The Emergent Risks of Food Waste Recovery: Characterizing the Contaminants in MSW Organics from Different Sources

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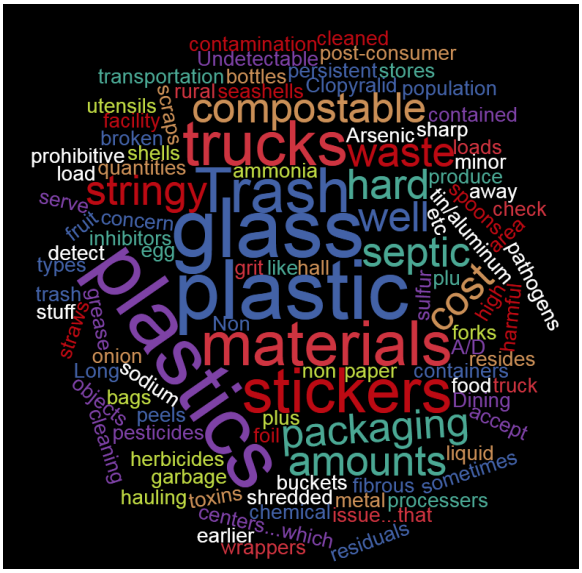

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Executive Summary

Composting and anaerobic digestion of food waste provide two means to recover and recycle some of the nutrients required to grow food. The use of these methods also reduces the amount of food waste going to landfill and incineration. Many communities and states are enacting programs and policies to reduce food waste and capture as much as possible for recycling. To ensure the recycled materials are safe and free from contaminants that could amplify within a circular food system, it is important to understand where and how contaminants are introduced into the system, and how policies affect the degree of contamination.

Source separated food waste was collected from two regulatory environments (mandated food waste separation vs unregulated) and six source types (grocery, hospital, school, restaurant, retirement community, residential) to test the hypothesis, based on previous stakeholder engagement, that voluntary participation in food waste recycling would result in lower contamination rates. Physical contaminants, heavy metals, organohalogens, pathogens and antibiotic resistance genes (ARGs) were measured. Food waste processors were also surveyed about their perceptions about contamination and associated risks.

Testing of processed food waste after removal of physical contaminants showed that mandated food waste recycling did **not** increase contamination rates. This finding contradicted food waste recyclers' perception that organics recycling mandates would result in higher levels of contamination. Source type influenced carbon, nitrogen phosphorus, calcium, and copper concentrations, *tet* (M) abundance, and physical contamination in our samples.

Physical contamination was high with over 80% of samples containing some non-food waste, and 57% containing non-compostable items such as plastics. The chemical composition of the processed food waste was highly variable. Most heavy metals were below the EPA method detection limit, and those that were detectable were well below any global regulatory limits on land application of compost or biosolids. Pathogens were also present, when detected, at very low levels, although microbial community analysis by high throughput sequencing showed that genera that contain pathogens were present in most of the samples tested, so care must still be taken while handling these materials. Halogenated organic contaminants were detectable by the EOX method in 14% of samples. PFBA, a perfluorinated chemical, was detected in 57% of the samples tested. Detection of these compounds is of concern due to their potential for bioaccumulation in the circular food system. Antibiotic resistance genes for beta lactams and tetracyclines were detected in almost all samples. This is cause for concern because increasing resistance is developing in pathogens, and food may be a vector for this transfer to humans.

The level of contamination in our source separated samples was relatively low, with the exception of some antibiotic resistance genes, however our processing method might have underestimated packaging-associated contamination. This should be explored further on depackaged food waste and field-pre-processed input materials, along with studies on the fate of these contaminants during treatment. Surveys and interviews suggest food waste managers were generally more concerned about physical contamination of food waste than trace contaminants, while our results show that awareness should be raised about PFAS and potentially ARGs, which were detectable in a majority of our samples.

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Introduction

About a third of the food produced globally goes to waste each year (Gustavsson, Cederberg, Sonesson, Otterdijk, & Meybeck, 2011). To approach a more sustainable food system in the United States, our system must become more energy, water and material-efficient. The ideal model is a circularized food system that eliminates waste by returning nutrients to agricultural soils while minimizing water and energy use. To move toward this more sustainable system, more people need to participate in the recovery of food waste. The safety of such a circular system, however, requires the minimization of contamination to avoid amplification of those contaminants over time. Different sources and strategies for food waste recovery produce materials of varying quality. The market value and social acceptance of land application of the treated residuals depend on both the quality of the product, which is related to input material quality and processing, and the end-users' trust in the product. With more organic material collected from different points along the food system, there is the possibility for new - unforeseen, unregulated and emergent - risks to arise.

Many contaminant types have been detected in food (Aslam, Diarra, Service, & Rempel, 2009; Bodiguel et al., n.d.; Esposito et al., 2018; Sonnier et al., 2018). Heavy metals are micronutrients which can be toxic at high concentration (Epstein, Chaney, Henrys, & Locans, 1992; Garcia, Hernandez, & Costa, 1990). Organohalogens are highly persistent organic chemicals and many are bioaccumulative (Bodiguel et al., n.d.; Ghisi, Vamerali, & Manzetti, 2019). Foodborne pathogens cause foodborne illness (Bintsis, 2017). Antibiotic resistance genes (ARGs) confer resistance to antibiotics. Tremendous use of antibiotics as growth promoters for livestock production has led to the emergence and amplification of ARGs in the environment and in food. The threat to the efficacy of therapeutic antibiotic use is realized when these genes are acquired by human pathogens, conferring resistance to the drugs used to treat infection (Pepper, Brooks, & Gerba, 2018). If contaminated food is wasted, any of these contaminant types may be recycled and accumulate in the circular food system. To our knowledge this is the first study to assess all of these classes of contaminants on a single set of food waste samples.

The goal of this work was to identify the risks associated with more cyclical food systems and to identify appropriate management procedures, policies, and programs to reduce these risks. Our research objectives were: (1) to screen for contamination of input organic wastes from different sources (residential, hospital, school, grocery, seniors residence, and restaurant wastes) and different regulatory environments (regulated and unregulated); and (2) to survey a group of waste management practitioners and stakeholders to explore risk perceptions associated with various feedstocks and practices.

The first objective was testing the common assumption that food waste streams are more likely to be contaminated when food scrap recycling is mandatory rather than voluntary. The contaminants that were tested included visible/physical contaminants, heavy metals, organohalides, pathogens and antibiotic resistance genes. We also wished to see if different food waste sources produced different levels of contamination in order to inform education and management options. The second objective was measuring perceptions about food waste contamination that could be compared with the results of our screening measurements to determine if there is any misalignment between perceived and measured contamination, thus indicating the need for targeted education or improved contaminant mitigation strategies.

Results and Discussion

Contaminant screening

Samples were collected from Maine (ME – all sources unregulated), Massachusetts (MA – all but residential food waste regulated) and Vermont (VT – regulated except for residential at the time of sampling). While 72 samples were collected, only 71 were submitted for chemical and biological contamination testing because one sample (school, unregulated) was composed entirely of trash. Of the source types there were 14 grocery samples (7 regulated, 7 unregulated); 10 hospital samples (5 regulated, 5 unregulated); 12 each from schools, retirement communities and restaurants (6 each regulated and unregulated, except one unregulated school sample was all trash), and 12 residential samples (all unregulated but collected from all states).

Physical contamination

Any non-food waste materials were considered contaminants, weighed and reported as % contamination by wet weight. Eighty two percent of samples, had some form of contamination. Fifty seven percent of samples contained non-compostable materials like plastics, gloves, and fruit stickers. Except for one outlier sample from a school in Maine (unregulated) which contained all trash, non-food materials accounted for up to 39% of the mass of samples. Because grocery stores in Maine use a processor with a depackager and do not remove packaging, these samples were removed before statistical comparison of regulated vs unregulated wastes. The median mass of contamination in Maine samples was higher than in the regulated states, although when all grocery samples were removed from analysis the difference was not significant (Figure 1), indicating that **mandated source separation does not result in greater contamination** as we had hypothesized. This result could point to effective communication and outreach strategies in the roll-out of the food waste diversion efforts in Massachusetts and Vermont, or a mistaken impression by the processors we interviewed.

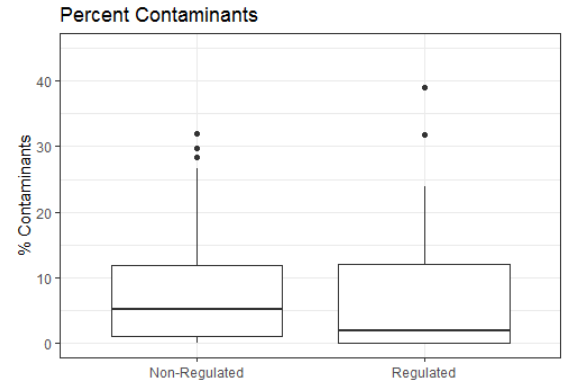

Figure 1: Percent by mass of physical contaminants Boxplots show the 25, 50 and 75% percentiles, with "whiskers" denoting the range except for outliers (dots >3/2 times interquartile difference)

Source type did influence physical contamination to some degree. Figure 2 shows the spread of physical contamination by source type. The (regulated only) grocery samples had low contamination and variability. Residential, restaurant and school samples were the most variable.

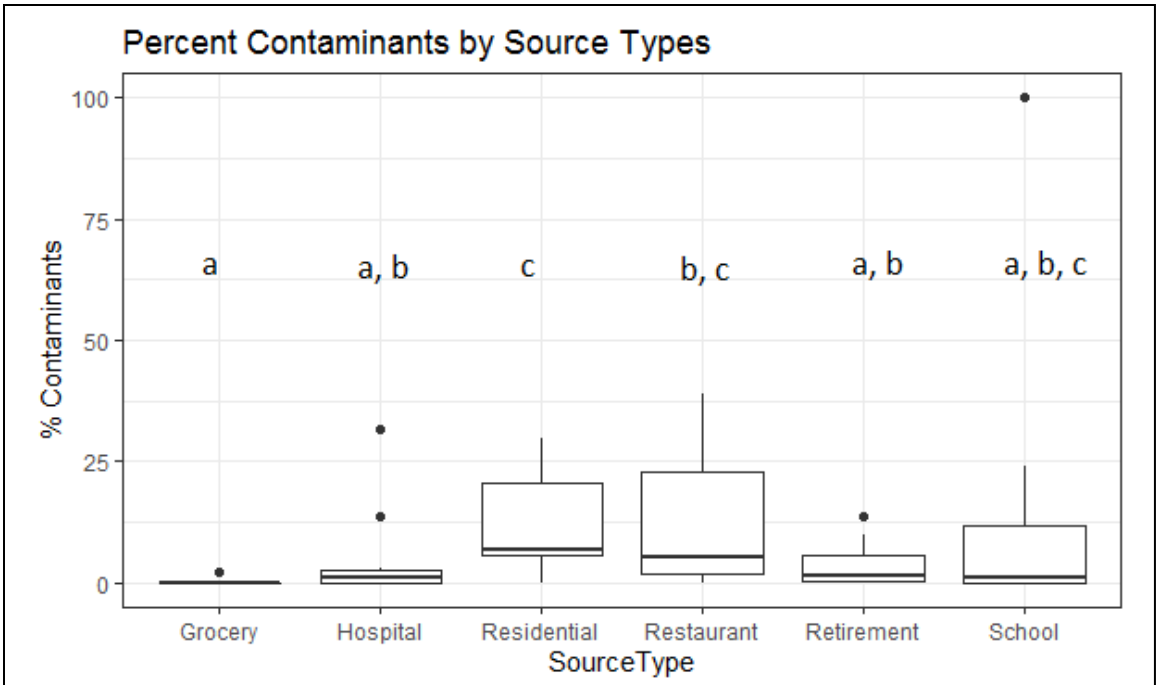

Figure 2: Percent physical contamination by source type. Sources that share a letter are not significantly different. The packaged grocery waste from Maine was omitted from this graph, so the number of samples by source type (left to right) were 7, 10, 12, 12, 12, and 12.

General sample characteristics

Characteristics varied greatly among samples. Regulatory environment was not a significant factor but there were some differences among sources. Table 1 provides a summary of sample characteristics, and Figure 3 shows the spread of data by source type.

Table 1: Results of the compost test (n=71)

Parameters	Range	Average ($\bar{X}$)	S.D.	C.V.(%)
Conductivity (mmhos/cm)	1.90-12.10	7.02	2.04	29
Carbon (%)	29.40-66.90	47.86	5.48	11
Nitrogen (%)	0.53-9.08	2.81	1.31	47
C: N	5.52-81.70	20.31	10.46	52
pH	3.8-6.3	4.58	0.54	12
Phosphorus (%)	0.08-0.74	0.27	0.12	44
Potassium (%)	0.22-3.3	1.04	0.74	71
Magnesium (%)	0.03-0.26	0.11	0.05	45
Calcium (%)	0.04-16	2.11	3.99	189
Boron (ppm)	0.05-29	8.30	6.59	79
Iron (ppm)	13.10-546	71.19	80.77	113
Manganese (ppm)	-0.54-45	13.95	9.17	66
Total Solids (%)	5.90-79.20	26.23	11.94	46

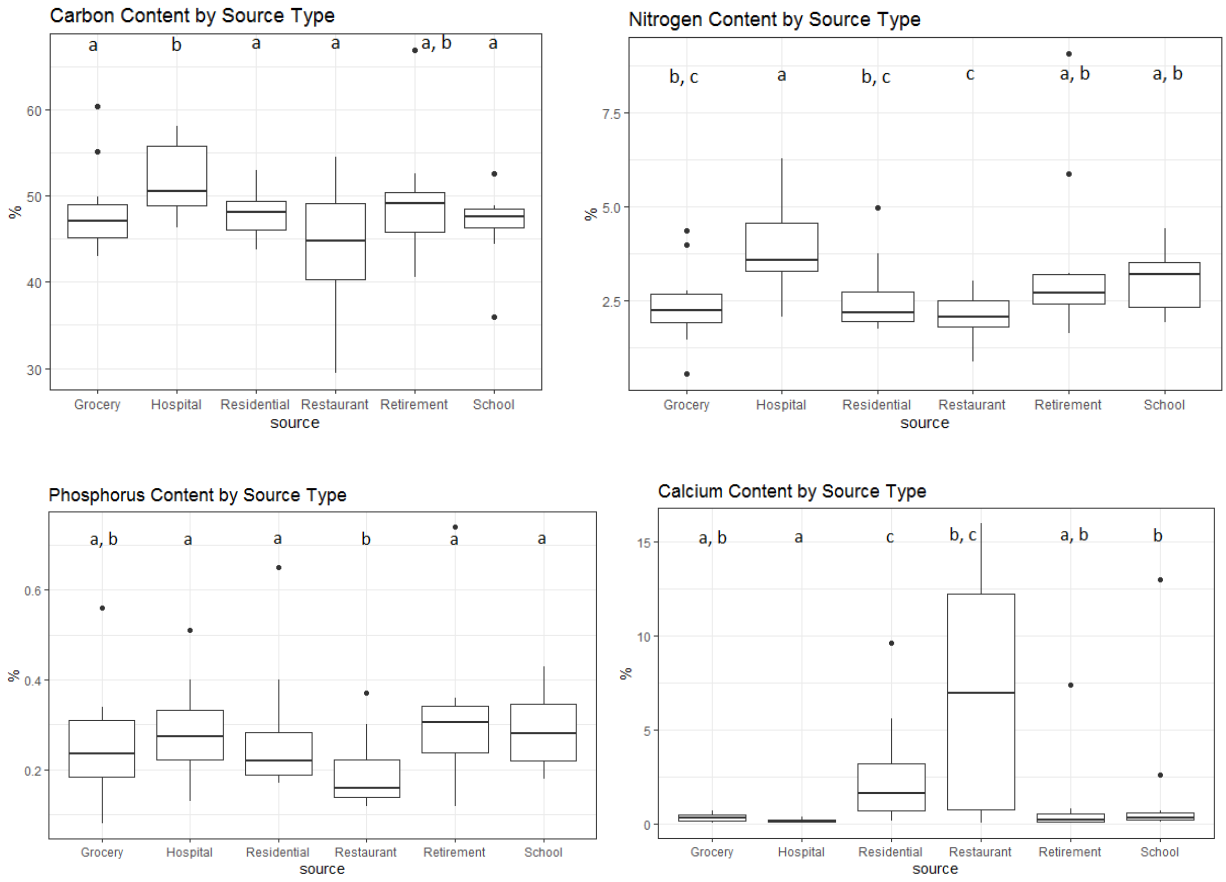

Figure 3: Nutrient Concentrations by source type. All samples were included in these analyses. Grocery n = 14, Hospital n = 10, Residential n = 12, Restaurant n = 12, Retirement n = 12, School n = 11.

Heavy metals

Heavy metals are typically present in soils and may be taken up by plants, however the levels are usually low in the absence of industrial pollution (Margenat et al., 2018). They may also be introduced into foods through contact with packaging materials, such as cans and recycled packaging materials (Ikem & Egiebor, 2005; Whitt, Brown, Danes, & Vorst, 2016). Metals were chosen based on their association with industrial contamination (Cd, Cr, Cu, Pb, Zn) and electronics waste (Ti, Sn). Of the eight heavy metals analyzed, five (Cd, Pb, Cr, Ti, Sn) were below the detection limit of the EPA method in all samples, one sample (grocery, ME) had 2.1 mg/kg Ni. The Cu concentration ranged from 0.251-13.8, with an average of 4.4 mg/kg. Zn averaged 21.19 (range 4.94-71.1) mg/kg. The regulatory environment did not affect

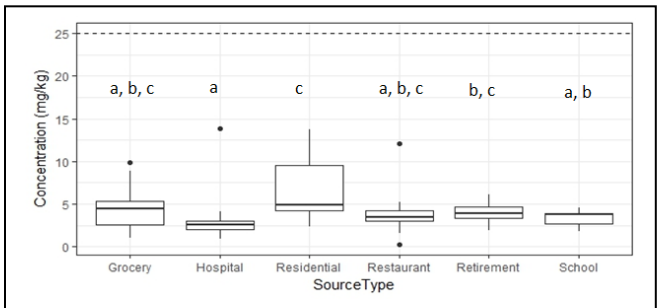

Figure 4: Copper concentration by source type

the concentration in either case, but there were some differences in copper concentrations by source type (Figure 4). Residential samples had significantly higher copper than hospital, restaurant or school samples; and retirement community samples were significantly higher than hospital samples. Despite the source type differences, all values agreed with reported values in food, and were well below any global regulatory limits for application to land, indicating **that heavy metal contamination was not a significant problem** in our source separated food waste samples.

Organohalogenated compounds

Organohalogens are synthetic organic compounds with halogen substitutions that make them chemically stable, which contributes to their usefulness, and environmentally persistent (Alharbi, Basheer, Khattab, & Ali, 2018). Potential sources of organohalogens include industrial air, water and soil pollution, and pesticide and herbicide use on crops (Batt, Wathen, Lazorchak, Olsen, & Kincaid, 2017). Organohalogens were measured in bulk using the extractable organic halogens (EOX) method, which measures chlorine, bromine and iodine associated with organics extracted from a solid matrix, expressed as mass of chlorine/mass of material. Since many halogenated organic compounds are toxic, bioaccumulative and persistent, this is a means of screening for pollutants that could accumulate in the food system. Most of the samples were below the detection limit of 5 mg/kg wet weight, but 10 samples had measurable values that ranged from 5 – 89.7 mg/kg (ww), with all but the highest (ME restaurant) less than 12 mg/kg. Regulatory environment and source type were not significant factors. The presence of these compounds is of concern due to the potential for organohalogens to bioaccumulate in the food system and the fact that 90% of human exposure to organochlorine compounds is through food (Ábalos et al., 2019; Fair et al., 2018; Ferrante et al., 2017; Schecter et al., 2010). That stated, these values are all well below the adsorbable organic halogens (AOX, a similar method) regulatory level of 500 mg/kg (dw) for biosolids use on land in Europe (Mininni, Blanch, Lucena, & Berselli, 2015)(Mininni et al., 2015).

Per- and poly-fluorinated organics (PFAS) repel both water and oil, so they are used in paper coatings and packaging; as surface protection products used on carpet and clothing to resist stains and water; as nonstick coatings on cookware; as industrial surfactants; and in the manufacture of fire-resistant foams (Fair et al., 2019; Schecter et al., 2010). Because of their use in food packaging and widespread presence in water, a subset of 25 samples were tested for PFAS, which are not efficiently measured by the EOX method. Of these samples, 14 (56%) had detectable perfluorobutanoic acid (PFBA average 0.6; range 0.11-1 µg/kg); two contained perfluorohexane sulfonic acid (PFHxS 0.11 and 0.15 µg/kg); and one contained perfluorononanoic acid (PFNA 0.28 µg/kg) (Figure 5).

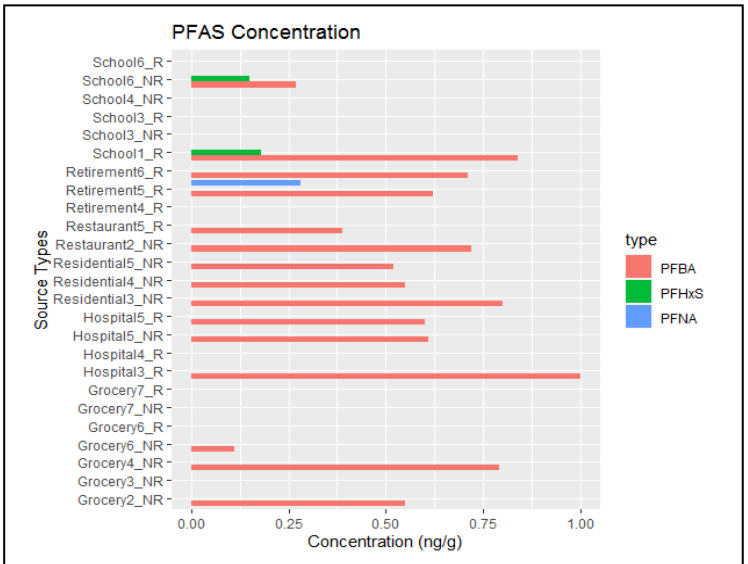

Figure 5: PFAS concentrations (µg/kg ww)

The presence of these compounds is of concern due to their impacts on health and potential to bioaccumulate (Ghisi et al., 2019). PFBA is among the compounds that replaced PFOA and PFOS upon the voluntary withdrawal of these compounds from production, and has similar toxicity (Eun et al., 2020). The range we observed was within the range observed in a study on composted municipal organic waste in the US (Choi, Lazcano, Youse, Trim, & Lee, 2019) , but lower than observed in a study done in China (Su et al., 2017). PFHxS is a longer chain compound that has been shown to have bioaccumulation potential (Ghisi et al., 2019). Interestingly, PFOS and PFOA were not detected in any of our samples despite being the most commonly detected compounds in many past studies. This finding could indicate that their concentration in the food system is declining since their withdrawal from the market (Ghisi et al., 2019; Schecter et al., 2010). Because PFAS are components of some food packaging materials (Schaider et al., 2017) and have been shown to migrate into foods, packaging could be a source of the PFAS we observed in this study (Pérez et al., 2014) even though packaging was removed prior to processing our food samples. The **large percentage of samples with detectable PFAS is cause for concern**.

Pathogens

Our samples were screened for the presence of three common foodborne pathogens: *Listeria monocytogenes*, non-typhoidal *Salmonella*, and shiga-toxin producing *Escherichia coli* (STEC). STEC was not detected in any of our samples, despite being a common foodborne pathogen. Two samples (~3%; one grocery and one residential sample) had low levels (below the limit of quantification) of *Salmonella*, which caused the highest number of deaths due to foodborne illness in 2017 (NORS CDC, 2019). Also of concern was the presence of *Listeria monocytogenes*, a cold-tolerant microbe which is another leading cause of death from foodborne pathogens (Barbau-piednoir, Botteldoorn, Yde, Mahillon, & Roosens, 2013; NORS CDC, 2019), in eight samples (~11%). Of these, only three could be quantified (1249-19140 copies/g (dw); relative abundance $1.72x10^{-8}$ to $2.41x10^{-6}$). The samples with detectable *Listeria* came from hospital (2), residential (1) and grocery store (5) waste. Thus, while foodborne pathogens were detected in a few samples, there was a relatively **low incidence of pathogens in the food wastes we tested**.

Eighteen waste samples were subjected to high-throughput sequencing to determine if there were microbes from these and other genera known to contain foodborne pathogens. The genera that were present in our samples were *Yersinia, Proteus, Bacillus, Clostridium, Escherichia/Shigella, Vibrio and Staphylococcus* (Figure 6), indicating that future efforts should be made to determine if pathogenic species in these genera are abundant in food waste. *Yersinia* was the most abundant and was also found in most of the samples, however this is rarely the cause of outbreaks (no outbreaks, illnesses, hospitalizations or deaths ascribed to *Yersinia* in 2017 (NORS CDC, 2019)), and the genus has a number of species that are associated with food animals but are not pathogenic to humans (Sulakvelidze, 2000). Although *Listeria* was detected in some of our food waste samples by qPCR, it was not detected in this method because it was below the detectable relative abundance ($3.3x10^{-5}$).

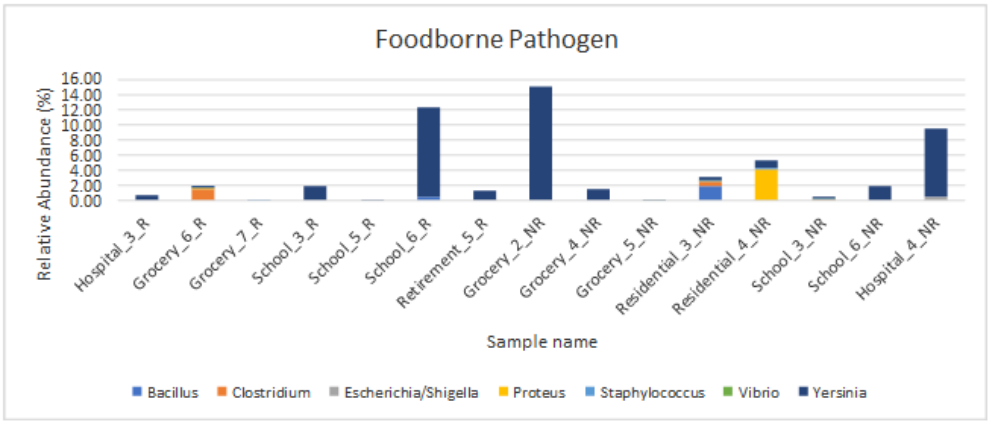

Figure 6: Relative abundance of genera with known foodborne pathogens

Antibiotic resistance genes

Three ARGs were screened in our study due to the use of the corresponding antibiotics in livestock (penicillins and tetracylines) or the importance of continued sensitivity of pathogens and novelty of the resistance gene (polymyxin). They are *tet*(M), bla_{TEM} and *mcr-1*. *Mcr-1* confers resistance to polymyxin E, which is considered the last resort drug to combat multidrug-resistant pathogens. Plasmid-borne *mcr-1*-mediated resistance has recently spread throughout the world (Caniça, Manageiro, Abriouel, Moran-Gilad, & Franz, 2019). No *mcr-1* was detected in any of our samples, which was similar to the results of a study by Mavrici, Yambao, Lee, Quiñones, & He, (2017) who screened 1000 *E. coli* isolates obtained from wildlife, produce and environmental samples from California for *mcr-1*, and all came out negative. The use of small doses of antibiotics for growth promotion, feed proficiency enhancement and prophylaxis has been identified as a contributing factor for the development and increase of antibiotic resistance (Van, Yidana, Smooker, & Coloe, 2019). In the US, colistin is not used in food animals whereas it has been extensively used in other countries (Sun et al., 2017). Plasmid-mediated colistin resistance was first isolated in 2015 in China (Liu et al., 2016). It has been noted that countries with uncontrolled and aggressive use of colistin have higher prevalence rate of *mcr* genes. The prevalence rate of *mcr* in the US is relatively low, which might be due to lack of selection pressure (Mavrici et al., 2017), and could explain the absence of *mcr-1* in our study.

Bla_{TEM} confers resistance to beta-lactams which include penicillin and its derivatives and cephalosporins (Rood & Li, 2017). Bla_{TEM} was detected in 97% of samples, although six of these detections were below the limit of quantification. The absolute abundance of bla_{TEM} in our samples was from <1000-6.66 x 10^9 copies per gram (dry weight) with an average of 6.81 x 10^8 copies/g dw. Its relative abundance, meaning the number of genes per microbe (measured as small subunit rRNA genes), ranged from nd-1.03 with an average of 2.69 x 10^{-2}. This indicates that on average about 3% of the microbes in the food waste contained beta-lactamases, although the incidence varied significantly. There was no significant difference between sample regulatory environments or source types.

Tetracycline resistance genes are abundant in food and foodborne bacteria. Sixty-eight (96%) samples were positive for *tet(*M), however 11 were below our limit of quantification. Wilcox rank sum test showed no significant difference between regulatory environments or source types, except the hospital mean was higher than grocery samples. The relative abundance of *tet*(M) was

from nd-1.53x10^{-1}copies/microbe (0-15% contain the gene) with an average of 9x10^{-3} (just under 1%). This average relative abundance is 4-5X higher than was observed in a study on *tet(M)* abundance in Chinese agricultural and greenhouse soils (Zeng, Sun, & Zhu, 2019). The absolute abundance of *tet*(M) ranged between non-detection to 1.53x10^{10} with an average of 6.79x10^{8} copies/g dw.

β-lactams and tetracycline antibiotics are among the oldest antibiotics, have been extensively used including in livestock rearing in the US, and resistance genes were detected and isolated long ago (Economou & Gousia, 2015; Roberts & Schwarz, 2015; Aslam et al., 2009), including in food. This could help explain the near ubiquitous detection of these antibiotic resistance genes in our food waste samples. That said, a higher abundance in food waste than in soil is cause for concern. The **abundance and frequency of detection of *tet(M)* and bla_{TEM}** and uncertainty about their fate during treatment **warrants further investigation** to assess the level of risk they present to the food and health care systems.

Survey Results

Surveys were sent to 118 composting and anaerobic digestion facilities in Maine, Vermont and Massachusetts, from which we received 33 responses (28% response rate). The sample was heavily weighted toward composting operations with only 4 digester operations represented. The geographical balance was better with 14 responses from Maine, 11 from Massachusetts, and 8 from Vermont. Seventy percent of the respondents only accepted source separated waste; 12% accepted packaged food waste, which was first processed in a depackaging machine, and 9% accepted comingled waste materials.

The majority of respondents accepted food processing waste (19/33), followed by grocers (14), restaurants (13), institutions (13) and residences (10). Figure 7 shows a circular food system. The order of source materials accepted as shown in Figure 8 potentially reflects perceived increases in the risk associated with input materials farther along the food system, in addition to increased cost of collection from smaller sources.

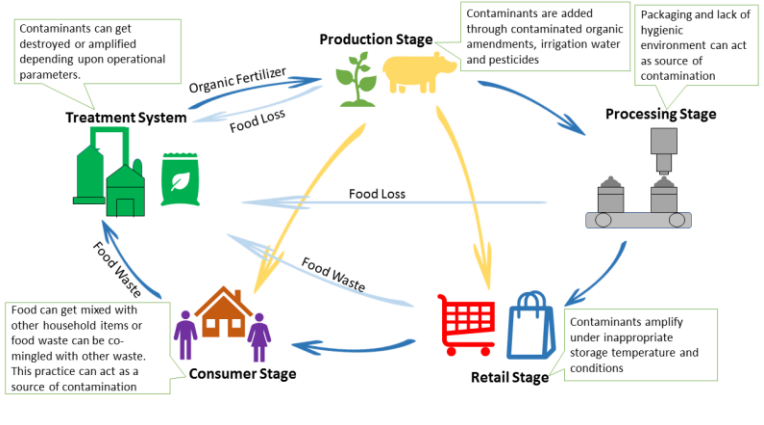

Figure 7: Circular food system and potential sources of contamination

In response to an open-ended question about the types of contaminants that are of concern to processors, the responses could be categorized as trash (20 mentions) > chemicals (6 mentions, including arsenic, pesticides, and cleaning chemicals) > sharps (5 mentions) > process inhibitors (ammonia, sodium, sulfur, fibrous materials, grit). When asked about which contaminants presented the most significant *risk*, trash again topped the list (12) due to the difficulty screening them out and lowered value of the product contaminated with plastic or glass. Other contaminants were considered to be lower risk, except three processors listed chemicals like pesticides because they are difficult to detect and can affect reuse; two listed process inhibitors like certain types of food or ammonia that can

force a facility to landfill or reprocess an entire batch; and finally one mentioned pathogens that were problematic because they are not tested and could represent a liability.

Among different sources of food waste, **perceived risk increased along the food system**, with the consumer stage (institutions, residential and restaurants) perceived to be higher risk than grocers and food distributors, which are higher risk than food processors and producers (see Figure 8). Part of this distinction is related to the inclusion of consumers in the sorting process and the nature of post-consumer food waste (food scraps and leftovers) which are more likely to be mixed with non-food waste.

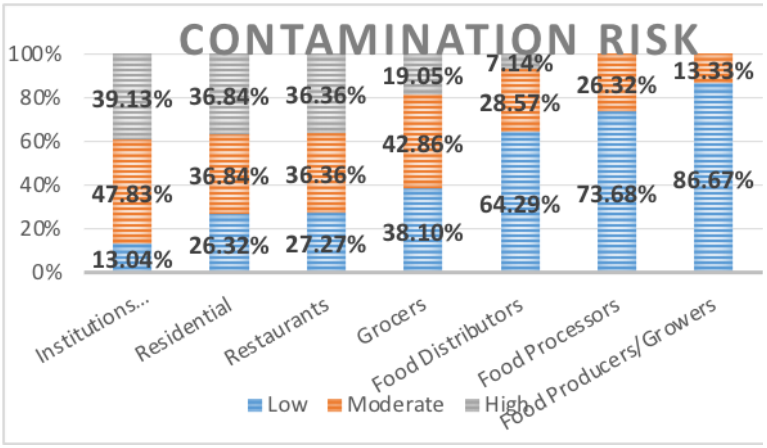

Figure 8: Perceived contamination risk from different sources

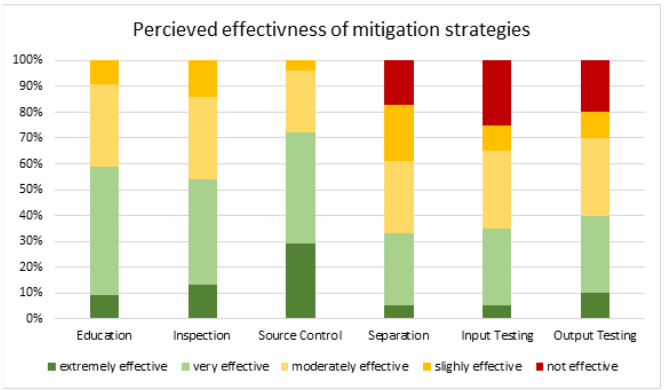

Figure 9: Perceived effectiveness of mitigation strategies

When asked about strategies used to prevent contamination risk, the most respondents mentioned steps related to inspection (9), working with generators through education initiatives (8), manual or mechanical screening of input materials (6), terminating contracts or levying fees for contamination (4), testing inputs (3), restricting intake from some sources (2), and growth trials on the end product (1). Asked about the effectiveness of mitigation strategies, **source control, education and inspection were seen as the most effective**, and separation, output testing and input testing were viewed as somewhat less effective (Figure 9).

From additional interviews with a few of the respondents, we also learned that generators within a source category vary widely and contamination may depend heavily on: whether the generator pays for composting; whether the person paying is the same person that does the sorting; and whether the generator is sending pre- or post-consumer waste. Plastic was seen as a problem because visible contamination can lead to angry customers but there was also concern about the buildup of plastics, and chemicals that leach from them, in soil. Another fear of waste handlers was the introduction of contaminated input materials such as: animal bedding material that has been treated with herbicides that persist through treatment; wood chips from treated lumber; pharmaceuticals in aquacultured fish; pesticides or street sweepings on grass clippings; mercury in crustacean shells and heavy metals in mill waste. While detection of EOX in our samples

could indicate trace herbicide contamination, we did not see evidence of heavy metal contamination as could occur from treated lumber or contaminated crustacean shells.

The interview respondents also expressed some frustration about unseen contamination because they would be held accountable and their business would suffer in the case of toxic contamination, yet they are neither the source of the contamination, nor could they detect it without incurring significant costs. This limitation underlines why source control and education are viewed as key risk mitigation measures. **Preventing contamination through careful source control and consistent and frequent communication with generators, especially early in a new contract, were seen as the most feasible and effective means of assuring the quality of the output materials**. In the words of one respondent: *"I would agree with the education idea and I would also say, especially when it comes to food scraps, education is our best and most effective method"*.

Conclusions

Our hypothesis that mandating food waste separation would result in higher levels of contamination was not borne out by our results. This result could reflect the **effectiveness of outreach efforts** in Massachusetts and Vermont in reducing contamination. The importance of such education efforts was also noted by interview participants as an effective element of their risk mitigation strategy.

Food waste handlers commented on the variability of food waste materials over time and among sources. This was in agreement with the characterization data. Survey respondents also thought the risk of contamination increased along the food system cycle and differed among consumer categories. The variability, combined with our relatively small dataset, resulted in fairly minor differences in chemical and biological contamination among source categories, so that observation was not confirmed with our research, although physical contaminants were lower in the grocery samples than some of the consumer categories.

Heavy metal contamination of the source separated food waste was insignificant, however 14% of samples had low levels of potentially bioaccumulative organohalogens as determined by the EOX method, which has a relatively high detection limit. **PFBA was found in 56% of the samples tested** for PFAS. This is of concern due to the health impacts of these contaminants, their extreme resistance to biodegradation, their capacity to bioaccumulate, and lack of evidence of industrial contamination of the waste materials to account for an external source. Food contact papers could be a source of these contaminants in food waste, and could be a problem, particularly at facilities that accept and compost coated papers with their food waste. Our sampling methodology, which removed any packaging prior to processing and analysis, could underestimate the presence of these materials in the final product. The contaminant concentrations in mechanically depackaged food waste, as well as samples processed for treatment, including residual packaging materials that were not efficiently removed by preprocessing, should be explored further.

Pathogens were not abundant in our samples, however we were not assessing all pathogen types, and some others could have been present at higher quantities according to our sequencing results. Thus care should be taken while handling input materials. That stated, well managed treatment should reduce pathogen abundance in the final product. **The near universal presence of tetracycline and beta-lactam resistance genes and their abundance are matters of concern** because of the potential for horizontal gene transfer to pathogens, and the lack of information

about the fate of these genes during treatment. However, **the absence of the *mcr-1* gene is a positive sign**.

This project is the only one we know of that assesses all of these contaminant types on the same samples. We have no evidence of gross contamination of any of our samples based on the chemical concentration levels seen here, so the widespread presence of PFAS, and antibiotic resistance gene levels in food waste above those found in agricultural soils, are the issues of concern identified in this study. We think there should be further study of these contaminants in pre-processed food waste, and especially depackaged food waste including any physical contamination that remains in the material to be processed, and finished products.

Food waste handlers who responded to our survey were primarily concerned about physical contamination, a problem we confirmed with our results (82% of samples contained non-food waste). However, some did mention potential trace chemical and biological contamination, but without much of a sense of the magnitude of the problem. Interestingly, much of the concern was about contamination of the carbon sources added to food waste during composting (wood chips, hay, bedding), which we did not measure. Our results showed that the food waste itself might be contaminated with halogenated organics either from packaging materials or other stages of the food system. Food waste could also be a vector to amplify antibiotic resistance in the environment. Thus easy and inexpensive monitoring methods would be of use in the field. In their absence, strong and ongoing outreach and education activities are critical to establishing and maintaining a safe, circular food system.

Materials and Methods

Sampling Sites and Sample Collection

Food waste was collected from two states (Massachusetts (MA) and Vermont (VT)) that mandate food waste diversion, and one unregulated state (Maine (ME)) in 2018 and 2019. Samples were collected from six different source types i.e. grocery stores, hospitals, retirement communities, restaurants, residential pick-up and drop-off locations, and schools by preceeding collection haulers to individual collection sites and combining two half-gallon grabs from collection totes in sample bags, and placing them in separate buckets, on ice, until returned to the laboratory. Upon return, any non-food items, including papers, were removed, weighed, inventoried and photographed. Food waste was processed in an industrial-grade food processor (Robot-Coupe R602), subsampled, and stored at -20˚C prior to analysis (qPCR methods) or shipping to an accredited laboratory for analysis.

Analytical Methods

Compost Test and Heavy Metals

Food waste samples were sent to the Maine Soil Testing Lab at the University of Maine for heavy metal and compost tests. The compost test includes: conductivity, Carbon (C), Nitrogen (N), C: N, pH, Phosphorus, Potassium, Magnesium, Calcium, Boron, Iron, Manganese and total solid tests. Heavy metals (Cd, Cr, Ni, Pb, Sn, and Ti) were analyzed by acid digestion using the EPA 3051 method and determined by ICP-OES (EPA, 2007). The detection limit for heavy metals by this method was 2 mg/kg dw.

EOX

Food waste samples were sent to Maine Environmental Laboratory (Yarmouth, ME) for EOX testing. EOX is used to determine Organohalogens in solids (Pöykiö, Nurmesniemi, & Kivilinna, 2008). EOX was determined using the EPA 9023 method that employs pyrolysis/microcoulometry (EPA, 1996). This method does not measure individual components but measures the total chlorinated, brominated and iodinated organics. The detection limit was 5 mg/kg as Cl^- (by wet weight).

PFAS

Four samples from each regulatory environment were tested for PFAS analysis by Eurofins, Test America (West Sacramento, California) using EPA method 537 modified (EPA, 2020). To avoid matrix effects on the results, the method was modified to use 1 g of food waste rather than 5 g of solid matrix as in the standard protocol. The samples were tested for 17 different PFASs compounds. They are Perfluorobutanoic acid (PFBA), Perfluoropentanoic acid (PFPeA), Perfluorohexanoic acid (PFHxA), Perfluoroheptanoic acid (PFHpA), Perfluorooctanoic acid (PFOA), Perfluorononanoic acid (PFNA), Perfluorodecanoic acid (PFDA), Perfluoroundecanoic acid (PFUnA), PErfluorododecanoic acid (PFDoA), Perfluorotridecanoic acid (PFTriA), Perfluorotetradecanoic acid (PFTeA), Perfluorobutanesulfonic acid (PFBS), Perfluorohexanesullfonic acid (PFHxS), Perfluoroheptanesulfonic acid (PFHpS), Perfluorooctanesulfonic acid (PFOS), Perfluorodecanesulfonic acid (PFDS) and Perfluorooctanesulfonamide (FOSA).

Deoxyribonucleic Acid (DNA) Extraction

Genomic DNA was extracted using Qiagen Soil DNA Extraction Kits (Qiagen, MD, USA) following the manufacturer's protocol. The DNA extracts were quantified with a Qubit fluorometer (Invitrogen, CA, USA). DNA samples were diluted/concentrated to 5 ng/µl except for eight samples whose concentrations were extremely low (<2 ng/µl).

Quantitative Polymerase Chain Reaction (qPCR)

Foodborne pathogens (*Salmonella*, *L. monocytogenes* and STEC *E. coli*), ARGs (bla_{TEM}, *tet*(M) and *mcr-1*) and 16S rRNA were quantified by qPCR. All qPCR assays were run using a BioRad CFX96 thermocycler (Bio-Rad Technologies, Hercules, CA) in a total volume of 10µl. qPCR assays consisted of 5µl SsoAdv Universal SYBR Green Supermix (Bio-Rad Technologies, Hercules, CA), 1 µl of each primer, 1 µl of DNA (5ng) and 2 µl nuclease-free water. The qPCR protocols for each of the targets and their primer information are given in the Table and

To generate positive controls for *tet(*M) and bla_{TEM}, PCR products of target gene fragments from wastewater DNA were ligated into TOPO-TA vectors (Invitrogen, Carlsbad, CA). The plasmids were transformed into TOP10 competent cells (Invitrogen, Carlsbad, CA) following the One Shot® chemical transformation protocol. Clones were picked, sequenced and confirmed as the target resistance genes using BLAST alignment tool. *E. coli* NCTC 13846 (Microbiologics, USA) DNA was used as the standard for the colistin-resistance gene (*mcr-1*). Standards for *Salmonella enterica* (ATCC® BAA-1045), *L. monocytogenes* (ATCC® 19115) and *E. coli* (ATCC® BAA-184) were kindly provided by Dr. J. Perry (School of Food and Agriculture, University of Maine).

Table . All qPCR runs were 40 cycles. The product specificity was affirmed by melting curve analysis (95˚C for 10 sec, 65˚C -95˚C, increment of 0.5˚C, for 0.05 sec).

Table 2: List of the primers used in qPCR for ARGs and pathogens

Name	Primers	Sequence (5'-3')	Amplicon size(bp)	Author
Tetracycline Resistance Gene	*tet*(M) (F)	ACAGAAAGCTTATTATATAAC	171	(Aminov, Garrigues-Jeanjean, & Mackie, 2001)
	tet(M) (R)	TGGCGTGTCTATGATGTTCAC		
Beta-Lactamase Resistant Gene	bla_{TEM} (F)	GCKGCCAACTTACTTCTGACAACG	247	(Xi et al., 2009)
	bla_{TEM} (R)	CTTTATCCGCCTCCATCCAGTCTA		
Colistin Resistant Gene	*mcr-1* (F)	GGGCCTGCGTATTTTAAGCG	183	(Hembach et al., 2017)
	mcr-1 (R)	CATAGGCATTGCTGTGCGTC		
Salmonella	*InvA* (F)	TCGTCATTCCATTACCTACC	118	(Hoorfar, Ahrens, & Radstrom, 2000)
	InvA (R)	AAACGTTGAAAAACTGAGGA		
L. monocytogenes	*hlyA* (F)	TGCAAGTCCTAAGACGCCA	112	(Barbau-piednoir et al., 2013)
	hlyA (R)	CACTGCATCTCCGTGGTATACTAA		
STEC E. coli	*stx-1* (F)	GTCACAGTAACAAACCGTAACA	95	(Fukushima et al., 2010)
	stx-1 (R)	TCGTTGACTACTTCTTATCTGGA		
16s rRNA	1369	CGGTGAATACGTTCYCGG	143	(Suzuki, Taylor, & DeLong, 2000)
	1492	GGWTACCTTGTTACGACTT		

To generate positive controls for *tet(*M) and bla_{TEM}, PCR products of target gene fragments from wastewater DNA were ligated into TOPO-TA vectors (Invitrogen, Carlsbad, CA). The plasmids were transformed into TOP10 competent cells (Invitrogen, Carlsbad, CA) following the One Shot® chemical transformation protocol. Clones were picked, sequenced and confirmed as the target resistance genes using BLAST alignment tool. *E. coli* NCTC 13846 (Microbiologics, USA) DNA was used as the standard for the colistin-resistance gene (*mcr-1*). Standards for *Salmonella enterica* (ATCC® BAA-1045), *L. monocytogenes* (ATCC® 19115) and *E. coli* (ATCC® BAA-184) were kindly provided by Dr. J. Perry (School of Food and Agriculture, University of Maine).

Table 3: qPCR primer conditions and working program

Name	Primer Concentration	Program
Tet(M)	0.4 µM	95˚C 5 mins, 95˚C 15 sec, 55˚C 30 sec and 72˚C 30 sec
Bla_{TEM}	0.2 µM	95˚C 15 mins, 95˚C 15 sec, 61˚C 30 sec and 72˚C 30 sec
Mcr-1	0.2 µM	95˚C 10 mins, 95˚C 15 sec, 60˚C 30 sec and 72˚C 30 sec
InvA	0.4 µM	95˚C 15 mins, 95˚C 15 sec, 55˚C 20 sec and 72˚C 30 sec
hlyA	0.5 µM	95˚C 10 mins, 95˚C 15 sec, 60˚C 1min and 72˚C 1 min
Stx-1	0.25 µM	95˚C 10 mins, 95˚C 15 sec, 55˚C 30 sec and 72˚C 30 sec
16S rRNA	0.4 µM	95˚C 10 mins, 95˚C 15 mins, 55˚C for 30 sec and 72˚C 30 sec

The total number of copies of the target gene in plasmid or genomic DNA was calculated using the equation: gene copy/µl DNA= (C x 6.022 x 10^{14})/(660 x N), in which C is DNA

concentration (ng/µl) and N is DNA fragment length (bp). Then, the plasmid/genomic DNA for each gene were serially diluted to obtain 10^7 to 10^3 copies for all the genes except 16S ribosomal RNA (rRNA) which were diluted to $10^9$to 10^4 for generation of a standard curve in the qPCR assay. Efficiency ranged from 93% to 102%.

Samples were run in triplicate in batches with standards, spikes (standards+ samples) and no template controls. Quantification of 16S rRNA was used to quantify the total bacterial population. 16S rRNA values were used to calculate the relative abundance of ARGs (fraction of microbes with the gene) in our study.

Standard curves were established by plotting the number of cycles to reach the fluorescence threshold against copy number. The threshold limit was manually set at 60 relative fluorescence unit (RFU) for all the genes except for *L. monocytogenes* which was set at 70 RFU. Samples possessing a signal above this value were assessed as positive and were quantified from the standard curve. In some cases, a sample did not reach the signal threshold within the allowable number of amplification cycles (40). In these cases, any sample that had a peak at the right temperature in the melting curve and had the right sized band when run on a 2% agarose gel was scored as positive but below the limit of quantification. A subset of these were Sanger sequenced to confirm the positive score.

Microbial Community Analysis

Eighteen recently-extracted DNA samples were picked for Illumina sequencing of amplicons of the V4 region of 16S rRNA for microbial community analysis. DNA extracts were normalized to 5 ng/µl and were shipped to MR DNA (Shallowater, Texas, US) for Illumina sequencing. Universal bacterial primers 515F (GTGYCAGCMGCCGCGGTAA) and 806R (GGACTACNVGGGTWTCTAAT) were used. Library preparation and sequence determination using paired- end Illumina MiSeq 2 x 250 reads was performed by MR DNA. FASTQ files were used for further data analysis using Divisive Amplicon Denoising Algorithm (DADA2) R package. Phyloseq was used for visualizing the results. Forward and reverse reads were trimmed off at 240 and 200 bp respectively because quality drops off towards the end. DADA2 was used for dereplication, inference, merging and chimera removal. The clean sequence variants obtained were assigned taxonomy using a Bayesian classifier method on the manually curated Silva training set Fasta files (Callahan et al., 2016). Sequences identified as chloroplasts and mitochondria were removed.

Food Waste Sample Data Analysis

The descriptive statistics were performed on Excel 2016 (Microsoft Corp., USA). Other statistical analyses were performed using R open source version 3.6.3. Box plots were made in R using the Tidyverse package (Duggan, 2018). As datasets did not fit normal distribution, nonparametric Wilcox rank sum tests were carried out in R to determine whether regulatory environment or source type were significant factors. Statistical significance was defined at 95% confidence intervals, $P < 0.05$.

Survey Methods

Database Construction

A database of all facilities licensed to receive food waste for recycling was compiled by requesting a database from each state, editing for uniformity and compiling the files. The resulting database included 114 licensed facilities in the three states. Entries were double checked through internet searches and phone calls to verify all contact information.

Survey Implementation

The survey was designed using the online survey design software Qualtrics (see Appendix C). Once the survey had been vetted by the research team and tested with three stakeholder partners, facilities with an email address in the database (n=72) were contacted with the recruitment script via email. In the next phase we sent a paper copy of recruitment script and survey to those facilities for which we did not have an email address and to those facilities that had not responded to email recruitment (n=46). In total we received 33 responses for a response rate of 29 percent.

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Appendix A – List of Publications

Papers in preparation:

Isenhour, C., Berry, B. Horton, S. MacRae, J. and Blackmer, T. ND. Taking It All In: Entanglement, Toxicity & Testing In New England's Emerging Circular Food Systems. Paper in preparation for submission to Ecology and Society.

Thakali, A., J.D. MacRae. N.D. Review of Chemical and Microbial Contamination in Food: What are the Threats to a Circular Food System? Accepted for publication in *Environmental Research*.

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Presentations:

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Blackmer*, T. (Meeting Facilitator) Maine Food Production Loss Leadership Council Working Group. November 18, 2019. Hallowell, ME.

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Nadeau*, H., S. Horton*, A. Flynn, S. Kleisinger, T. Patterson*, D. Saber*. Behavior and Waste: Reaching the Future Workforce. Presented at the Maine Resource Recovery Association Meeting, April 30, 2019, Northport, ME.

Thakali*, A., J.D. MacRae. The emergent risks of food waste recovery: characterizing the contaminants in MSW organics from different sources. Poster presented at UMaine Student Symposium, April 10, 2019, Bangor, ME.

Horton*, S., C. Isenhour. Working Towards Creating a Circular Nutrient System. Poster presented at UMaine Student Symposium, April 10, 2019, Bangor, ME.

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Berry*, B., S. Horton, H. Nadeau. Co-Learning Sustainability Science and Policy: An Interdisciplinary Approach to Food Waste Reduction. Presented at the Maine Water and Sustainability Conference March 28, 2019

Horton*, S., H. Nadeau*, S. Kleisinger*, A. Flynn*, T. Patterson*. Talking Trash: Creating a Circular Food System in Maine. Presented at the Senator George J. Mitchel Center for Sustainability Solutions, March 4, 2019.

Appendix B1 – General Characteristics

Source	#	Regulation	Mn (ppm)	pH	TS (%)	Contam. (%)	Cond. (mmhos/cm)	C (%)	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	B (ppm)	Fe (ppm)
Hospital	1	YES	6.68	4.3	28.5	13.63	2.8	58.1	4.73	0.21	0.51	0.05	0.25	3.85	83.6
Hospital	2	YES	11.1	5.1	25.3	1.31	5.9	56.9	4.08	0.4	0.75	0.11	0.4	6.71	34.7
Hospital	3	YES	8.47	4.4	26.6	0.00	8.1	50.6	4.81	0.34	0.82	0.09	0.19	3.45	32.7
Hospital	4	YES	32	4.5	32.9	31.76	3.6	54.2	2.04	0.13	0.24	0.12	0.13	3.04	35.7
Hospital	5	YES	13.9	4.3	35.9	0.00	6.9	46.3	2.68	0.23	0.4	0.06	0.09	1.43	31
Hospital	6	NO	-0.5	5.5	29.3	0.00	9.5	56.2	6.28	0.51	0.5	0.04	0.28	1.21	26.9
Hospital	7	NO	4.7	4.3	37.3	1.27	9.6	48.4	3.2	0.26	0.72	0.05	0.09	1.04	27.7
Hospital	8	NO	4.57	4.5	26	0.00	7.3	49.8	3.5	0.29	0.79	0.05	0.12	3.11	28.3
Hospital	9	NO	5.84	4.6	20.1	2.06	8	48.6	3.52	0.22	1.24	0.13	0.22	4.42	121
Hospital	10	NO	10.7	4.1	23	0.00	7.9	50.4	3.59	0.31	0.65	0.08	0.08	2.01	44
Grocery	1	YES	14	4	10.5	0.00	4.4	45.5	1.44	0.2	1.06	0.09	0.2	12.6	220
Grocery	2	YES	6.14	4.2	36.6	0.04	8.5	49.9	1.82	0.15	0.62	0.05	0.04	9.89	38.3
Grocery	3	YES	38.1	4.4	10.8	2.11	8.1	43	2.1	0.31	2.59	0.22	0.7	18.1	125
Grocery	4	YES	6.75	4.3	28.7	0.00	5.5	48.2	2.3	0.16	0.51	0.04	0.06	4.44	40.8
Grocery	5	YES	19.5	4.4	5.9	0.00	6.1	45	2.76	0.31	2.98	0.21	0.37	14.5	88.5
Grocery	6	YES	29.2	3.8	8.1	0.11	6.1	47.4	2.74	0.32	2.86	0.24	0.72	29	188

Source	#	Regulation	Mn (ppm)	pH	TS (%)	Contam. (%)	Cond. (mmhos/cm)	C (%)	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	B (ppm)	Fe (ppm)
Grocery	7	YES	19.5	4.5	10.6	0.15	7.3	45	4.36	0.56	3.3	0.26	0.51	26.1	64.4
Grocery	8	NO	2.38	4.2	41.4	2.70	5.5	60.3	2.44	0.25	0.36	0.04	0.15	2.06	47
Grocery	9	NO	9.28	4.2	25.4	8.06	3.2	43.3	0.53	0.08	0.73	0.06	0.12	4.05	15.5
Grocery	10	NO	29.8	4.2	9	0.86	4.8	46.4	2.42	0.34	2.13	0.2	0.53	19.5	285
Grocery	11	NO	15.8	4.1	10.4	7.71	6.1	55.1	2.13	0.24	1.5	0.12	0.32	10.5	52.4
Grocery	12	NO	10.8	4	30.3	10.95	9.4	48.8	3.98	0.18	0.8	0.08	0.36	4.57	28.5
Grocery	13	NO	7.47	4.2	12.7	0.90	4.6	49	2	0.23	1.2	0.11	0.3	16.4	28.1
Grocery	14	NO	12.5	4.3	28.1	8.94	5.4	46.8	1.89	0.2	0.65	0.07	0.19	5.41	51.8
Residential	1	NO	23.6	6.3	20	22.88	4.7	45.4	1.95	0.18	1.61	0.2	5.6	20.5	64.2
Residential	2	NO	11.1	4.4	13.9	1.35	5.8	46.3	1.72	0.19	2.2	0.12	2.3	13.1	40
Residential	3	NO	28.1	4.5	26.7	15.13	5.4	49.4	2.66	0.21	0.86	0.11	0.84	5.99	56.3
Residential	4	NO	8.63	4.2	27.6	2.90	5.7	49.4	4.97	0.32	0.88	0.07	0.15	3.26	36.4
Residential	5	NO	18.9	3.8	26.2	0.08	9	52.9	2.21	0.23	0.83	0.1	0.39	8.2	83.2
Residential	6	NO	14.7	5.6	30.5	6.90	6.3	49.1	1.92	0.65	0.88	0.14	2.7	26.5	48.4
Residential	7	NO	26.8	4.8	10.2	29.71	5.7	46.9	2.24	0.2	1.49	0.16	0.74	9.86	83.5
Residential	8	NO	20.1	5.4	29.1	6.82	7.2	43.7	1.91	0.17	1.44	0.14	9.6	12.6	26.4
Residential	9	NO	15.5	4.5	27.9	19.93	8.4	50.4	3.73	0.27	0.81	0.1	0.7	4.02	51.1
Residential	10	NO	12.4	5.2	19.4	28.29	10.2	48.5	2.91	0.4	1.52	0.11	3.1	9.68	104

Source	#	Regulation	Mn (ppm)	pH	TS (%)	Contam. (%)	Cond. (mmhos/cm)	C (%)	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	B (ppm)	Fe (ppm)
Residential	11	NO	9.41	4.1	34	6.55	6.9	47.7	1.97	0.26	0.5	0.05	1	4.24	28.3
Residential	12	NO	9.68	5	28.6	6.90	8.6	43.9	2.12	0.17	0.96	0.1	3.5	6.68	38.7
Retirement	1	YES	6.33	4.4	48.7	4.75	1.9	66.9	1.65	0.12	0.52	0.04	0.08	2.3	48.2
Retirement	2	YES	6.04	4.1	40.9	0.70	5.3	52.5	2.51	0.24	0.49	0.06	0.12	1.81	37.4
Retirement	3	YES	9.97	4.2	22.1	1.93	5	49.8	1.61	0.23	1.19	0.11	0.24	9.08	42.5
Retirement	4	YES	4.89	4.5	18	0.00	7.1	50.1	9.08	0.36	0.75	0.06	0.14	2.87	34.3
Retirement	5	YES	31.8	3.9	9.1	0.00	7.2	42.4	2.52	0.35	3.16	0.21	0.84	20.6	89.8
Retirement	6	YES	32	4.4	10.6	0.00	5.4	43	2.76	0.33	2.41	0.22	0.67	19.9	49.2
Retirement	7	NO	27.1	4.4	16.4	5.07	5.8	49.5	2.64	0.24	0.91	0.09	0.23	7.32	51.2
Retirement	8	NO	12.1	5.1	30.5	13.64	10.3	40.6	3.21	0.74	0.77	0.13	7.4	10.2	184
Retirement	9	NO	9.38	4.5	33.2	7.01	9	51.3	5.86	0.3	0.56	0.06	0.08	1.13	77.6
Retirement	10	NO	8.43	4.3	24.7	1.07	6.5	46.7	2.87	0.22	0.75	0.07	0.13	5.07	63.4
Retirement	11	NO	14.8	4.3	21.4	9.99	6.1	48.8	2.07	0.34	0.72	0.09	0.52	5.55	36.5
Retirement	12	NO	11.5	4.4	22.2	0.60	6.2	48.4	3.19	0.31	1.1	0.07	0.27	4.19	37.7
Restaurant	1	YES	8.57	4.5	22	7.09	12.1	54.5	2.82	0.37	0.96	0.07	1	4.44	56.2
Restaurant	2	YES	18.7	6.3	27.9	21.41	7.3	29.4	1.1	0.12	0.81	0.18	16	8	22.4
Restaurant	3	YES	2.06	5.4	79.2	3.90	4.5	46.9	0.87	0.12	0.22	0.03	0.04	0.05	13.1
Restaurant	4	YES	9.1	5.7	34.5	4.74	7.4	48.9	3.01	0.22	0.5	0.09	11	17.1	293

Source	#	Regulation	Mn (ppm)	pH	TS (%)	Contam. (%)	Cond. (mmhos/cm)	C (%)	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	B (ppm)	Fe (ppm)
Restaurant	5	YES	14.6	4.2	20.9	0.00	8.4	44.1	1.88	0.21	1.27	0.1	0.08	6.4	26.9
Restaurant	6	YES	10.6	5.2	32.7	39.01	10.1	45.5	2.75	0.23	0.73	0.11	12	9.61	49
Restaurant	7	NO	5.93	5.2	44	2.20	7.6	42.3	1.57	0.15	0.22	0.1	10	2.1	34.7
Restaurant	8	NO	45	4.9	47	31.99	9.9	49.9	2.26	0.14	0.37	0.05	3.9	4.8	89.6
Restaurant	9	NO	9.19	5.2	38.6	17.77	10.8	38.9	2.02	0.16	0.69	0.13	13	14.9	53
Restaurant	10	NO	17.4	5.1	25.9	0.66	5.6	49.6	2.11	0.14	0.82	0.1	0.85	7.29	40.9
Restaurant	11	NO	14.3	4.1	11.6	0.44	8.4	40.8	2.4	0.3	1.7	0.11	0.42	11.9	57.6
Restaurant	12	NO	5.78	5.2	39.8	5.94	7.3	35.6	1.97	0.16	0.5	0.17	15	10.3	18.7
School	1	YES	8.52	4.3	31.3	0.00	9.8	52.6	4.42	0.43	0.62	0.09	0.17	2.28	53.5
School	2	YES	9.22	4	22.1	15.74	5.8	47.3	1.92	0.21	1.04	0.08	0.34	13.4	95.2
School	3	YES	30.1	4.3	17.7	0.27	5.1	46.5	2.27	0.18	0.71	0.13	0.15	6.86	37.1
School	4	YES	17.1	4.3	32.7	23.93	7.8	48.3	2.81	0.33	0.82	0.08	0.27	5.97	30.9
School	5	YES	6.87	4.4	22.6	10.26	7.2	48.2	2.37	0.28	1.71	0.12	0.26	6.67	39.6
School	6	YES	7.5	5.5	32.3	0.00	8.4	36	1.93	0.23	1.43	0.21	13	8.63	38
School	7	NO	12.1	4.6	28.3	0.87	7.6	47.6	3.2	0.36	0.62	0.09	0.32	1.31	44.8
School	8	NO	8.98	4.2	15	2.52	5.6	44.4	3.19	0.29	1.14	0.1	0.73	12.2	24.9
School	9	NO	15.3	4.5	25.4	0.00	10.9	48.7	3.56	0.27	0.78	0.07	0.13	5.4	546
School	10	NO	6.74	4.8	44	6.28	8.7	48.9	3.44	0.37	0.4	0.06	0.48	2.56	32.5

Source	#	Regulation	Mn (ppm)	pH	TS (%)	Contam. (%)	Cond. (mmhos/cm)	C (%)	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	B (ppm)	Fe (ppm)
School	11	NO	15.1	4.8	21.3	0.00	8.1	46	3.73	0.2	0.84	0.12	2.6	5.27	206
Mean			14	4.58	26.2	6.757	7.02	47.9	2.806	0.267	1.04	0.11	2.106	8.303	71.2
Standard Deviation			9.17	0.54	11.9	9.361	2.04	5.48	1.31	0.118	0.70	0.05	3.99	6.59	80.8
Maximum			45	6.3	79.2	39.01	12.1	66.9	9.08	0.74	3.30	0.26	16	29	546
Minimum			-0.5	3.8	5.9	0	1.9	29.4	0.53	0.08	0.22	0.03	0.04	0.05	13.1

Appendix B2 – Contaminant Concentrations

Source Type	SN	Regulation	Cu(ppm)	Zn (ppm)	Ni (ppm)	EOX (mg/kg wet)	PFBA (µg/kg wet)	PFHxS (µg/kg wet)	PFNA (µg/kg wet)	Accession Number	S. enterica	L. monocytogenes (genes/g)	16S gene(genes/g)	bla (genes/g)	tet(M) (genes/g)
Grocery	1	YES	4.35	20.6	<2	<5					(-)	(-)	6.85E+10	2.84E+07	(+)
Grocery	2	YES	4.56	10.6	<2	<5					(-)	(-)	4.72E+10	(+)	10455100
Grocery	3	YES	3.31	24.4	<2	<5					(-)	(-)	2.47E+11	(+)	16351659
Grocery	4	YES	1.76	9.22	<2	<5					(-)	(+)	6.73E+10	(+)	(+)
Grocery	5	YES	9.89	23.1	<2	5.2				PRJNA631964	(-)	(+)	3.82E+11	(+)	(+)
Grocery	6	YES	8.91	71.1	<2	<5	<MDL	<MDL	<MDL	PRJNA631964	(-)	(+)	1.45E+10	9.65E+06	9.21E+08
Grocery	7	YES	4.73	32.9	<2	<5	<MDL	<MDL	<MDL	PRJNA631964	(-)	(+)	4.20E+10	1.98E+09	7.91E+08
Grocery	8	NO	2.49	13.9	<2	<5					(+)	(+)	7.09E+10	1.03E+08	5.29E+08
Grocery	9	NO	2.07	4.94	<2	<5	0.55	<MDL	<MDL	PRJNA631964	(-)	(-)	4.95E+10	4.13E+06	(-)
Grocery	10	NO	6.31	23.7	2.1	<5	<MDL	<MDL	<MDL	PRJNA631964	(-)	(-)	7.45E+10	(+)	(+)
Grocery	11	NO	5.06	18.6	<2	<5	0.79	<MDL	<MDL	PRJNA631964	(-)	(-)	3.44E+11	8.94E+06	(-)
Grocery	12	NO	1.08	10.3	<2	<5				PRJNA631964	(-)	(-)	7.80E+10	1.45E+07	1.96E+08
Grocery	13	NO	5.4	13.4	<2	<5	0.11	<MDL	<MDL		(-)	(-)	2.16E+10	2.38E+07	(+)
Grocery	14	NO	2.76	12.6	<2	<5	<MDL	<MDL	<MDL		(-)	(-)	2.90E+10	7.60E+08	1.65E+08
Hospital	1	YES	1.54	26	<2	<5					(-)	(-)	6.68E+10	1.91E+07	1.58E+08
Hospital	2	YES	4.1	28.1	<2	<5					(-)	(-)	5.54E+11	5.14E+06	17152221
Hospital	3	YES	2.46	22.9	<2	<5	1	<MDL	<MDL	PRJNA631964	(-)	(-)	1.64E+11	3.56E+06	(+)
Hospital	4	YES	13.8	8.15	<2	<5	<MDL	<MDL	<MDL		(-)	3050	1.26E+09	4.07E+08	89892555
Hospital	5	YES	2.72	14.5	<2	<5	0.6	<MDL	<MDL		(-)	(-)	1.66E+10	3.69E+08	1.32E+08
Hospital	6	NO	0.94	34.5	<2	<5					(-)	(-)	3.22E+08	(-)	4375478
Hospital	7	NO	3.03	24.1	<2	6					(-)	(-)	7.06E+09	(-)	4485567

Source Type	SN	Regulation	Cu (ppm)	Zn (ppm)	Ni (ppm)	EOX (mg/kg wet)	PFBA (µg/kg wet)	PFHxS (µg/kg wet)	PFNA (µg/kg wet)	Accession Number	S. enterica	L. monocytogenes (genes/g)	16S gene(genes/g)	bla (genes/g)	tet(M) (genes/g)
Hospital	8	NO	1.96	15	<2	<5					(-)	(-)	2.82E+11	1.50E+09	1.53E+10
Hospital	9	NO	2.8	13.9	<2	<5					(-)	(-)	1.22E+11	6.66E+09	1.30E+09
Hospital	10	NO	2.5	19.7	<2	<5	0.61	<MDL	<MDL		(-)	1249	4.55E+09	4.67E+09	6.96E+08
Residential	1	NO	9.41	27	<2	<5					(-)	(-)	9.59E+11	4.98E+06	1.69E+09
Residential	2	NO	4.58	18.3	<2	<5					(-)	(-)	2.72E+11	1.79E+07	3.89E+08
Residential	3	NO	9.75	14.7	<2	<5					(-)	(-)	1.71E+11	5.66E+07	2.09E+08
Residential	4	NO	3.06	20	<2	<5					(-)	(-)	2.79E+11	(+)	1.30E+08
Residential	5	NO	13.7	22.7	<2	<5					(-)	(-)	1.64E+11	1.81E+09	3.02E+08
Residential	6	NO	11.8	28.9	<2	<5					(+)	(-)	2.44E+11	9.71E+08	6.21E+08
Residential	7	NO	9.3	34.4	<2	<5					(-)	19140	1.11E+12	4.74E+08	9.33E+08
Residential	8	NO	4.3	12.8	<2	<5					(-)	(-)	1.26E+12	6.73E+08	1.82E+08
Residential	9	NO	5.26	24.2	<2	<5	0.8	<MDL	<MDL		(-)	(-)	3.29E+11	1.46E+07	5.35E+08
Residential	10	NO	4.59	34.1	<2	<5	0.55	<MDL	<MDL		(-)	(-)	7.07E+11	1.84E+09	2.03E+08
Residential	11	NO	2.32	13.1	<2	10.9	0.52	<MDL	<MDL	PRJNA631964	(-)	(-)	6.19E+11	1.08E+09	1.35E+08
Residential	12	NO	4.13	13.7	<2	<5				PRJNA631964	(-)	(-)	1.67E+11	1.48E+07	1.13E+08
Restaurant	1	YES	3.1	19.8	<2	<5					(-)	(-)	1.95E+11	6.38E+06	6.30E+09
Restaurant	2	YES	5.2	5.74	<2	<5					(-)	(-)	6.23E+09	1.10E+06	(-)
Restaurant	3	YES	0.25	10.5	<2	9.3					(-)	(-)	1.54E+11	1.11E+07	60200365
Restaurant	4	YES	3.94	35.1	<2	<5					(-)	(-)	1.54E+11	5.77E+07	5.99E+08
Restaurant	5	YES	2.89	29	<2	<5	0.39	<MDL	<MDL		(-)	(-)	2.91E+11	1.90E+07	(+)
Restaurant	6	YES	3.04	23.1	<2	<5					(-)	(-)	1.29E+11	1.38E+07	5556499
Restaurant	7	NO	1.56	10	<2	<5					(-)	(-)	6.79E+10	3.57E+07	2.14E+09
Restaurant	8	NO	4.85	22.6	<2	89.7	0.72	<MDL	<MDL		(-)	(-)	8.42E+10	1.67E+06	61181475
restaurant	9	NO	3.85	20	<2	<5					(-)	(-)	5.62E+10	3.71E+08	1.47E+08
Restaurant	10	NO	12.1	10.1	<2	<5					(-)	(-)	6.95E+10	3.25E+09	1.29E+09

Source Type	SN	Regulation	Cu (ppm)	Zn (ppm)	Ni (ppm)	EOX (mg/kg wet)	PFBA (µg/kg wet)	PFHxS (µg/kg wet)	PFNA (µg/kg wet)	Accession Number	S. enterica	L. monocytogenes (genes/g)	16S gene(genes/g)	bla (genes/g)	tet(M) (genes/g)
Restaurant	11	NO	4.06	26	<2	<5					(-)	(-)	1.26E+11	3.37E+09	1.02E+09
Restaurant	12	NO	3.09	9.28	<2	<5					(-)	(-)	7.58E+10	8.51E+08	1.97E+08
Retirement	1	YES	3.78	16.3	<2	<5					(-)	(-)	1.98E+10	2.79E+06	3.56E+08
Retirement	2	YES	1.91	11	<2	11.3					(-)	(-)	2.59E+11	1.26E+07	32483474
Retirement	3	YES	2.61	13.2	<2	<5					(-)	(-)	2.06E+12	4.98E+06	2.01E+08
Retirement	4	YES	3.41	15.1	<2	<5	<MDL	<MDL	<MDL		(-)	(-)	1.58E+11	1.94E+07	(+)
Retirement	5	YES	3.58	20.3	<2	5.7	0.62	<MDL	0.28	PRJNA631964	(-)	(-)	5.34E+11	7.02E+08	3.02E+08
Retirement	6	YES	4.71	35.3	<2	<5	0.71	<MDL	<MDL	PRJNA631964	(-)	(-)	5.22E+10	2.53E+09	6.57E+08
Retirement	8	NO	3.13	29.2	<2	10.5					(-)	(-)	4.21E+10	1.90E+06	1921961
Retirement	9	NO	4.72	34.4	<2	7.3					(-)	(-)	9.46E+10	4.72E+08	1.42E+08
Retirement	10	NO	4.57	12.5	<2	<5					(-)	(-)	2.69E+10	4.12E+08	(+)
Retirement	11	NO	4.1	17.2	<2	<5					(-)	(-)	3.51E+10	2.01E+09	1.17E+08
Retirement	12	NO	4.8	22.5	<2	<5					(-)	(-)	1.30E+10	1.89E+08	80884196
Retirement	7	NO	6.13	24.7	<2	<5					(-)	(-)	6.45E+10	8.11E+07	2.85E+08
School	1	YES	3.25	33.2	<2	5	0.84	0.18	<MDL		(-)	(-)	8.85E+09	1.88E+06	(+)
School	2	YES	3.75	54.7	<2	<5					(-)	(-)	1.55E+11	6.32E+07	2.48E+08
School	3	YES	4.07	13.4	<2	<5	<MDL	<MDL	<MDL	PRJNA631964	(-)	(-)	1.59E+12	2.69E+07	4.25E+09
School	4	YES	3.28	23.7	<2	<5					(-)	(-)	1.57E+10	1.85E+09	7.00E+08
School	5	YES	4.27	20.7	<2	<5				PRJNA631964	(-)	(-)	2.81E+11	5.15E+08	84097312
School	6	YES	2.22	9.67	<2	<5	<MDL	<MDL	<MDL	PRJNA631964	(-)	(-)	6.06E+11	2.09E+09	4.78E+08
School	7	NO	3.78	28.9	<2	<5					(-)	(-)	2.04E+11	3.35E+09	2.71E+08
School	8	NO	3.83	17.6	<2	<5					(-)	(-)	1.13E+11	4.72E+08	1.78E+09
School	9	NO	4.54	29.9	<2	<5	<MDL	<MDL	<MDL	PRJNA631964	(-)	(-)	1.40E+14	2.03E+09	6.47E+08
School	10	NO	1.77	27.8	<2	<5	<MDL	<MDL	<MDL		(-)	(-)	1.14E+10	3.85E+06	27754797
School	11	NO	2.21	11.7	<2	<5	0.27	<MDL	<MDL	PRJNA631964	(-)	(-)	1.05E+11	2.37E+07	(+)

Source Type	SN	Regulation	Cu (ppm)	Zn (ppm)	Ni (ppm)	EOX (mg/kg wet)	PFBA (µg/kg wet)	PFHxS (µg/kg wet)	PFNA (µg/kg wet)	Accession Number	S. enterica	L. monocytogenes (genes/g)	16S gene(genes/g)	bla (genes/g)	tet(M) (genes/g)
Mean			4.41	21.19	2.1	16.09	0.6053	0.18	0.28			7813	2.21E+12	7.68E+08	8.47E+08
Standard Deviation			2.859	10.88		25.98	0.2275					9850.7	1.66E+13	1.29E+09	2.21E+09
Maximum			13.8	71.1	2.1	89.7	1	0.18	0.28			19140	1.40E+14	6.66E+09	1.53E+10
Minimum			0.25	4.94	2.1	5	0.11	0.18	0.28			1249	3.22E+08	1.10E+06	1.92E+06

Appendix C – Survey and Results

Dear xxxx,

We are writing to request your help with a University of Maine research project. It shouldn't take you more than 10 minutes, but your help will go a long way helping us all to better understand how to anticipate, reduce and manage the risk of contamination. We are a group of researchers at the University of Maine - Jean MacRae (Environmental Engineering/Microbiology), Travis Blackmer (Economics) and myself (Cindy Isenhour, Environmental Anthropology). We have funding to conduct a study focused on methods to reduce contamination risks in food scrap recovery and processing efforts in New England. More specifically we are interested in understanding your experiences with contamination as well as the processes you have implemented to reduce the risk of system contamination.

What will you be asked to do: If you decide to participate in the study, you will be asked to answer a series of questions designed to gather information about your processing facility, the sources of food waste your organization receives, your perceptions of contamination risk, your experiences with contamination, and any processes you currently have in place to manage contamination risks. We expect that most participants will be able to complete the survey in approximately 10 - 15 minutes.

Risk Statement: Except for your time and inconvenience, we do not anticipate that there are any risks associated with your participation in this study.

Benefits: While we do not anticipate that you will directly benefit from your participation in this research, the results are intended to help facility managers to more accurately predict contamination and to reduce and manage risk.

Confidentiality: The data that you provide will be completely confidential. We do not ask any questions about your contact information or the name of your facility in the survey. A separate key will be created that includes your contact information and the survey code, for the purposes of potential follow up interviews in the future. Isenhour is the only researcher who will access to this key. All other personnel will only have access to the de-identified data. The data key will be kept separately from the data on Isenhour's password protected laptop using software that provides additional security. After five years (Jun 2023) the survey codes will be deleted from the key file. Contact information will be kept indefinitely to ensure that the research team can maintain contact for longer-term study. The de-identified data files will be kept indefinitely.

Voluntary: Your participation in this research is completely voluntary. If you choose to participate you may skip any question and stop at any time. By advancing to the next page to take the survey you are signaling your voluntary consent to participate.

Contact Information: Should you have any questions about this research please feel free to contact Cindy Isenhour at cynthia.isenhour@maine.edu or at (207)581-1895. If you have questions about the rights of research participants please contact the Office of Research Compliance, University of Maine, 207/581-1498 or 207/581-2657, umric@maine.edu.

1. What type of organic waste processing does your facility provide?

- ○ Composting
- ○ Digestion
- ○ Other_____

2. If you compost, please indicate which methods you utilize. Check all that apply.

- ○ Not applicable
- ○ In-vessel
- ○ Windrow
- ○ Aerated, static pile
- ○ Other _____

3. How would you classify your operation?

- ○ Private
- ○ Public or municipal
- ○ Public/private partnership

4. What, approximately, is your **maximum** monthly processing capacity? (please list either in weight or volume)

Cubic Yards _____

Tons _____

5. What, approximately, is your **average** monthly processing total (please list either in weight or volume)

Cubic Yards_____

Tons_____

6. Do you accept liquid and solid residuals?

- ○ Liquid only
- ○ Solid only
- ○ Both liquid and solid residuals

7. Please indicate the composition of the food scraps you receive (click all that apply)

- ○ source separated, no packaging
- ○ source separated, with packaging (original packaging and bagged food waste)
- ○ co-mingled
- ○ other? _____

8. What types of materials do you accept and process? (click all that apply)

- ○ leaf and yard trimmings
- ○ food scraps
- ○ sewage residuals
- ○ agricultural manure/slurries
- ○ fats, oils, grease
- ○ crop residues/spent grains
- ○ fish/shellfish waste
- ○ septage
- ○ other industrial organics
- ○ others?_____

9. Do you utilize any of the following pre-processing technologies? (click all that apply)

- ○ depackaging
- ○ mixing with other feedstocks
- ○ grinding/pulping
- ○ size classification/separation
- ○ other _____

10. Please indicate how you and/or your partners source the **food scrap feedstocks** you process. (click all that apply)

- ○ residential collection
- ○ restaurant collection
- ○ grocer collection
- ○ institutional (hospitals/universities/schools) collection
- ○ food distributor/service collection
- ○ food processor collection
- ○ food producer collection
- ○ other_____

11. If you accept **residential food scraps**, please indicate the various means through which that material is collected (choose all that apply).

- ○ municipal curbside collection
- ○ private subscription curbside collection
- ○ residential drop off consolidation
- ○ other? _____

12. How are **food scrap** feedstocks transported to you? (click all that apply)

- ○ drop off
- ○ your own private fleet
- ○ municipally owned fleet
- ○ private, contracted fleet
- ○ other? _____

13. In your experience, what types of contamination are of concern when accepting and processing **food scraps**?

_____

_____

14. Of the contaminants you listed above, which presents the most significant risk? Why?

_____

_____

15. How concerning do you find the following food scrap-related contaminants?

	a serious concern	a concern	not a big concern	not applicable
Plastics	○	○	○	○
Glass	○	○	○	○
Pathogens (Salmonella, E.coli)	○	○	○	○
Heavy metals	○	○	○	○
Toxic organic contaminants (pesticides, etc)	○	○	○	○
Process inhibitors (salt, ammonia, etc)	○	○	○	○

16. In your experience, which **sources of food scrap** feedstock present the biggest contamination risks?

_____

_____

17. Based on your experience, please indicate how much contamination risk you associate with the following **food scrap feedstock sources**.

	High contamination risk	Moderate contamination risk	Low contamination risk	No contamination risk	Not applicable
Source separated (pick up)	○	○	○	○	○
Source separated (drop off)	○	○	○	○	○
Source separated with packaging	○	○	○	○	○
Commingled waste	○	○	○	○	○

18. Based on your experience, please indicate how much contamination risk you associate with the following **sources of food scraps**.

	High contamination risk	Moderate contamination risk	Low contamination risk	No contamination risk	Not applicable
residential	○	○	○	○	○
institutions (university/hospital/school)	○	○	○	○	○
restaurants	○	○	○	○	○
Grocers	○	○	○	○	○
food distributors	○	○	○	○	○
food processors	○	○	○	○	○
food producers/growers	○	○	○	○	○

19. What strategies does your facility use to prevent contamination risks?

_____

_____

20. How frequently do you sample/test your input materials?

_____

21. What contaminants do you test for in your input materials?

_____

22. In your experience, which are the most effective strategies to prevent contamination risks?

	Extremely effective	Very effective	Moderately effective	Slightly effective	Not effective at all
Supplier training/education	○	○	○	○	○
Feedstock source control (contracts, acceptance of only certain feedstock)	○	○	○	○	○
Visual inspection of feedstock	○	○	○	○	○
Mechanized inspection/sorting	○	○	○	○	○
Pre-processing testing/chemical analysis	○	○	○	○	○
Post-processing testing/chemical analysis	○	○	○	○	○

23. How frequently do you sample/test your output materials?

_____

24. What contaminants do you test for in your output materials?

_____

25. Are there other quality control measures that you think could or should be put in place that would effectively reduce contamination risk - at your facility or by your partners (suppliers, haulers)?

_____

_____

Thank you very much for your time!

We appreciate your participation and invite you to get in touch with us (cynthia.isenhour@maine.edu) should you have any more information you would like to share or if you have additional questions about this research.