans). Uncontainerized liquids were not included. Dirt and fines often coated materials, but these were ignored in terms of classifications.

2.2.1 Further specific sampling procedures

For discards, the delivered wastes were mixed by the transfer station front-end loader for several minutes. A partial bucket was taken from the discard pile and spread on a level asphalt surface. Sorting continued until the entire pile had been sorted or it was estimated that considerably more than 90 kg had been sorted. Materials were stored in 110 L containers, and weighed by electronic scale (data given in 0.2 lbs [0.1 kg] increments). Tare weights were used for each container.

With container recyclables, a truck load was mixed by loader for several minutes. A partial bucket load was selected from the pile and brought into the MRF to an open area where the materials were sorted into the same 14 categories as the discards. The segregated recyclables were entirely sorted each time.

These procedures are generally in compliance with ASTM guidance (ASTM 2006). However, ASTM specifications suggest slicing along the waste slug to gather materials, and would cone and quarter this selection to achieve the sample material. ASTM also suggests proportionate distribution among categories for multimedia or mixed materials. ASTM would not like sampling to extend for as long as we conducted it.

2.3 Data Analysis

The weights in the 14 sorted categories were converted into percentages. Rate measures were generated using the total amount of wastes delivered in each district each day (collected at the scale house), the percentages in each category, and the time from the last waste collection. For paper deliveries, 100% of the delivery was assumed to be recyclable paper (per above).

The most commonly used waste rate in the US is per capita computations (e.g., Greene and Tonjes 2014; USEPA 2013; van Haaren et al. 2010). However, the waste districts do not conform with census tracts, and certain housing types (multi-family housing, condominiums, and co-ops) are not included in the waste district. Therefore, the number of people served by each waste district was thought to be very difficult to determine accurately. Household rates are commonly used in European waste studies (e.g., Beigl et al. 2008; Johnstone and LaBonne 2004). The prejudice against "household" as the base unit in solid waste analyses in the US relies on the accurate perception that all households do not have the same number of members. However, households are a self-defined unit for waste collection for curbside programs, and they are the billing unit for the waste districts (and so are carefully tracked by both the Town and the contract carters), and so we selected “per household” values for this report. We chose “week” as our unit of time to prevent presentations with many values <1 (sometimes considerably <1).

There was an obvious mismatch between the frequency of waste analyses (17 over 10 weeks) and recyclables analyses (five container analyses, five paper data points over 10 weeks). We combined the waste data into two week increments. The estimates of container separation, derived from scale data and the sort data, were added to the paper tonnage from the two week interval to create an estimate of district wide source separation. These two values could be summed to estimate the district wide amount and composition of curbside set out wastes over each two week interval. This process therefore created five estimates of composition (by percent and weight) and total amounts of discards, recyclables, and total curbside waste generation over the study period.

Town carters also collect source separated yard wastes. However, the period of August to October is not a peak generation time for yard wastes on Long Island, so yard waste was thus collected irregularly during our sampling period. We collated records for yard waste collections for each of the three months and used that as a measure of yard waste diversion over the sampling period.

The waste data were not normal, and were not generally transformable to normal distributions. This resulted from the heterogeneity of solid waste generally, and from the "batch" nature of discards. In a 100 kg sample, a single 10 kg bag of yard waste could skew the entire distribution of the sampling results. One closet clean-out could also bias a sample. Because wastes adhere naturally, were almost always disposed in plastic bags, and then were compacted in the truck, the loader mixing did not separate householder wastes much. We inferred (from similarities in the garbage, and direct evidence such as mail) that each sample was derived from a few households: perhaps as few as six or eight, but seemingly never more than 20 distinct households. This may have also enhanced the inherent heterogeneity of wastes compared across samples. The estimates of district wide waste composition for each collection day were based on tonnages recorded at the scale house. This had a good deal of variability within each district. Compared to the greatest delivery tonnage, the mean delivery tonnages were about half, and varied from a low of 31.9% of the maximum to 91.7% (container recyclable deliveries were much more consistent, averaging 90% of the maximum delivery with a range of 77.6% of the maximum to 97.5%). Thus, particular heterogeneities in the sampled waste may have been suppressed or made greater, depending on the amount of waste delivered that day. For some of our data, increasing the number of samples considered in the analyses (from five to 17, for instance) increased overall variance measures.

Because the data were not normal, we analyzed the data using PERMANOVA (Anderson 2005), a multi-variate, non-parametric approach, using rank ordering of permutations of the groups being tested (the null hypothesis is that substitution from one group into another should not affect the ordering). Therefore, references to mean values with associated standard deviations do not imply the statistical significance measures were actually made on these values. Differences in mean values can only be inferred from differences in the ordering of the results across districts. The statistical analyses were made across all three samples; we will not report any pair-wise tests. We used a sample size of 17 for the discards analysis only; all other analyses were based on five samples. The significance level used for all analyses was $p<0.05$.

3.0 Results

Scale house records and raw sorting data are available in the Supplementary materials (Tables S1-S8). Source separated yard waste collection data are included in Table 4.

3.1 Capture Rates for Recyclables

Previously we identified recycling percent and per capita recovery rates as two of the better measures of recycling program performance (Greene and Tonjes 2014). Therefore, we focus here on the per household recovery weights (for total recyclables, and the constituent materials of the recycling program) and the percentage of the total waste stream of these materials to determine differences across the districts, a largely pro forma exercise, given the districts had been selected based on prior differences in overall recycling percents.

The rate of curbside recyclables separation across the three districts, in kg/HH/wk (Figure 2), was significantly different when measured in terms of all 13 constituent materials (mixed paper and corrugated cardboard had been collapsed into one material category, recyclable paper), five materials (the primary recyclable categories of paper, plastic containers, glass containers, and recyclable ferrous and aluminum), two general categories (paper and containers), or one lumped sum. The same was true for the sum of the five recyclable materials only (excluding non-recyclable materials) (significant differences for five constituent categories, two categories of paper and containers, or one category only). The rate of paper separation (in kg/HH/wk) was significantly different across all three districts, as was the rate of total container separation (as four constituent materials and as a single summed term). The rate of glass separation as a single constituent was also statistically significant. The rate of separation of the other containers was not found to be significantly different (only recyclable plastics is illustrated in Figure 2, however).

The percentage separated from the whole waste stream (here considered to be only discards and recyclables) (Figure S1) was significantly different across all three districts, as was the percent of the five target recyclables (as five constituent variables, as two variables of paper and containers, and as a single summed variable). The percentage of paper, total containers (as four constituent variables and a single summed variable), and glass separated across the three districts were also significantly different. Other recycling separation percents were not significant (again, only recyclable plastics are shown in Figure S1).

3.2 Discards and Recyclables Composition

The amount of discards were significantly different across the three districts, considered by each constituent material (a 14 variable set), the two major divisions of recyclable and non-recyclable materials, or the single sum of materials. Plastic bags, yard waste, and other organics were specific materials where the discard rates were found to be significantly different. Non-recyclables (as an eight material set or as a sum) and recyclables plus yard waste (as a three constituent set of paper, containers, and yard waste, or as a single sum) were also significantly discarded differently across the three districts. Recyclables (as a sum, as individual constituents, and as the grouped sets of recyclable paper and containers) and other individual constituents not specified above were not discarded significantly differently (Figures S2 and S3). When the percentage of these constituents were considered, the 14 variable sets as a whole were significantly different across the three data sets, although the only individual constituent that was significantly different was yard waste (Figure S4). The only aggregated data sets that were significantly different across the three districts were non-recyclables (as an eight variable set, but not as a single value) and recyclables plus yard waste (as a seven variable set or as the grouping of paper-containers-yard waste, but not as a single value) (Figure S5).

The composition of the curbside recyclables has been partially presented above (Section 3.1). There it was shown that the total composition of the collected curbside recyclables, measured as 13 constituent materials, the five primary recyclable categories, or as the two general recyclable categories of paper and containers, were all significantly different when measured by weight. The composition of the recyclables was significantly different by weight considering the total paper category alone, and for total containers (as four constituent materials and as a single summed term). However, the only container type with a significantly different composition amount across the three districts was glass.

In terms of percentages of the source separated curbside recyclables, the only statistically significant differences were for a bivariate comparison of total recyclable paper and containers as a summed category, and for total paper as a single category. All other percentage composition comparisons were not significantly different (Figure S6).

3.3 Overall Waste Composition

We constructed an overall waste composition for each district by summing the discards and recyclables for each two week collection period. We lost the distinction between mixed paper and corrugated cardboard in doing so, because we did not sort the collected paper recyclables.

The total waste stream, as a rate (kg/HH/wk), was statistically significantly different across all three districts, measured for 13 categories, a bivariate division into recyclables and non-recyclables, and as a single value. Non-recyclables, as an eight variable measure or as a single value, were also significantly different across all three districts. Recyclable containers, as a four constituent variables measure but not as a single value, were statistically significantly different across the three districts, as was the constituent category, glass. Other organics were also statistically significantly different. All other measures were not found to be statistically significantly different (Figures 3 and 4).

The composition of the waste stream was also determined in terms of percentages. There were more statistically significant differences determined for this measure. Significant differences were found for the composition of the total waste stream, using 13 variables and the two variables of recyclables and non-recyclables, recyclables considered by itself (with five variables of paper and the four container types, two variables of paper and containers, and as a single value), recyclables and yard waste as a combined category (using six variables, and the three variable measure of paper, containers, and yard waste, but not as a single variable), for recyclable paper, and for containers (but only as four constituent variables; the single variable measure of containers was not found to be significantly different). All other measures were not found to be statistically significantly different across the three districts (Figures 5 and 6).

3.4 Separation Efficiency

The Town collects seven different types of recyclables; because we constructed an overall waste generation composition for the three districts, it was possible to compute the separation efficiency for paper recyclables and containers (as a whole and as the four constituent materials). We also estimated yard waste separation efficiency, although it was not statistically analyzed, being a single data point for each district.

There were significant differences across the three districts for separation efficiencies for curbside recyclables as a whole (considered as two variables of paper and containers, and as a single variable, but not as the five constituent variables of paper and the four constituent container materials), for recyclable paper, and for containers as a whole (as a single variable, not as the four constituent variable test). Separation efficiencies for the four individual container types were not found to be statistically significant across the three districts (Figure 7). Yard waste separation rates and estimates of separation efficiency are shown in Table 3.

4.0 Discussion

We were able to reconstruct the initial composition of wastes generated in our three waste districts. We measured the amount and composition of the waste streams set out for management in the districts, and so we can determine the differential effects of the recycling actions taken by the residents.

Residents are asked to separate out paper and container recyclables for collection on alternate Wednesdays. District 1 appears to set out more paper (mean of 3.47 kg/HH/wk) compared to District 18 (mean of 2.51 kg/HH/wk) and District 31 (mean of 1.58 kg/HH/wk). District 1 sets out more containers (mean of 1.71 kg/HH/wk) compared to District 18 (mean of 1.21 kg/HH/wk]) and District 31 (mean of 0.96 kg/HH/wk). This results in a higher mean recovery percentage (measured as the sum of recyclables set out curbside against the sum of discards and recyclables set out curbside) of 20.3% for District 1 compared to 11.8% for District 18 and 8.4% for District 31. This unsurprising result mirrors and closely matches the basis for our selection of the districts (see Table 1).

Not only do the residents follow the Town requirements to recycle differently (as measured by separation amounts and efficiencies) but the composition of their wastes prior to recyclables set out are different (in some ways). So, our data suggest that District 1 generates less waste overall (mean of 26.66 kg/HH/wk) than District 31 (mean of 30.21 kg/HH/wk), which appears to be less than is generated in District 18 (mean of 33.64 kg/HH/wk). But because District 1 seems to have a higher proportion of recyclable materials in its wastes (mean of 46.0% recyclable materials compared to District 18 which has a mean of 35.3% and District 31, with a mean of 34.3%), there seems to be not too much difference in the overall amount of recyclables generated by each household in the three districts. The total of recyclables in the waste stream for District 1 is a mean of 12.29 kg/HH/wk compared to District 18 which has a mean of 11.84 kg/HH/wk, although District 31 is notably lower at 10.38 kg/HH/wk, with the latter difference stemming entirely from a deficit in paper waste generation (paper mean waste generation values are 8.48 kg/HH/wk for District 1, 8.17 kg/HH/wk for District 18, and 6.73 kg/HH/wk for District 31; the difference appears negligible for containers, with mean values of 3.83 kg/HH/wk for

District 1, 3.68 kg/HH/wk for District 18, and 3.66 kg/HH/wk for District 31). So this interpretation suggests that the difference in recycling rates is directly related to the efficiency that residents separate out their recyclable materials – their degree of compliance with Town recycling regulations – because they have approximately the same amounts of recyclable materials for sorting.

It is interesting, however, that District 1 is relatively enriched in recyclables, considered as a percentage of its wastes. When residents of District 1 examine their wastes, there are relatively more recyclables available for selection, on a per item basis. That may allow for easier selection of recyclable items out of all wastes; since the District 1 waste stream proportionately contains more recyclables, if those residents separated them at the same rate as residents of the other districts, they would separate out a greater percentage of their wastes. But apparently they tend to separate out a higher percentage of recyclables, and this increases the difference in recycling rates.

Another perspective is to say that the amount of non-recyclable materials appears to be much less in the District 1 waste stream: a mean value of 14.38 kg/HH/wk for District 1, compared to a mean of 19.83 kg/HH/wk for District 31 and a mean of 21.80 kg/HH/wk for District 18. District 1 also seems to discard much less than District 18 and District 31 (a mean of 21.27 kg/HH/wk compared to a mean of 27.19 kg/HH/wk for District 31 compared to a mean of 29.41 kg/HH/wk for District 18). However, because the District 1 overall waste stream appears to contain proportionately more recyclables than the other two districts, the amount of recyclable material discarded across the three districts appears to be very similar: a mean of 7.04 kg/HH/wk in District 1, 7.86 kg/HH/wk in District 18, and 7.90 kg/HH/wk in District 31. Thus, in a sense the residents of District 1 are as wasteful as the residents in the other two districts, because their increased recovery efficiency is not enough to account for the proportionately enriched waste stream with which they begin.

Details become a little more complicated. For instance, residents in all three districts appear to be more faithful in recycling glass than any other material. District 1 residents appear to do better (a separation efficiency of 58.7%) than District 18 residents (separation efficiency of 49.3%) and the residents of District 31 (separation efficiency of 40.7%). However, because of waste generation differences, the residents of District 1 separate nearly twice as much glass on average (1.09 kg/HH/wk) than District 18 (a mean value of 0.58 kg/HH/wk) and nearly three times as much as District 31 (mean value of 0.38 kg/HH/wk). Still, District 1 residents appear to discard a little more glass than the residents of the other two districts: a mean of 0.73 kg/HH/wk compared to 0.60 kg/HH/wk in District 18 and 0.61 kg/HH/wk in District 31.

Sometimes the combination of different waste stream percentages, waste generation rates, and separation efficiencies combine in ways that hide very large differences in processes. Figure 8 illustrates how all three districts appear to have very similar mean recovery rates (in kg/HH/wk) for plastic containers, ferrous metals, and aluminum. However, presenting discard data for these same categories (Figure 9) shows that recovery performances, as measured by their opposite (the discards of recyclables) appear to be quite different across the districts. Even the small absolute difference in mean values for aluminum discards between Districts 1 and 18 (0.05 kg/HH/wk) is a 20% relative difference.

Recyclable paper was computed to be the largest single category of generated waste, based on discard and recycling sorts (although “other organics” was nearly as large in Districts 18 and 31). The mean overall waste composition percentages ranged from 22.3% (District 31) to 32.3% (District 1). Although District 1 residents separated out a mean of 3.47 kg/HH/wk, nearly

43% of what was available, this effort still left a mean of 4.95 kg/HH/wk in the disposed waste. So, after recovery efforts, recyclable paper was the second largest component in the discards (behind other organic) for District 1, which was also the case in the other two districts. In the Town's best recycling district, the discard waste stream after recycling was nearly 25% recyclable paper by weight (a mean value of 23.8%) (because District 18 and 31 began with more wastes per HH, and a smaller proportion of paper, after recycling the mean recyclable composition was less at 18.1% and 19.4%, respectively).

The Town has operated its recycling program for over 20 years. The last major change (prior to the 2014 modification to single stream recycling) was over 10 years before this sampling program. This is a mature recycling program, in a fairly affluent, fairly well-educated, and still relatively ethnically homogenous suburb. The Town has conducted continuous outreach programs, through presentations at public events, Town-wide mailings, public service announcements, school outreach and education programs, and the like. Still, compliance rates (as measured by separation efficiencies) are not robust. The best overall separation efficiency was less than 50% for the curbside recyclables (District 1); separation efficiency was less than a third for District 18 and less than one-quarter for District 31. Curbside recycling is the easiest and most convenient form of recyclables collection program, and is generally thought to have the best participation rates (Best 2009; Ebreo and Vining 2000) (compared to drop-off or buy-back programs, for instance). The poor performance by the residents means that approximately one-third of District 1 discards are recyclable, and a little more than one-quarter of District 18 and 31 discards are recyclable, too. If yard wastes are included in the tally, the percentages of discarded recoverable materials increases to 40% or so for all three districts (please note that yard waste collections over the August-October period were sporadic, and when generation rates of yard wastes increase, collection frequency increases; so we think the amount of discarded yard wastes would be found to be less on an annual accounting).

The Town's discards are transferred to a Long Island waste-to-energy plant (in another municipality). The Town pays approximately \$110/tonne for this disposal (\$88/tonne for the tipping fee, and approximately \$20/tonne for operations of the transfer station and the hauling of the wastes). In 2012 the Town disposed of 173,044 tons (~155,000 tonnes) this way. Using a conservative estimate of 25% recyclables content, this suggests that the Town spent \$4 million - \$5 million to dispose of potentially recyclable materials.

Another perspective to consider is lost revenue. District 1 households discard a mean value of 1.00 kg/wk of PET and HDPE containers and aluminum. The similar mean value for District 18 is 1.20 kg/HH/wk and for District 31 it is 1.36 kg/HH/wk. This means that between 50 and 75 kg of these valuable recyclables are discarded by each household each year. The value of the materials on the secondary market has been well in excess of \$500/tonne for several years. This suggests each household discards more than \$50 worth of plastics and aluminum each year, conservatively. The district waste fee charged by the Town is approximately \$375/HH/yr; therefore, if these revenues were realized instead of being lost in the discards, residents might receive as much as a 15% reduction in direct waste costs.

The irony is that valuable plastics and aluminum are recovered at much lower rates than glass is. Glass was recovered at higher rates than all other materials except for yard waste. Glass has no real reuse market in the New York metropolitan area. The management of recovered glass represents an ongoing problem for all local waste systems. The most common reuses for glass are as structural materials in landfill cell management (berms and roadways). Another common management technique has been to stockpile the glass and wait for offers. Yard waste, on Long

Island, has substantial fees associated with its management at compost sites ($60/tonne and higher, often with extra transportation costs). Thus, the two materials source separated with the greatest efficiencies by Town residents either have no or negative market value.

Poor performance by recycling programs is not limited to the Town of Brookhaven. USEPA data (2013) suggest 11.5% of the total residential, commercial, and institutional discards waste stream is newspaper, corrugated cardboard, and PET (#1) and HDPE (#2) plastic, ferrous, and aluminum containers. The New York City waste sort (RW Beck 2005) found that about 23% of New York City residential refuse consists of materials designated by the City as curbside recyclables. The study also found that 47% of street basket waste could have been recycled under the City's curbside recycling program. The last time San Francisco published its waste composition, the discards from the residential and small business sector (the Fantastic Three program) were determined to be approximately 50% recyclable (although San Francisco has an expansive definition of recyclable materials) (ESA Assoc. 2006).

5.0 Conclusions

We sorted approximately 6 tonnes of waste and recyclables from three waste districts in the Town of Brookhaven. One district was a good recycling district, the other was a median recycling district, and the third had poor recycling performance (relative to performances in the other 32 waste districts in the Town).

We made some unsurprising findings. Paper constituted most of the curbside recyclables, which agrees with 20 year data sets from the Town MRF, and echoes USEPA reports. The recycling district with the highest recovery rate recovered a higher percentage of its available recyclable materials, and the district with the lowest recycling rate had much lower recovery efficiencies. Glass was the largest constituent of the container recyclables, again in agreement with Town and national data compilations.

We made some unexpected discoveries. Our data suggest that containers are recovered at a higher rate than recyclable paper, overall. But separation efficiencies vary for different materials, and some container recyclables (such as aluminum) were recovered at fairly low rates (a mean separation efficiency of 14.7% for aluminum in the poorest performing district). Generally, less than half of recoverable materials was separated in the best recycling district; that value was closer to one-quarter of the available material in the poorest performing district. This also meant that the discards stream was relatively rich in recyclables: at least one quarter and as much as one third of the discards were curbside recyclables.

The composition of the total waste stream, pre-recycling, was different in many aspects for the three districts. In terms of percentage composition, the better recycling district had an enriched environment for recycling, which coupled with its higher efficiency rates led to appreciably more recovered materials.

Although the better recycling district had a smaller overall waste stream and then recycled available material with a higher efficiency, the difference in waste composition meant that its discard stream appeared to hold more recyclables of some kinds (such as glass) than the other districts. So although the overt compliance with Town recycling rules, as measured by separation efficiencies, was much higher in the best recycling district, those residents still left a great deal of recyclable materials in their waste, sometimes more (by some measures) than the poorer performing districts.

We have not investigated the causes of the differences in waste composition. We noted that there are some demographic differences across the districts, but our sample size of three is too small to seriously investigate that complicated issue. Our subjective, qualitative collective observation is that the wastes from the three districts are different in kind, and that some differences appear to be linked to socio-economic factors, such as more expensive wine bottles and more newspapers in District 1. But our slice of these areas is somewhat limited: we estimate we sorted discards from some 60 to 150 households in each district over the 10 weeks. That is a large sample, but our formal waste categorizations are a little too gross, and our observations too subjective to parse disposal habits that closely. New York State is also a "bottle bill" state, with a $0.05 deposit required at the purchase of many container drinks. Differential returns of deposit containers could also affect the measured waste stream differences (again, subjective, qualitative observations were that all three districts disposed of many deposit containers).

It is clear that this long-standing, fairly typical suburban recycling program is not succeeding at recovering most recyclables in the waste stream. There are many who believe that reuse of materials ("closing the loop") is essential if we are to be more sustainable in our use of the Earth's resources. The Town's program is legally mandatory, but admittedly the Town is loathe to fine its residents for non-compliance with recycling regulations. A local, but Long Island-wide political consensus was reached in the 1980s and 1990s that an active enforcement program with recycling would not help re-elect current office holders, and so there has been little enthusiasm to increase rates that way. Pay-As-You-Throw (either weight or volume based fee systems) has faced opposition, as well, despite some compelling evidence that it leads to higher recycling rates (Skumatz 2008), as managers believe capital costs for provided container systems or difficulties in distributing bags in decentralized suburbia outweigh perceived benefits. The Town of Brookhaven has instituted single-stream recycling. The increased convenience of one set out a week of all recyclables (no one needs to remember the alternation of materials and weeks) is expected to increase performance of the program. We sorted wastes for the three districts in the fall of 2014 and hope to report our findings soon.

If higher recovery rates are required, we believe that post-collection sorting should be considered. The Town of Brookhaven is a good example of the large amounts of materials left behind by traditional curbside recycling programs. A recent report on post-collection waste processing in San Jose (CA) found that the combination of continued residential source separation and additional post-collection recovery efforts appeared to work well (SWANA Applied Research Foundation 2013). Our analysis of recycling economics (Tonjes and Mallikarjun 2013) found that the economics of source separation appear to be positive at almost all levels, even the lowest recovery percentages, as long as truck allocations are optimized and there is at least a $20 difference between tipping fees at the disposal point and the recyclables collection point. For the Town of Brookhaven, disposal fees are approximately $110/tonne, and recyclables earn money. Disparities such as these are found throughout the northeast US. So we believe curbside collection, which produces higher quality recovered materials, will continue to make economic sense, but needs to be augmented by post-collection recovery systems. We believe it is time to clean up after the residents, after they have done their best.

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Tables

	District 1	District 18	District 31
Carter	Jody	T&D Doherty	European
Households (2012)	2,316	4,059	6,234
Population estimate*	6,173	16,365	26,163
2011 Separation Percentage	20.5%	12.2%	8.5%
2011 Discards (kg/HH/wk)	26.7	33.8	31.6
2011 Paper Recyclables (kg/HH/wk)	3.5	2.7	1.6
2011 Container Recyclables (kg/HH/wk)	2.0	1.4	1.1
2011 Yard Waste (kg/HH/wk)	6.4	7.9	5.6
2011 Separation Percentage (including Yard Waste)	35.9%	28.8%	22.3%
Median per capita Income**	$51,796	$34,207	$36,963
Some College Education***	86.7%	62.7%	40.2%
Black Population*	1.1%	1.1%	5.3%
Hispanic Population*	7.0%	11.4%	19.1%

* estimated based on interpolations from 2011 ACS (American Community Survey) data from census tracts that show partial or complete overlap with the geographic extents of waste districts; the following census tracts were used – CT 158002 for District 1; CT 158512, 158511, 58508 for District 18; and CT 159511, 159506, 159408, 159404 for District 31

** Derived from the selected census tracts (see above)

*** Derived from the selected census tracts; 25 years old and older

Table 1. Selected characteristics of the sampled waste districts

Category	Materials included
Mixed paper*	Newspaper, office paper, magazines, mail, boxboard (non-corrugated boxes)
Corrugated*	Corrugated boxes and brown/kraft paper bags
Plastic Bags	Included sheet plastic and garbage bags (included some retained food and other organic matter)
#1/#2 Plastic*	PET (#1) and HDPE (#2) rigid plastic containers
Rigid Plastic	Plastic containers and materials not #1 and #2 plastic containers
Yard waste	Branches, twigs, leaves, grass, flowers
Food waste	(included some packaging materials)
Wood	Manufactured wood: lumber, pallets, furniture
Other organics/ combustibles	Textiles, rubber, leather, and other primarily burnable materials not included in the above component categories, especially soiled paper, diapers, food cartons
Ferrous*	Magnetic metal containers, aerosol cans, small appliances
Aluminum*	Fabricated aluminum, aluminum cans, and aluminum foil
Glass*	Glass containers (broken or intact)
Other inorganics	Non-combustibles, such as rock, sand, dirt, concrete, ceramics, plaster, non-ferrous metals not containers, aerosol cans, or foil, metal chunks, sheet glass and other glass, bones
Electronics	Electrical/electronic equipment

Table 2. Sorting categories (* = recyclables)

District	Tonnes Collected, Source Separation	kg/HH/wk, Source Separation	Mean kg/HH/wk in Discards	Separation Efficiency
1	84.41	2.77	1.28	70.3%
18	97.98	1.84	3.88	29.9%
31	137.58	1.68	2.05	44.0%

Table 3. Yard waste separation amounts, rates, and separation efficiencies, August-October 2012

Figure Captions

Figure 1. Town location map

Figure 2. Mean recyclables separation rates (kg/HH/wk) (with std. dev.) (black = District 1, white = District 18, gray = District 31) (COL = amount collected curbside; REC = recyclables; ALL RP = mixed paper + corrugated; CONT = #1/#2 plastics + ferrous + aluminum + glass; GLS = glass; TRP = #1/#2 plastics)

Figure 3. Mean total waste stream composition (total waste stream = discards + curbside recyclables) (kg/HH/wk) (with std. dev.) (black = District 1, white = District 18, gray = District 31) (TOT = total; REC = recyclables; NONREC = non-recyclables; CONT = #1/#2 plastics + ferrous + aluminum + glass; REC-YRD = recyclables + yard waste)

Figure 4. Mean total waste stream composition (total waste stream = discards + curbside recyclables) (kg/HH/wk) (with std. dev.) (black = District 1, white = District 18, gray = District 31) (ALL RP = mixed paper + corrugated; BGS = plastic bags; TRP = #1/#2 plastics; RGD = rigid plastic; YRD = yard wastes; FD = food wastes; WD = wood; ORG = other organics/combustibles; FE = ferrous; AL = aluminum; GLS = glass; INORG = other inorganics; ELC = electronics)

Figure 5. Mean total waste stream percentages (amount of discarded and curbside recycled materials/[total discards + all curbside recyclables]) (with std. dev.) (black = District 1, white = District 18, gray = District 31) (REC = recyclables; NONREC = non-recyclables; ALL RP = mixed paper + corrugated; CONT = #1/#2 plastics + ferrous + aluminum + glass; REC-YRD = recyclables + yard waste)

Figure 6. Mean total waste stream percentages (amount of discarded and curbside recycled materials/[total discards + all curbside recyclables]) (with std. dev.) (black = District 1, white = District 18, gray = District 31) (ALL RP = mixed paper + corrugated; BGS = plastic bags; TRP = #1/#2 plastics; RGD = rigid plastic; YRD = yard wastes; FD = food wastes; WD = wood; ORG = other organics/combustibles; FE = ferrous; AL = aluminum; GLS = glass; INORG = other inorganics; ELC = electronics)

Figure 7. Separation efficiency percentages (amount of curbside recyclables/amount of curbside recyclables in total waste stream) (with std. dev.) (black = District 1, white = District 18, gray = District 31) (REC = recyclables; ALL RP = mixed paper + corrugated; CONT = #1/#2 plastics + ferrous + aluminum + glass; TRP = #1/#2 plastics; FE = ferrous; AL = aluminum; GLS = glass)

Figure 8. Mean recyclables separation rates (kg/HH/wk) (with std. dev.) (black = District 1, white = District 18, gray = District 31) (TRP = #1/#2 plastics; FE = ferrous; AL = aluminum)

Figure 9. Mean discards rates (kg/HH/wk) (with std. dev.) (black = District 1, white = District 18, gray = District 31) (TRP = #1/#2 plastics; FE = ferrous; AL = aluminum)