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Facilitators & barriers to organic waste and phosphorus re-use in Montreal

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Abstract

Cities have the capacity to play a key role in resource and pollution management through their decisions about organic waste. Often overlooked, but nevertheless essential, is the role that cities can play in increasing phosphorus (P) recycling because cities are consumers of large amounts of P-dense food and producers of vast amounts of P-rich waste. Most cities do not take advantage of this potential, seeing P as simply another part of organic waste to be disposed of elsewhere. For example, in Montreal, Canada, only 6% of P in waste is currently recycled. We used semi-structured interviews with key stakeholders (19), participant observation (over 1.5 years), and document review to identify key barriers and facilitators for Montreal to achieve a high level of organic waste recycling through composting. We found that a provincial law mandating 100% recycling of organic matter has great potential to facilitate increased P recycling. However, lack of a shared vision about the role of government, private sector, and citizens in producing high quality compost from waste products is a barrier that inhibits this potential. Cultural inertia, lack of knowledge, and lack of infrastructure also act as barriers to increasing composting in Montreal. Urban agriculture could be a means to overcome some of these barriers as it currently benefits from strong citizen support and is both a consumer and producer of compost. However limited access to potential garden space and training and diversity in desired fertilizer qualities among gardeners somewhat limit this potential. Investing in increasing social capital, and specifically in connecting urban agriculture to waste management objectives, and in linking key stakeholders to co-create shared visions about how to produce high quality compost may act as a stepping stone towards increasing Montreal citizens' knowledge about, and support for, increasing organic waste and thus P recycling.

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1. Introduction

1.1 The importance of cities in sustainable organic resource management

Cities, home to over 50% of the global population (United Nations, 2011), play a key role in the demand for resources and the production of waste, affecting populations and ecosystems inside and outside their geographical limits (Grimm et al., 2008; Kennedy et al., 2007). Urban solid waste management is thus an integral part of sustainable resource and environmental management, affecting human and environmental health, as well as the capacity to recover resources within waste (Hoornweg and Bhada-Tata, 2012). Urban solid waste generation has increased from 0.68 billion tonnes a year in 2002 to over 1.3 billion tonnes today; with continued urban growth, the burden of municipalities to sustainably treat this waste is increasing (Hoornweg and Bhada-Tata, 2012).

Organic waste, comprising 46% of urban waste globally, is an important resource if recovered, as it contains both critical energy and nutrients. It is, however, more commonly managed as an environmental burden (Hoornweg and Bhada-Tata, 2012). Currently, landfilling of organic waste takes up large amounts of land and the decomposition process contributes to greenhouse gas emissions. If properly treated, cities can recover energy from the decomposition process of organic waste, as well as essential plant nutrients for agriculture like nitrogen and phosphorus. There are a multitude of ways to recover energy and nutrients (see Eriksson et al.,

2005; Smit and Nasr, 1992; Zurbrugg, 2002) but changing current practices requires changes in attitudes and practices at many scales and by many stakeholders.

Because change, adaptation, and innovation are dependent on multiple actors and their relationships, social capital (i.e., the social networks, bonds, and norms a community shares; Pretty, 2003) is a key part of our capacity to alter resource management (Adger, 2010; Heemskerk and Wennink, 2004). High social capital is characterized by high trust, reciprocity, and exchanges within the group, a shared understanding of rules and norms, and connectedness, and is an important part of sustainable resource management (Pretty, 2003; Putnam, 1993). Increasing social capital can help create a shared understanding of a problem, or vision towards the future, allowing different actors in the system to collaborate on innovative solutions (Smith et al., 2010). Understanding which city-specific factors drive or regulate the management of organic waste can help us understand how social capital is contributing to the current organic waste management as well as social capital's capacity to help implement more sustainable solutions in the future.

1.2 The importance of phosphorus as a resource to recover in cities

Phosphorus (P) is an essential nutrient for agriculture, but can also be a major pollutant if not properly managed. Most fertilizer is produced using mined P, which is both limited in overall quantity and found primarily in just a few countries, leading to concern about P scarcity and the geopolitics of access (Cooper et al., 2011). Despite its global scarcity, situations of local overabundance occur when P runoff from agricultural fields or lawns reaches sensitive waterways, where it causes eutrophication (Elser and Bennett, 2011). Sustainable P management is a pressing problem; populations around the world are increasingly vulnerable to spikes in food prices that are partially driven by increasing fertilizer (P) prices (Cordell and Neset, 2014), as well as to spreading eutrophication in water bodies around the world (Diaz, 2001).

Sustainable P management will require increasing P use efficiency and recycling throughout the food system, including P recycling from urban waste to agricultural land, though details of specific solutions will vary from location to location (Cordell et al., 2011, 2012), as solutions are not "one size fits all" (Tödtling and Trippl, 2005; Smith et al., 2005). In the urban context, increasing efficiency will include decreasing food waste, eating less meat, and ensuring correct fertilizer applications to landscaping and urban agriculture (UA). Increasing recycling will include composting green waste and food waste for re-use as fertilizer, as well as using properly treated sewage waste to produce fertilizer for agricultural production. The relevance of solutions will vary based on the dynamic interplay of the social and biophysical factors that drive P cycling in that city (Alberti, 2008; Folke et al., 2002). Previous research has identified eight key factors that drive and regulate urban P cycling: 1) biogeophysical situation, 2) infrastructure and land use, 3) market and capital availability, 4) knowledge and access to information, 5) governance and actors, 6) government and regulations, 7) cultural norms and priorities, and 8) future priorities and plans (Metson et al., 2015). Incorporating city-specific factors in these categories to a quantitative understanding of P could increase our understanding of urban P cycling, and help suggest P management strategies that take into consideration local context.

Cities have the capacity to play a key role in increasing sustainable P management through the food system because they are consumers of large amounts of P-dense food and producers of large quantities of high-P organic waste. And although the social components that drive urban P cycling are particularly important (as P cycling is dependent on human actions around food and waste), these social factors have been understudied in past urban P studies (Baker, 2011; Chowdhury et al., 2014; Kennedy et al., 2010). In this article we use Montreal, Quebec, Canada as a case study to explore locally relevant driving factors, and their relationships to one another, in order to identify barriers and facilitators to increasing organic waste recycling, and thus P recycling, through composting. We build upon a quantitative analysis of P flows in the food and urban agricultural systems of the island of Montreal (Metson and Bennett, 2015), and explicitly look at the factors driving the current low levels of organic waste recycling in the system and how these factors may affect future organic waste recycling.

1.3 Montreal case study

The island of Montreal, Quebec, Canada (which includes the city of Montreal and 17 smaller municipalities, which we refer to as Montreal throughout this article) is located on the Saint-Lawrence River. Once a mostly agricultural settlement, it is now the most densely populated area of the province of Quebec, home to 24% of the provincial population (Canada Economic Development for Quebec Regions, 2010). Montreal is a major port city that historically supported a much larger industrial sector (Lewis, 2001), even including a cement quarry on its territory. Because of this history of industrial production and land use, some neighborhoods now have high levels of heavy metal and hydrocarbon contamination, affecting modern land use decisions (Ville de Montréal, 2014a).

Montreal employs a similar waste management approach to other modern cities in North America, treating a high proportion of its waste to minimize certain environmental externalities, but continuing to apply an "out of sight, out of mind" management philosophy that externalizes problems by putting them elsewhere.

Until 1984, the city disposed of all its untreated sewage waste directly into the Saint-Lawrence River. While the city began treating sewage in 1984, it wasn't until 1996 that the whole island was connected to the sewage treatment plant (Ville de Montréal, 2014c). Solid waste (including food and green waste that are high in P) was landfilled on the island until space limitations began to move landfilling progressively off-island. The last on-island landfill was closed in 2009 (Front commun québécois pour une gestion écologique des déchets, 2002; Ville de Montréal, 2014b). Montreal now pays high landfilling costs for its solid waste to be trucked off the island (Ville de Montréal, 2009). In 2013, 87% of organic waste produced on the island was landfilled (Ville de Montréal, 2014d; latest available report), but a Provincial government mandate (MDDEP, 2009), which was formally adopted in Montreal's waste management plan (CMM, 2008), requires municipalities to divert 60% of their organic waste from landfills by 2015, and 100% by 2020. Montreal is not on target to meet its 2015 objective.

The physical setting of Montreal, its history, and its current land use, consumption, and waste management practices all shape the P cycle on the island. Phosphorus entering the island of Montreal as food mostly accumulates in landfills (approximately 2.63 Gg P yr^{-1}; Metson and Bennett, 2015). All the P from biosolid incineration at the wastewater treatment plant (including the P excreted by residents) and the large majority of P collected municipally as food and green waste is disposed of by landfill. Just 6% of P in food and green waste is composted. These P flows were calculated using substance flow analysis methods, drawing from site-specific information for 2012 whenever possible. In addition to looking at the whole-island food and waste system, government reports, land use information, and surveys of 143 UA practitioners on their nutrient management practices were used to assess the role of UA in P recycling (Metson and Bennett, 2015). The food produced by the UA system and consumed on-island only represents about 0.44% of all P consumed by island residents. Overall, 73% of P applied to UA was from on-island recycled sources in 2012. In other words UA plays a small quantitative role in the Montreal P system as a whole, but practitioners of UA seem to favor recycled P sources as fertilizer. Considering the large amounts of sewage, food, and green waste produced in Montreal, peri-urban agricultural recycling will be necessary to close the P cycle. Although UA could not recycle a large proportion of P in waste (in large part because of space limitations on the island), composting through UA could possibly act as a catalyst for larger scale change, translating in to more sustainable P management at the regional scale (including peri-urban farms off-island). This quantitative analysis of P flows, which serves as both a benchmark and highlights where efficiency and recycling could be increased, is a key component of understanding how we can manage P more sustainably. It does not, however, fully explore the factors that drive and regulate P flows and thus cannot explain how they can be changed. Here, we aim to examine these driving and regulating factors, focusing on the recycling of wasted P back into the food system, and the role UA practices may play in facilitating or impeding such recycling.

In summary, Montreal is a city where P recycling is currently low, where most management practices do not encourage high waste reuse, but where increasing concerns about sustainability, and specifically increasing UA and changing organic waste management practices, may be leading to a change. Thus, Montreal is a case study of a fairly typical, modern North American city. At the same time, more information is needed to understand if and how Montreal will accomplish their sustainability goals. A better understanding of what facilitates and restricts current composting practices, as well as the factors that act as facilitators and barriers to future composting could help us understand the potential for various interventions to increase organic waste and P recycling flows, including the posited role UA may be able to play. Although we use the lens of P management and sustainability to focus our analysis and discussion, the questions and findings raised here are relevant to organic waste management more generally as well as to other resources present in organic matter such as nitrogen (although the atmospheric component of the nitrogen cycle does make management more complex, requiring further study). The goal of this article is to address the following question: What are the key barriers and facilitators for Montreal to achieve high organic waste and thus P recycling through composting, and what role could UA practices play in increasing this recycling?

2. Methods

We used a case study framework (Yin, 2003), combining three data collection methods (using qualitative methodologies described in Creswell, 2013) in order to iteratively build a list of facilitators and barriers to organic waste recycling in Montreal. We used a case study approach because this is a good method for examining a contemporary situation, exploring phenomena where local "real life" context is intrinsically tied to the phenomena, and where the research team has little or no control, all of which are features of our research question (Yin, 2003, and demonstrated in Brunet et al., 2014 and Burch, 2010). Case study design also allowed us to use a full suite of data sources to answer our research questions (interviews, participant observation and document review). We defined the boundaries of our case study as the organic waste management and UA systems on the island of Montreal, creating clear geographical and management sector limits to our data collection. Here, Montreal refers to the whole island of Montreal, while the City (with a capital C) refers to the municipal government entity.

Our research design maximized content validity by ensuring that we considered the full scope of facilitators and barriers that may occur within the boundaries of our study system. We tackled the complexity of the system and potential biases in reporting with triangulation among our three data collection methods (Creswell, 2013; Thurmond, 2001). Multiple measures can be used throughout the research process to ensure the validity of a qualitative study (Whittemore et al., 2001), and here we focused especially on a prolonged engagement in the field and the use of multiple lines of inquiry in our research process. As we were particularly concerned with gaining a detailed understanding of the Montreal system, we remained open to emergent themes (i.e., inductive process of building an understanding of the system of interest based on collected data).

In May 2014, we conducted semi-structured interviews with 19 key stakeholders in the system deemed to be experts (simply referred to as experts in the text). Experts were identified through snowball sampling throughout the participant observation process, and were selected for their access to multiple types of knowledge about composting, waste management, and UA, which we expected would lead to a broader view of the system (Marshall, 1996). These experts were based in city and municipal departments (n=4), universities (where the experts involved in pertinent research topics and were also involved in community outreach or journalism (n=6)), environmental education groups (n=6), and private companies in UA and composting (n=3). We asked these experts two open-ended questions: 1) What do you view as facilitators and motivators to composting in Montreal, and 2) What do you view as barriers to composting in Montreal. Follow-up prompts to questions were informed by participant observation and document analysis to help focus interviewees (see Text S1 for full interview scripts, noting that Research Ethics Board approval was obtained prior to starting any research). Interviews lasted between 8 and 19 minutes, were recorded and transcribed, and analyzed using *Dedoose* software.

Participant observation took place over a year and a half (August 2012 thru May 2014), through visits to gardens and farms to conduct quantitative surveys of P management (Metson and Bennett, 2015), and through public events (including municipal sponsored events, and community and NGO meetings and events). Through discussion with practitioners individually, and through group presentations and discussions, it was possible to iteratively narrow the list of initial factors that may be relevant to the Montreal context to those that were indeed important, and expand research into those locally relevant themes or factors. Information was recorded in field notes, meeting minutes, and in the "additional information" section of the survey forms on P management administered in gardens and on farms (see Metson and Bennett, 2015). This prolonged participant observation allowed the research team to gain a much fuller picture of the Montreal system and provided a way to better analyze interview data.

As participant observation and interviews focused on UA and waste managers, document review was an essential step towards understanding the issues of food and waste management that pertain to the larger Montreal community. We reviewed key government policy documents and reports, including public consultation reports that included hundreds of citizen and group reports filed with the City's public consultation commission. We also reviewed media coverage of events related to organic waste management and UA in both French and English, focusing on the implementation of the Montreal waste management plan (thus reviewing documents and media coverage from 2008 when the policy was announced through July 2014). In addition to locally-specific document review, we considered a broader list of driving and regulating factors that may be relevant to the amount of UA, and fertilization and waste management practices, based on the American Planning Association's list of important characteristics to consider for UA (Hodgson et al., 2011).

We used coding and content analysis (conventional coding as defined by Hsieh and Shannon, 2005), as well as constant comparison methods (Boeije, 2002; Glaser and Strauss, 1967) to analyze interviews, and to complement data from interviews with information from participant observations and document review. Coding involved assigning categories to interview passages, first allowing the categories to emerge from the interview material, and then recoding to include theories emerging from the review of other data sources and the peer-reviewed literature, until clear themes could be identified (see Tables S1 and S2 for all final codes used and their occurrence in interviews). We use direct quotes in the results and discussion section of this article to represent the themes that emerged from the analysis. The process of data analysis was highly iterative; we constantly reevaluated the evidence presented in all data sources to identify both reoccurring themes and divergent perspectives about themes. Through this reflexive process, allowing emergent themes to reveal themselves, we focused on key driving factors that created barriers and facilitators towards increased organic waste recycling, with a primary interest in highlighting the link to potential P recycling and thus keeping Metson et al. (2015) driving factor categories in mind throughout the analysis. The results and discussion section remains focused on these key driving factors in order to create a concise narrative and a full list of the factors and references considered during our research can be found in Tables S3 and S4.

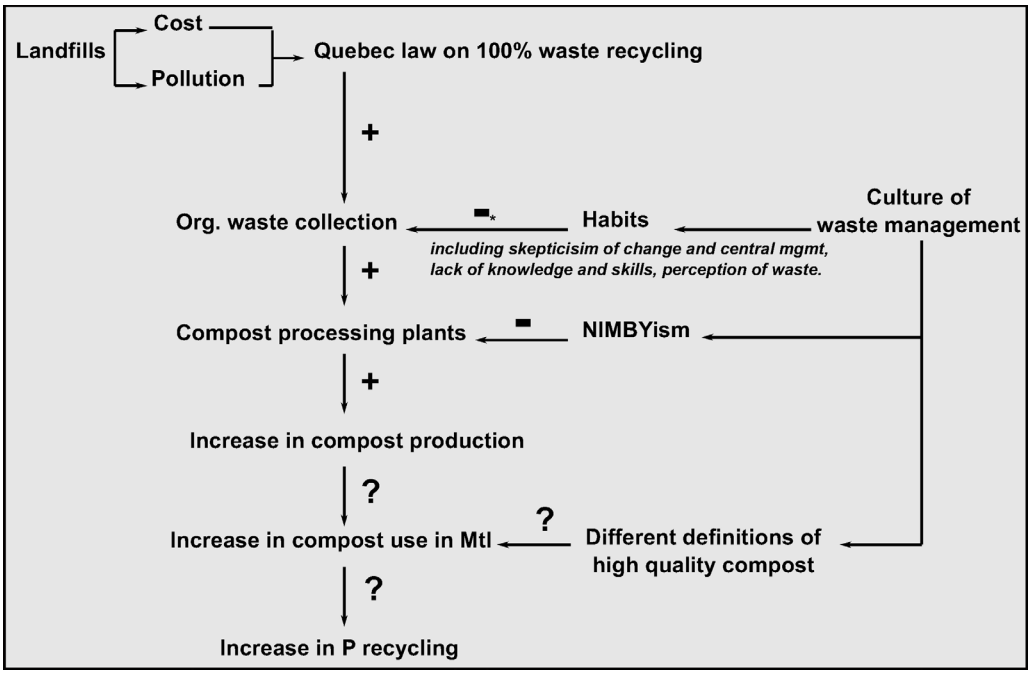

Figure 1

Factors influencing the level of organic waste and P recycling on the island of Montreal.

The Quebec law on organic waste recycling is a major facilitator to increasing P recycling, but the current prevailing culture of (and beliefs about) waste management acts as a barrier to the full implementation of the law. Arrows indicate influence or causal relations. Plus signs (+) indicate an increase or a positive effect towards P recycling, minus signs (-) indicate a decreasing or negative effect towards P recycling, and question marks (?) indicate that that the effect and outcome are uncertain with respect to P recycling. Montreal is abbreviated as Mtl, NIMBYism refers to "Not In My BackYard" sentiments (see text for more explanation). Furthermore, "organization" is abbreviated org., and "management" is abbreviated mgmt. The * indicates that the negative effect associated with this linkage reflects prevailing habits in Montreal, although habits of some residents, especially urban agricultural practitioners, are having a positive effect on composting.

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3. Results and discussion

We identified a large set of factors that influence organic waste management on the island, focusing on key facilitators and barriers to increasing P recycling in Montreal. We differentiate between recycling, which means all methods to reuse P, and composting, which is one method of recycling and reuse of P. In the following sections we expand on 1) the facilitators and barriers that affect P recycling at the whole-island level, 2) the facilitators and barriers to P recycling within the UA system, and 3) a path that takes advantage of existing facilitators to overcome barriers.

3.1 City-wide waste management facilitators and barriers to P recycling

3.1.1 Facilitators

The key facilitators that could increase P recycling at the whole island scale are a law on organic waste management and the existence of many small scale composting projects. Citizens compost at home, through Éco-quartier projects (borough level environmental awareness organizations), through private companies (e.g., Compost Montreal), and through select borough pilot projects (e.g., Rosemont borough), or smaller municipality organic waste collection programs (e.g., Cote-Saint-Luc). Environmental organizations see an increasing citizen interest in composting. As one stakeholder puts it:

"People are more and more concerned [about doing something with biodegradable waste]. Their number one concern seems to be the environment. People who come to see us really come because they know the effects landfills have."

Motivators to participate in separate organic waste collection and composting include individual environmental consciousness, and a need for fertilizer for gardening. Borough and municipality desires to comply with the Quebec waste management law also motivate some projects across the island. Successful participation in composting seems to happen when citizens are knowledgeable about proper composting techniques, and the process of waste separation and/or composting is made easy and accessible. The qualities of "easy and accessible" vary by project scale and with the type of people involved. Examples of "accessible" infrastructure characteristics include having enough space for home composting, being in walking distance of community compost facilities, and having access to free organic waste collection bins and bags that are adapted to family size.

The Quebec provincial government enacted a law mandating that cities divert 100% of their organic waste (food waste, green waste, and biosolids) away from landfilling by 2020 (MDDEP, 2009; CMM, 2008). This law should, by increasing organic waste reuse, increase P recycling because it requires Montreal to divert high P waste from landfills and produce a reusable product such as compost (Figure 1). Governments (provincial and municipal) were motivated to put such a law into place because they were concerned with the space landfills take away from other land uses, their contribution to climate change, and the possibility of

long-term environmental pollution to soils and water (MDDEP, 2009). Montreal plans to comply with this law by producing compost that can be reused, even if reuse was not the primary motivation. A stakeholder says:

"In the municipal waste plan, our objective was really to produce a very good quality compost. Our treatment technology choices were made to do so. We will make sure it's safe and make a high quality compost."

Despite these important facilitators, and even though the Montreal waste management plan was adopted unanimously by council members after public consultation showed general support for the project, Montreal is not on track to meet these goals (Beaudin, 2014; Robillard, 2013; and shown by the fact that in 2013 reuse was only at 13% Ville de Montréal, 2014d). Key barriers stand in the way.

3.1.2 Barriers

Although easy access to infrastructure and sufficient knowledge of composting has allowed some composting to flourish at smaller scales in Montreal, existing habits, conception of waste as "dirty", and a lack of ease and knowledge is hindering larger scale adoption of composting (Figure 1). To divert food and yard waste from landfills, the City must collect organic matter separately from other solid waste and recyclables, and treat the organic matter so that it can be reused. Citizens have yet to fully embrace the idea of separate organic waste collection and composting. Concerns over organic waste bins being smelly and attracting flies, maggots, and rodents are widespread, increasing the challenge of changing existing habits of not separating organic from non-organic waste. A lack of information and knowledge, and existing misinformation, about waste separation and composting also remains a barrier to the adoption of the waste management plan. Even in boroughs that have piloted organic waste collection, thus providing infrastructure to citizens, have not all been successful because of a lack of initial information dissemination about the project, and follow-up with citizens about problems after implementation of the pilot programs. As one stakeholder puts it:

"…people were not necessarily well informed on how to compost. I am talking about the little brown bins that are collected each week in boroughs that are composting. For example, in the summer people often skip a week [of putting the compost bin to the curb] and then, in no time, there are maggots and worms in the bin. People will often be disgusted, they won't want to clean, and then it's over. We will have lost those people, they will no longer be interested in composting after that."

In the past, Montreal put in place infrastructure to separate urban populations from their waste to reduce disease and increase general cleanliness (Melosi, 2005). However, this practice has created cultural and knowledge barriers to viewing organic matter as a "clean" resource when properly treated.

As a large and dense city, producing much more organic waste than could be managed and reused by individual citizens (Metson and Bennett, 2015), Montreal is building five large organic waste processing plants (two of which will do biomethanation to produce energy from the organic waste decomposition process) to fulfill the City's waste management plan objectives. However, the City has had difficulty finding sites to build the processing plants they need. One stakeholder says: "Where are we going to compost? We know this is the big fight: not here, not where I live, not where he lives…, finding a site for compost processing is an issue." This difficulty in site identification was also clear throughout Montreal's public consultation procedures and media coverage (see Table S3 for sources).

One of the sites proposed by the City initially, the Saint-Michel Environmental Complex, is a particularly poignant example of the political, social, and economic history and context surrounding some of the "Not in My Backyard" attitudes (NIMBYism) that exist in Montreal about composting. The Saint-Michel site was initially a cement quarry, then transformed into a landfill. The site was one of the last landfill sites to be decommissioned on the island (stopped receiving putrescible waste in 2000, and dry construction waste in 2009) and is located in the densely populated borough of Villeray – Saint-Michel – Parc Extension. Currently, the site houses a small municipal open-air composting operation, but there has been strong citizen and political opposition to building a larger indoor composting facility (including petitions, and municipal election platforms see Table S3). Residents were concerned about noise and smells associated with having an organic waste processing plant near their homes. One stakeholder said:

"I think [the political opposition to the Saint-Michel site] is merited, because [the City] has violated the rules laid-out by the Ministry to protect peoples well-being in siting those locations [being more than 150m from residences]."

Ultimately, the Quebec Minister of the Environment did not approve Saint-Michel as a location for the composting plant (see Table S3), and the City has now proposed the purchase of private land in the Rivière-des-Prairies-Pointe-aux-Trembles borough as an alternative site (Chapdelaine, 2014). The City has faced similar lack of local "buy-in" at other proposed sites (Marchal, 2012; Office de consultation publique de Montréal, 2012b), making it difficult to move forward with the implementation of the City waste management plan.

In addition to barriers associated with organic waste collection and processing, there exist barriers to compost use in and around Montreal associated with different stakeholder views about the appropriate scale of composting and compost quality. Many experts believe that large-scale composting projects do not produce high quality compost because the waste used to produce it could be contaminated (organic waste can sometimes contain non-organic waste such as plastics and metals) and/or because highly processed foods do not produce high quality compost. An underlying assumption is that smaller scale composting can

ensure more traceability of materials, and thus higher quality compost. As such, some believe that large-scale compost production is a waste management strategy, and not an option for reuse in agriculture (especially in horticulture where crops are destined for direct human consumption and thus where pathogenic and metal contamination must be avoided). One stakeholder sums up this view by saying:

"Waste management and producing a good end-product for gardening are two separate worlds. It's a real mistake to try to glob those two things together."

A lack of "buy-in" by one important stakeholder may impede the whole system from working. One stakeholder says:

"I think that from the moment where one actor, one borough, isn't on-board, it slows down the whole process. […] if one actor doesn't participate, there is a lack of awareness, then there is a risk that costs will go up for all the other actors."

Overall, the provincial law on the recycling of organic waste should facilitate the reuse of P in Montreal. However, current infrastructure for collection and processing, in addition to a lack of political and cultural support for the collection, processing, and reuse of organic waste, have translated into low recycling in the system (although smaller subsets of the population do successfully compost). As such there seems to be an uncertain future for increasing P recycling through composting (as noted by the question marks in Figure 1). There exists a lack of trust and knowledge among different actors in the system, in addition to different norms about what can and should be reused. These lacking elements point to low social capital hindering Montreal's ability to successfully implement a law that could increase P recycling.

3.2 Facilitators and barriers to P recycling in urban agriculture

Urban agriculture (UA) requires P inputs to produce food, making it an integral, although small, part of Montreal P cycling (Metson and Bennett, 2015). Increasing the area dedicated to UA and the amount of locally-recycled P applied to this area are two ways UA can contribute to increasing urban P recycling. Understanding the factors that facilitate and constrain the urban area under cultivation, the type and amount of P fertilizer application, stakeholder's feelings about changes to the type and amount of fertilizer applied to plots, and waste management practices is key to determining the role UA can play in P cycling.

3.2.1 Facilitators

Practitioners of UA are more inclined to participate in composting than average Montreal residents because they have more knowledge of composting, access to composting sites, and have a use for compost; these factors act as facilitators. Many, if not most, current UA practitioners share a desire to move towards alternatives to conventional, high-input and high-waste, systems. Compost production can be one way to achieve such a goal. Metson and Bennett's (2015) surveys with local UA practitioners revealed that the majority of them practiced some type of green waste or food waste recycling strategy. "Generally, [urban agricultural practitioners] need compost to ensure their plants are productive and to fertilize their soil. Needing compost is a motivating factor" (interviewed stakeholder). UA is thus both a compost producer and a compost user, creating an incentive to seek tools (e.g., composting bins), space, and knowledge to do it properly. As such UA can support increased P recycling on the island.

Montreal has seen a sharp increase in interest in UA in recent years, which should lead to increased P recycling (Table S4). More than 29 000 residents signed a petition in 2011 to initiate a public consultation process about UA (in support of increasing UA) with the City through the Office of Public Consultation of Montreal (OCPM). In October 2012, the OCPM produced a recommendation report for the City, where it summarized the thoughts of 15 000 stakeholders and 103 written statements submitted during the consultation process. The report specifically mentions the importance of compost in UA, and suggested that the City of Montreal should create of a permanent committee to support and coordinate UA efforts, which was done in 2013 (OCPM, 2012a). In addition, the Conférence régionale des élus de Montréal (CRÉ) has created a Montreal food-system plan. The plan is a guide for Montreal to develop a sustainable and equitable food system. One of the plan's core themes is to reduce the ecological footprint of Montreal's food system, through measures such as reducing food waste, increasing food waste recycling, and increasing local production in UA (CRÉ, 2014). Together the OCPM recommendations and the CRÉ plan support more efficient use of P (decreased food waste), more local compost production (and thus recycled P), and a market for compost (through increased area of UA).

3.2.2 Barriers

Some types of UA might discourage the use of certain fertilizers (including compost), and as such this can act as a barrier for UA to increase P recycling on the island. Individuals and groups have different motivations for participating in UA (Duchemin, 2013), and as such use different nutrient management practices, including some that may unintentionally discourage P recycling. For example, educational UA projects often have rules to ensure that participants, including children, are not in contact with any type of heavy metal, organic, or pathogen contamination. As such, non-certified inputs, and composting on-site may be discouraged. One

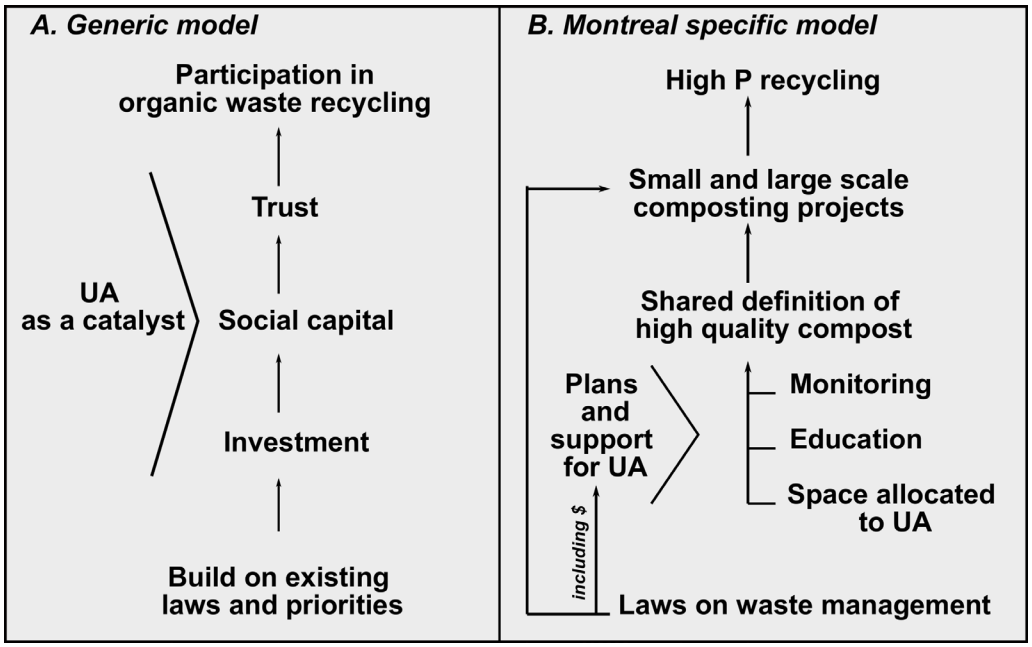

Figure 2

Model to overcome barriers to increasing organic waste and P recycling.

The *Generic model* (Panel A) shows how increasing trust through investment in urban agriculture (UA, an existing priority in Montreal) could increase social capital and trust. The *Montreal specific model* (Panel B) shows which laws and priorities can be used, and what types of investment could lead to increased organic waste and P recycling on the island based on our study.

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stakeholder says, "Schools also have public health guidelines, and if they want to compost at school, I know with the School Board, there are guidelines for on-site home composting." Because urban compost comes from large scale collection, there is a potential of contamination; thus, most educational projects prefer not to use City compost. Concerns about urban soil contamination also means that education-oriented UA is often done in containers, and practitioners cultivating in containers tend to use less recycled sources of P as fertilizer (Metson and Bennett, 2015).

In addition to barriers to using compost in UA, there are also factors that limit the presence and expansion of UA overall. Many current UA practitioners feel that a lack of physical and monetary capital is hindering local UA endeavors and future expansion (OCPM, 2012a). Limited financial resources allocated to UA by the municipality (and other government levels), as perceived by stakeholders in the system, may be creating situations where there is a lack of knowledge about proper P application and proper composting. Specifically, cuts in financial resources has resulted into less horticultural councilors in community and collective gardens, and access to such specialists for private gardeners as well. Although spatially variable, there is a lack of space to practice UA (e.g., waiting lists in community gardeners), and lack of financial resources to transform spaces that could be used for UA.

3.3 Opportunities to overcome barriers by using UA as a catalyst

UA production may not be a large quantitative P recycler (Metson and Bennett, 2015), but it may indeed act as a catalyst for larger scale compost production and reuse. A focus on UA could be a way to fully realize and synergize the benefits of two key facilitators toward P recycling: 1) the law on organic waste diversion and, 2) the large public support for increase UA (Figure 2). When speaking about the role of UA in Montreal's compost production, one stakeholder said:

"… I focused on urban agriculture in my neighborhood since I arrived at the organization 4 years ago. I feel like it is the window, or the door, that allows you to engage on the whole landscape of environmental themes".

Montreal residents want more UA (as seen through the public consultation process) and this can align with organic waste reuse goals if stakeholders can create a shared definition of "high quality" compost such that UA becomes bigger user of larger-scale compost and the P it contains, and there is trust between stakeholders in the system. A shared definition of "high-quality" would allow for production processed to match this definition, ensure a market for the product, and facilitate reuse beyond UA as urban consumers may be more comfortable purchasing from peri-urban farmers that use Montreal-sourced compost.

Based on interviews and participant observation, there are four key elements that must be present in Montreal for P recycling through composting to be successful: 1) Knowledgeable citizens, 2) Ease of practice through infrastructure, 3) Compost as a valued product (including perceived high quality), and 4) Monitoring to ensure adherence to a composting program and continued high quality compost product. Based on our understanding of the Montreal system, we believe support for UA may in fact support larger-scale P recycling by engaging elements 1, 3, and 4. The permanent committee on UA (based on the OCPM recommendation)

and the Sustainable Montreal Food System plan (CÉM, 2014) may present two opportunities to educate about, support, and monitor composting. They could serve as starting points for "innovation platforms", an infrastructure for actors with diverse types of knowledge and resources to come together to find innovative solutions to a problem, while meeting multiple goals at once in a complex system (as shown in Consoli and Patrucco, 2008). Both of these initiatives act as shared spaces between the City, and citizens and organizations (and could include universities). As such, these initiatives can act as facilitators for the co-creation of a high quality compost definition by building social capital.

A shared, or coproduced, waste management plan, based on a common definition of "high quality" compost, could ensure that UA practitioners and local peri-urban farms trust and use Montreal compost (i.e., a valued product they trust). In fact, the majority of the experts we interviewed expressed that combining both small scale and large scale composting was a possible and desirable path to take, indicating that increasing composting through UA could indeed be complementary to larger scale processes. Sixteen out of 19 interviewed experts discussed the roles and responsibilities of actors in the system in such a way that favored the involvement of individual citizens, all the way to municipal government in compost production. In addition, nine experts explicitly mentioned UA as a catalyst to increasing composting, not only as a small-scale producer and user of compost. As described by one stakeholder, we must take a multi-pronged approach in order to achieve organic waste recycling, where people trust the end-product:

"Cities must take care of [composting] and the provincial government as well. The citizen is at the base of the whole concept, if he wasn't here there wouldn't be any organic waste. Yes, we need to centralize, but it should be a bottom-up process that takes into consideration citizen participation."

Increased funding for UA projects could further contribute to increasing knowledge of practitioners and the general public, thus directly increasing small scale composting, and indirectly decreasing negative perceptions or misconceptions about organic waste reuse at larger scales. In addition, it would be beneficial to implement monitoring programs on UA practices (e.g. composting practices, rates of fertilizer and compost application, soil P tests), citizen concerns (e.g., facility of collection system, access to compost), and on compost quality (large and small scale), so that the City may constantly reevaluate their outreach and compost production to ensure that they are meeting citizen expectations and environmental objectives. Using UA as a building block, or a catalyst, may actually decrease the need for large scale monitoring and enforcement around organic waste separation because building on existing desires (i.e., UA) in Montreal and increasing social capital can decrease transaction costs by creating a shared understanding of why compost is being produced (Isham, 2002).

Our analysis of increasing P recycling in Montreal and the barriers we identified, are similar, in general terms, to literature about other complex environmental challenges and how a lack of social capital and trust can sometimes be a larger barrier to change than physical or economic capital. Although studies on urban P management have not often explicitly considered the role of social capital, studies on urban climate change adaptation and mitigation have. For example, Burch (2010) found that successful implementation of climate mitigation and adaptation plans, overcoming path dependency in municipal institutions, was more about building on existing capacity by fostering a culture of collaboration, leadership, and innovation, rather than investing in new policies or resources in the Vancouver metropolitan area. We can draw parallels between the situation described by Burch (2010) about Vancouver's climate change policies, and Montreal's organic waste management. In both cases there exists inertia in current culture and organizations that acts as a barrier to taking advantage of laws, and even public desire, to facilitate more sustainable resource management. Investing in social capital to increase trust may be one way to overcome these barriers, where building on existing capacity within the cities is possible.

4. Conclusion

Cities are hotspots of resource consumption and waste production. As such, developing locally adapted organic waste management strategies for cities around the world is key to local and global resource management including P sustainability and P recovery from organic waste streams. In every city, there are facilitators – factors that encourage organic waste recycling – and barriers – factors that discourage it. In Montreal, a law mandating 100% organic waste recycling by 2020 and recent support for UA act as facilitators towards increased organic waste, and thus P recycling. But in order for Montreal to take advantage of this, it will be necessary to increase knowledge and trust among actors and build an infrastructure and culture that is conducive to waste collection, processing, and reuse. A current lack of social capital, especially tensions between the role of large-scale centralized compost production and small-scale production, hinders the implementation of any organic waste reuse plan. Closer collaboration between waste management and UA sectors may be one

way to increase P recycling by 1) increasing citizen knowledge about composting, 2) creating shared definitions about compost quality, 3) increasing trust among actors, and 4) implementing continuous monitoring, in order to overcome barriers to organic waste recycling. Although Montreal currently recycles only small amounts of its P via composting, more recycling seems possible by focusing on existing synergistic municipal priorities, and using them as a type of "innovation platform" to increase social capital in order to implement a composting plan that increases recycling.

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Contributions

- GSM contributed to conception and design, acquisition of data, analysis and interpretation of data, drafted and revised the article and approved the submitted version for publication.
- EMB contributed to conception and design, drafted and revised the article, and approved the submitted version for publication.

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Competing interests

The authors have declared no competing interests exist.

Supplemental material

- **Text S1. Interview scripts (DOC).** doi: 10.12952/journal.elementa.000070.s001
- **Table S1. Occurrence of themes related to Montreal's facilitators and barriers to composting in interviews (DOC).** doi: 10.12952/journal.elementa.000070.s002
- **Table S2. Co-occurrence of themes related to Montreal's facilitators and barriers to composting in interviews (DOC).** doi: 10.12952/journal.elementa.000070.s003
- **Table S3. Lines of evidence used to select relevant factors (facilitators and barriers) to recycling through composting (DOC).** doi: 10.12952/journal.elementa.000070.s004
- **Table S4. Justification of factors selected affecting composting of organic waste (city and urban agriculture (UA)) (DOC).** doi: 10.12952/journal.elementa.000070.s005

Data accessibility statement

Interview data summaries are available in Table S1 and S2, and interview questions are available in Text S1. Transcripts of interviews are not made publicly available because, although responses have been anonymized, we did not conduct random sampling and must protect the identity of participants. Table S3 and S4 provide details of government, peer-review literature, and media sources used in the article.