Confronting Environmental and Social Drivers of Lead Exposure in Urban Gardens
Through Community Centered Remediation

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Executive Summary

The legacy of anthropogenic soil lead pollution continues to pose a serious health risk in the urban environment despite bans on lead based paint and leaded gasoline in the late 20th century. As with so many environmental problems, low-income communities of color bear a disproportionate share of this health burden. As cities fail to address soil lead contamination today, they uphold a pattern of environmental racism that urban communities of color have experienced in various forms throughout their history.

The social benefits from urban agriculture provide grassroots methods to confront the injustice these neighborhoods face. In addition to increasing access to fresh, healthy food, urban community gardens provide opportunities for youth empowerment, political organizing, and cultural preservation. However, gardeners’ regular interaction with soil increases their lead exposure. The central goal of this ongoing project is to support urban agriculture by providing strategies to decrease lead exposure in urban gardens. Identifying the environmental and social drivers of lead exposure in urban gardens is essential to successfully address it. An effective remediation plan must prevent lead exposure at a local level while confronting the systems level root cause of the contamination.

From lead bioaccessibility and environmental transport to systemic oppression, this study takes a systems approach to understanding the lead health risk in urban gardens. This work requires an interdisciplinary toolset and it aims to be community-based and action-oriented to reduce gardeners’ lead exposure. By integrating urban geochemistry and participatory action research methodologies, this study presents new model for conducting environmental health research that aligns with residents’ vision and goals for their community. Partnership with The Food Project, a non-profit urban agriculture organization based in the Dudley neighborhood of Boston, forms the basis of the research model. This collaboration enables a community-academic knowledge exchange that leads to remediation options tailored for and readily implementable in Dudley and other low-income communities of color.

The study begins with geochemical investigation of lead bioaccessibility, or the fraction of lead that’s soluble in gastric fluid and can cause health detriments. Changes in lead bioaccessibility are measured across growing materials (unamended soils, garden soils, raised beds, and composts), grain sizes, and by lead source. Results show low lead compost is a
valuable alternate growing material or amendment for contaminated soil, as it dilutes lead concentrations, reduces lead bioaccessibility, and limits fine particle resuspension. By working with The Food Project, these results have shaped gardeners’ behavior to reduce lead exposure. At a national level, these results contribute to a growing body of research on urban soil lead bioaccessibility that influence policy decisions such as benchmarks for safe soil or compost lead levels.

The social and historical context of the Dudley neighborhood provides systems level insight into the urban agriculture – lead contamination intersection. Through an interdisciplinary literature review and interviews with stakeholders in the Boston urban agriculture network, this analysis explores who’s impacted by lead and why. Products of structural racism – in particular redlining and disinvestment – created the social and physical environments that allow lead contamination to persist in low-income communities of color like Dudley.

Taken together, these perspectives on lead contamination highlight remediation methods that reduce lead exposure immediately at the local level while supporting long-term community sovereignty. A community led urban agricultural system serves as an example, as it presents an opportunity for soil management that simultaneously provides a range of social benefits. Ultimately, the most effective pathways to address soil lead contamination will reflect the understanding that social and environmental injustices cannot be separated, and therefore must be addressed synergistically to produce sustainable, equitable outcomes.
Introduction

The legacy of anthropogenic soil lead pollution poses a serious health risk to many urban communities. Leaded gasoline and leaded paint used extensively in the 20th century account for the primary sources of urban soil lead present today (Clark, Brabander, & Erdil, 2006; Mielke & Reagan, 1998). While these sources are no longer contributing to the urban lead burden, lead is stable in typical soil conditions so the contamination remains a public health threat in the built environment (Filippelli, Laidlaw, Latimer, & Raftis, 2005).

Lead poisoning causes a variety of negative neurological effects. Even at low levels of exposure, lead can cause serious intellectual deficits, especially in children, and increase the likelihood of depression, anxiety, and other detriments (D. Bellinger et al., 1991; Bouchard et al., 2009; Lanphear et al., 2005). As research on the health impact of Pb expands, it is becoming clear that there is no safe level of lead uptake (WHO, Oct 2014). The implications of this health burden span the global scale; approximately 250 million people worldwide have blood lead levels above the current CDC benchmark for lead poisoning (Fewtrell, Prüss-Üstün, Landrigan, & Ayuso-Mateos, 2004).

Soil lead disproportionately affects low-income communities and communities of color (Aelion, Davis, Lawson, Cai, & McDermott, 2012; D. C. Bellinger, 2008; Campanella & Mielke, 2008; Filippelli & Laidlaw, 2010; Filippelli, Risch, Laidlaw, Nichols, & Crewe, 2015). Social, political, and economic forces including discrimination, business disinvestment, and redlining have left many of these neighborhoods without basic goods and services, forcing residents to leave their community to purchase food, clothes, and other amenities. The absence of a local economy limits job opportunities and perpetuates poverty (Alkon et al., 2013; Medoff & Sklar, 1994). Residents face restricted access to fresh, healthy food, employment opportunities, good schools, recreational facilities, and healthcare, which constitutes a serious public health problem that only amplifies the negative outcomes of lead exposure (D. C. Bellinger, 2008). Since low-income urban populations who face the highest risk for lead exposure also face other disproportionate burdens that harm health and wellbeing, these issues must be understood as interrelated and driven by systems of social, environmental, and economic injustice (D. C. Bellinger, 2008; Bullard, 2002; Phoenix, 1993; Subica, Grills, Douglas, & Villanueva, 2015).
The social benefits from urban agriculture provide grassroots methods to confront the injustice these neighborhoods face. In addition to increasing access to fresh, healthy food, urban community gardens provide opportunities for youth empowerment, political organizing, and cultural preservation—all of which help create strong, supportive social networks that catalyze bottom-up neighborhood revitalization (Ober Allen, Alaimo, Elam, & Perry, 2008; Okvat & Zautra, 2011; Saldivar-tanaka & Krasny; Subica et al., 2015). The central goal of this project is to support long term, resident driven urban agriculture by providing strategies for decreasing lead exposure in urban gardens.

This study takes an interdisciplinary, community based, applied approach to identify and confront the social and environmental drivers of lead contamination. This research mode takes a systems perspective to inform remediation pathways for the lead health burden. As an interdisciplinary, multifaceted project, the writing style varies to meet the goals of each chapter, which are outlined below. While this work is most informative if read as a whole, each section can stand alone for readers who are interested in particular themes or goals.

Chapter 1

GeoHealth is an emerging branch of the Urban Geochemistry discipline that links biogeochemical flows with public health problems to inform remediation decisions. Since these problems are tied to complex human and environmental systems, research requires innovative methodology that is interdisciplinary and centers on the goals of the communities bearing the health burden. While established geochemistry methods are essential for conducting GeoHealth research, they are not sufficient. This chapter presents a new model for urban geochemistry research to meet these additional needs, and uses this research project on the social and environmental drivers of lead exposure as an example. This model is informed by over a decade of GeoHealth research on soil lead contamination in urban gardens, and draws on principles from other fields of research, primarily Participatory Action Research, to enhance existing GeoHealth strategies. In our experience, this framework for practicing interdisciplinary, community-based, and action-oriented research enables comprehensive problem definition and identifies solutions that align with community goals.
Chapter 2

While the presence of lead in the urban environment is well documented, less is known about the bioavailability and transport of urban soil lead, which is essential information to accurately assess risk and develop effective solutions (Henry et al., 2015; Mielke et al., 1983; Mielke & Reagan, 1998; Mielke, Laidlaw, & Gonzales, 2011; S. Zahran, Laidlaw, McElmurry, Filippelli, & Taylor, 2013; Zia, Codling, Scheckel, & Chaney, 2011). Chapter two uses Geochemistry and GeoHealth perspectives to study the mobility and uptake of Roxbury and Dorchester urban gardens. This approach is a quantitative investigation of how lead bioaccessibility changes as a function of growing material, grain size, and source. By working with The Food Project to identify and answer questions that are useful to urban farmers, the results have shaped local agricultural decisions to reduce lead exposure. Further, since lead bioaccessibility assessments have yet to be conducted in most US cities, the results from this study have broader applications to understanding the lead health risk in other settings.

Chapter 3

Many scholars identify that low-income Black and Latino populations are disproportionately impacted by soil lead contamination and are more likely to have elevated blood lead levels (Campanella & Mielke, 2008). While this is a crucial observation that enables population-targeted solutions, it does not capture the causes of environmental health disparities. Chapter three provides a systems level analysis of the social drivers of urban soil lead contamination. It’s not by chance that urban communities of color are disproportionately affected; rather, systemic racism present in US social, political, and economic systems has created the social and physical environments within which lead pollution persists. Understanding systemic racism and the role it plays in environmental pollution is essential to understand the problem of environmental lead contamination in its entirety and identify solutions that will meet long term community needs.

This study is the outcome of a long-term relationship with gardeners in the Roxbury and Dorchester neighborhoods of Boston that was formed to support safe, just, and sustainable urban agriculture. Taken together, these chapters provide a systems perspective on the drivers of soil lead pollution from the local scale to structural scale. Reaching this comprehensive problem
definition requires community collaboration and a trans-disciplinary perspective. Both of these factors have enhanced the applicability of research by focusing on questions centered on reducing residents’ lead exposure. This study is not the end-point of this project; rather, the outcomes presented here represent a checkpoint the current state of this research that will continue as long as Dudley growers are still finding lead in their backyards.
Chapter 1

A New Paradigm for Community-Based Urban Geohealth Research

1. Introduction

1.1 New Directions in Environmental Geochemistry

In the past decade, Urban Geochemistry and Public Health have intersected and emerged as a new field of geoscience termed ‘GeoHealth’ that examines the impact of chemical element flows on the health of urban populations (Brabander & Fitzstevens, 2014; Figure 1). Many geochemists recognize the value of studying biogeochemical cycles within broader social, political, and economic systems (Fyfe, 1998; Ludden, Albarède, & Coleman, 2015; Lyons & Harmon, 2012), and GeoHealth provides a framework for doing so. GeoHealth uses an interdisciplinary environmental studies perspective to link humans, health, and environmental systems to address urban public health issues. This approach is key to understanding risk associated with urban contaminants and developing effective remediation schemes (Chambers et al., 2016; Filippelli, Morrison, & Cicchella, 2012).

Figure 1: A conceptual representation of the emerging GeoHealth discipline presented by D.J. Brabander & M.F. Fitzstevens at the 2014 GSA annual conference. While this model is useful, community members are key constituents missing from this space.
As the field continues to evolve, GeoHealth scholars are finding that the local social and cultural context of their work is essential to understand and apply their geochemical findings (Filippelli et al., 2015). However, practicing human centered research is new for many Geoscientists, and the discipline offers limited methodological frameworks for doing so. Adopting a new research approach that crosses disciplinary boundaries is not intuitive; it requires openness, patience, and intentionality. Geochemists experimenting with citizen science and/or forming interdisciplinary partnerships to enhance their work are taking the first steps to develop a research methodology that includes a wider network of stakeholders and forms of knowledge (eg. Filippelli et al., 2015; Stewart, Farver, Gorsevski, & Miner, 2014). New approaches for bridging geoscience, health, and environmental justice at a local scale will provide useful methodological and conceptual tools for GeoHealth scholars seeking to practice community-based research.

1.2 Chapter Goals & Overview

In the Brabander lab’s 15 years of lead (Pb) mobility and exposure research in Boston, collaborating with organizations and residents has shaped our approach to research by situating urban geochemistry in the local social and physical environments. We aim to practice community-based, interdisciplinary, and applied research, which are central principles to research fields outside of the geosciences, namely Participatory Action Research (PAR). We believe incorporating these principles into GeoHealth projects can amplify their positive impacts. Practicing interdisciplinary community-based research facilitates a collaborative process in which a range of stakeholders can be involved. With a diversity of perspectives, problem definition is more comprehensive and accurate, yielding scientifically informed solutions that align with community goals.

By routinely reflecting on our own research and drawing on the experience and theory of other community-based research practitioners, we have developed a framework to incorporate community voices, interdisciplinary thought, and apply scientific findings in geochemistry based projects. In this chapter we present this framework and discuss our experience investigating Roxbury soil and compost Pb. Our proposed model is a starting point for researchers to begin practicing community-based GeoHealth research.
2. Overview of Participatory Action Research

Non-academics and scholars alike have been practicing forms of community-based Participatory Action Research (PAR) since the mid 20th century (Bacon, Mendez, & Brown, 2005). The underlying principles of PAR align well with our own, so the experiences, research theories, and strategies of Participatory Action Researchers inform and inspire our model. Though our research is not strictly PAR, we’ve drawn from its general methodology to develop our research process. This experience shows that PAR core principles are transferable and can enhance community-based GeoHealth research.

2.1 Origins and Description

PAR is a process of community-based investigation and action practiced collaboratively by a team of community and academic partners to create positive change. Rural farming communities primarily in the Global South developed PAR in response to imperialist research projects that disrupted and misrepresented their livelihoods and cultures while claiming to be a force of good (Smith, Pyrch, & Lizardi, 1993). PAR breaks out of the traditional researcher-researched dichotomy and instead seeks collective empowerment for meaningful change (Baum, MacDougall, & Smith, 2006). Collaborators collectively define a problem, conduct research, reflect on results, and take action (Figure 2; Bacon et al., 2005; Smith et al., 1993). The explicit intent to create positive change and redistribution of power differentiates PAR from scientific inquiries that claim objectivity.

Figure 2: Illustrated cycles of PAR research, from Bacon, et al., 2005.
2.2 Shifts in Mindset for Academics

Moving away from the conventional research paradigm presents a significant challenge for many academic researchers. While incorporating PAR strategies into research can facilitate this cognitive shift over time, there are two fundamental concepts that scholars, including myself, must understand and apply to incorporate PAR methods successfully. First, we must learn to see and confront power hierarchies and second, we must create open systems of knowledge production.

Seeking to understand and change conventional power structures at the systemic and interpersonal scales is an essential component of PAR that is not typically embraced in mainstream academia. In the US, people hold power and privilege inequitably based on race, class, nationality, gender, and sexuality, among other determinants (Johnson, 2006). Structural inequality is a core driver of injustice and oppression and therefore must inform the way we understand environmental health problems and conduct research (Bullard & Lewis, 1996; Morello-Frosch & Jesdale, 2006; Morello-Frosch & Lopez, 2006).

Since we learned these structural power hierarchies throughout our lives they will manifest in our interpersonal relationships unless we choose to resist them (hooks, 1995; Lorde, 1984; Vigen, 2006). This is a complex, lifelong process, and it can begin with acknowledging and confronting micro-level forms of oppression evident in the tendency of those with privilege – white folks, cis-men, academics, etc – to exert power over others by dominating conversations, making major decisions, using inaccessible language, and not listening ("Anti-Oppression Principles and Practices," ; Baum et al., 2006; Vigen, 2006). As PAR requires collaboration with a range of stakeholders, it’s essential to acknowledge power dynamics and actively seek equitable power distribution among project participants (Baum et al., 2006; hooks, 1994; Minkler & Wallerstein, 2011).

Building on this concept, GeoHealth practitioners must learn to value all forms and sources of knowledge, not just those that are traditionally valued in the Western academic and social hierarchies. Bacon, et al., highlights the importance of local knowledge by describing an interaction between a farmer and a visiting researcher. The farmer understands her land, climate, livelihood, and community through lived experience and offers a first hand perspective that cannot be found through the researcher’s technology (Bacon et al., 2005). Most scientific communities operate within closed systems of knowledge production that only include a
minority of the global population and favor groups with power and privilege (TallBear, 2014). Recognizing lived experience as an equal knowledge production process is one way to broaden this circle and include voices that typically go unheard in large-scale decision-making (Nazarea, 2006). This approach creates what Inhorn and Whittle call “an open system of knowledge production” that allows for more accurate problem definition and provides essential information for creating long-term change that meets community needs (2001).

2.3 PAR Core Principles & Adaptability

PAR must take a variety of forms depending on the project goals, community setting, and the team of collaborators. Time and resource limitations for academics and community partners create less ideal (though no less realistic) reasons to adapt the PAR process. In these cases, it’s important for the academics to make sure the underlying principles of PAR outlined below remain at the center of their work if they wish to adopt this new research paradigm.

Prior to the start of the Brabander Lab – Food Project partnership in the early 2000s, Dudley residents had already identified, reflected, and acted on environmental pollution by collectively cleaning garbage filled vacant lots in their neighborhood. As their process stemmed from identifying community values, it provided a framework and direction for addressing lead contamination in urban gardens by community organizations, academics, and the City of Boston. Due to time constraints, the turnover of students and Food Project employees involved with this project, and the existing foundation created by residents for dealing with environmental pollution in Dudley, this project has not followed published models of PAR. However, it has drawn on the following principles put forth by PAR practitioners to ensure that community-based research is useful and non-oppressive. As discussed, these core PAR principles are in line with our research goals and values. Work should be:

1. Community-Based: Community residents identify what action is useful, and their visions for their neighborhood are at the center of decision-making.

2. Applied: Research leads to outcomes that aid local scale solutions for the problem being studied. Ideally, research also yields outcomes applicable at systemic level to inform remediation decision-making in other contexts.
3. Interdisciplinary: Work must be interdisciplinary, at least in part, as a more comprehensive problem definition will lead to a more holistic solution capable of addressing multiple problem drivers.

Collaborating with residents or neighborhood organizations that are engaged with the research topic from a different perspective supports these principles, particularly the first and second. Partnership focuses the work on community members’ goals, which leads to outcomes that are applicable in the neighborhood. The nature of these relationships will vary depending on community interests, setting, and project longevity. Building trust is essential to form and maintain community partnerships. This process takes time, patience, and vulnerability on behalf of the academic researchers (Christopher, Watts, McCormick, & Young, 2008).

2.4 The Food Project- Wellesley College Partnership

Our primary connection to the Roxbury/Dorchester community is through a partnership with The Food Project, a non-profit organization that practices urban farming for youth and community empowerment. This relationship has evolved over the past 15 years, but the connection has kept our geochemistry work rooted in the community’s needs and vision for change.

For the most recent period of research presented in Chapter 2, working with Food Project employees has shaped our research questions, sample collection, and our perspective on outcomes. This relationship provides insight into the social and cultural context of the project, provides applications for our findings, and informs this proposed research model.

2.5 Academic Rigor

This form of research varies from a traditional mode of scientific inquiry, but not at the expense of scientific rigor (Han & Stenhouse, 2014). This approach aligns with feminist scholars who embrace personal investment and positionality as factors that influence and enhance their work (TallBear, 2014). In fact, holding a high standard for data collection and interpretation is a key priority; both academics and community partners are invested in reliable results since they will ultimately inform action. PAR scholars regularly publish in peer-reviewed journals, present at national conferences, and receive grant funding, which reflects the high academic standard of their work.

We are proposing a new framework for integrating Participatory Action Research practices into GeoHealth scholarship. When applied to our work on urban soil Pb contamination, we’ve found that this model broadens the scope of potential solutions, which allows our partners to identify and implement sustainable solutions that are in line with community desires. Since every community partnership is unique, we encourage scholars to adapt our model based on the goals and resources of the neighborhood they’re working in and academic constraints. Although the exact methodology is intentionally flexible, the core principles of PAR – research is community-based, applied, and interdisciplinary – provide a strong foundation for urban Geohealth scholarship and should be the common thread uniting projects of this nature and scope.
**Figure 3:** Proposed model for community based, applied, interdisciplinary urban geochemistry. This diagram illustrates the intersectional space between the natural and social sciences where collaborative, community based research can occur. Community partnership formation is a precursor to this process.

### 3.1 Phase 1: Question Generation

As with any research process, this work begins with question generation. Researchers should begin practicing interdisciplinary thought at this step, since the most useful questions will likely be tied to both social and environmental systems. This thinking should carry throughout the project, since employing a trans-disciplinary perspective will enrich all of the phases (Figure 3).

All project collaborators should be involved in this phase. Often, collaborators will be interested in different questions depending on what draws them to the project; this is to be expected and embraced. Collaboration broadens the range of questions, which ultimately provides a more comprehensive understanding of the issue that any single researcher couldn’t access. For academics, it’s important to remember that community partners’ questions must be prioritized over our own to uphold the ‘community based research’ principle.

Reaching out to a grassroots organization can be a good place to start this process, since they better understand and can advocate for the needs of their community (Subica et al., 2015). If they are interested in partnering and welcome the research project into their community, academic partners should be upfront about their intentions and what they will gain from the work. Being patient and transparent throughout this phase builds trust and creates a foundation for the project (Christopher et al., 2008).

### 3.2 Phase 2: Applying Research Lenses

The lenses provide ways of thinking that focus and direct our research questions. In this phase, researchers engage more deeply with the questions and begin a research cycle. Prioritizing the appropriate lenses is a significant decision that ultimately shapes methods and results. Choosing lenses should be informed, but not governed, by academic background and provide a useful perspective for understanding the complexity of the questions.

The natural science lenses for this project were selected because we believe that Urban Geochemistry and GeoHealth provide essential frameworks for understanding soil Pb contamination. These lenses bridge geochemistry and health in an urban setting, so the way we approach the question will link Pb environmental presence, exposure, and impact.
We drew on the work of Subica, et al., to select the social science lenses (2015). They propose social justice, culture and place, and community organizing lenses to develop action plans around childhood obesity in communities of color. Their approach is applicable to a range of issues and aligns with the core principles of PAR. The social justice lens identifies systemic drivers of health problems, while the culture-place lens situates the problem in a specific community context. Together, they aim to capture scale and history of a problem’s social system context. This perspective is key to understand social inequality as a core driver of the lead health burden and situate the study in the unique context of the Dudley Neighborhood.

3.3 Phase 3: Synthesis & Interpretation of Findings

This phase brings together the threads of disciplinary questions for deeper inquiry and interpretation of results. After interdisciplinary, collaborative question generation and lens analyses in phases one and two, synthesis allows researchers to truly understand their results from a systems perspective. Interpreting results without this progression can be misleading since the data appears to exist outside the broader social and environmental context. For this project, the Synthesis and Interpretation phase bridged the local scale lead exposure sources with societal scale drivers of lead. Examining these findings together highlights that sustainable solutions to urban lead contamination must confront the literal soil pollution (see chapter 2) and the systemic problems that created the disproportionate health burden – primarily systemic racism (see chapter 3).

Community and academic partners should discuss the results together to blend the various ways of knowing and understanding present in the group. Any outcomes of disciplinary research should be integrated to gain a comprehensive perspective on the issue. This phase is comparable to a reflection phase in PAR projects, when the partners reflect on the research process up to that point, and, if necessary, return to the looking and question generation phase (Figure 2). All partners should feel comfortable with the interpretation of the results before moving towards the action phase.

3.4 Phase 4: Identifying and Implementing Solutions

A community based interdisciplinary approach expands the vision for possible applications of the results. By working with community partners, creating an open system of knowledge
production, and shifting their disciplinary perspective throughout the previous phases, researchers can conceive more solutions to the issue at hand. By identifying a range of paths forward, collaborators can use the options that best meet community priorities.

These applications will vary across scale. The local scale applications of this project inform best practices for urban gardeners to reduce bioaccessible Pb exposure. Info-graphics have been effective ways to communicate key scientific findings to community partners (Appendix 2). Sharing lead exposure and uptake information in an accessible way allows gardeners in Roxbury and Dorchester to make informed decisions for their community.

At the national scale, our results contribute to a growing body of research on urban Pb bioaccessibility and transport that informs benchmarks for safe soil Pb and best practices for gardening in contaminated soil. Raised beds are a useful example; by working with The Food Project, Clark, et al., identified raised beds as an affordable way reduce gardeners’ exposure to lead contaminated soil. This method is applicable beyond Dudley in other low-income neighborhoods of color across the country where full yard soil capping is cost prohibitive (Clark, Hausladen, & Brabander, 2008).

Since academics can operate at the local, regional, and national scales, we should apply results in across these settings. Our position can also allow community partners to enact policy change beyond their region in spaces they may not otherwise have access to (Caldwell, Reyes, Rowe, Weinert, & Israel, 2015).

4. Conclusions

This proposed model draws from PAR to integrate its core principles into geochemistry work. This approach will always be dynamic, and scholars should be open to adapting their work based on the community needs and resource limitations encountered along the way. Ultimately, the underlying values of the work are what remain constant: GeoHealth research should aim to be community based, interdisciplinary, and applied. We’ve found that this approach produces informed solutions that match the desires of community stakeholders and provides insights applicable at a broader scale.
Chapter 2
The GeoHealth path to safe urban agriculture:
Assessing lead (Pb) bioaccessibility and mobility to inform gardening best practices

1. Introduction

Urban agriculture plays a key role in food justice movement, providing fresh produce and an abundance of social benefits. However, in many cities the legacy of anthropogenic soil lead (Pb) pollution poses a serious health risk, particularly in low-income communities of color that have the most to gain from practicing urban agriculture (Aelion et al., 2012; Bernard & McGeehin, 2003; Campanella & Mielke, 2008; Cheng et al., 2015; Filippelli et al., 2005; Filippelli & Laidlaw, 2010; McClintock, 2012; Mielke, Laidlaw, et al., 2011). Patterns of disinvestment, redlining, and discrimination have left these communities with limited access to basic goods and services, including affordable fresh food (Alkon et al., 2013). Urban agriculture provides a quality source of produce as well as opportunities for youth empowerment, political organizing, and cultural preservation (Ober Allen et al., 2008; Okvat & Zautra, 2011; Saldivartanaka & Krasny; Subica et al., 2015). For cities to continue benefitting from urban farming, overcoming the Pb legacy in urban soils is essential.

A number of best practices and remediation schemes have been proposed to reduce lead exposure in urban gardens (Kessler, 2013; Mitchell et al., 2014). Planting crops in raised beds filled with low-Pb compost or diluting contaminated soil with compost are two popular, accessible methods for gardeners to reduce Pb exposure at a local scale (Clark et al., 2006). Since cities reliably produce large amounts of organic waste, recycling this waste into low-lead compost is a promising alternative source of high quality growing material that cities are beginning to utilize (City Soil, 2016; Fitzstevens, Sharp, & Brabander, 2016; SF Rec & Parks, 2016). Soil management strategies like these can ultimately reduce risk of lead exposure by lowering garden soil Pb concentrations below the neighborhood average (Clarke, Jenerette, & Bain, 2015), but to truly practice safe and sustainable urban agriculture the garden lead concentrations must be low enough to prevent negative health outcomes.

Recent research shows that there is no safe level of lead uptake, which calls existing benchmarks for safe Pb exposure into question (WHO, Oct 2014). In 2012, the Center for Disease Control and Prevention (CDC) lowered the blood lead level (BLL) benchmark from 10
to 5 µg/dL (CDC, 2016), which increases the number of people considered to have toxic BLL (Handler & Brabander, 2012). Since the Environmental Protection Agency’s (EPA) safe soil lead level of 400 mg/kg was developed to prevent blood lead levels from exceeding the 10 µg/dL benchmark (US EPA, Jan 2001), scholars are finding that in many regions it is no longer a useful regulation for environmental safety (Stewart et al., 2014).

However, the lead health burden is ultimately governed by the fraction of Pb absorbed into the bloodstream, or bioavailable Pb, rather than total Pb in the soil. Since Pb bioavailability in urban soils can vary (Zia et al., 2011), recent studies are framing urban soil exposure risk in terms of bioavailable Pb instead of the total soil Pb (Cheng et al., 2015; Clarke et al., 2015; Henry et al., 2015). As this study seeks to examine urban gardeners’ lead exposure risk through a geohealth lens, adopting this framing is essential. However, since in-vivo Pb bioavailability studies are time and resource intensive, this study measures in-vitro bioaccessible Pb, or the fraction of lead soluble in simulated gastric fluid, which is a reasonable proxy for bioavailability (Zia et al., 2011).

Zahran et al. found that Detroit children’s elevated BLLs are linked with seasonal trends of suspended soil dust, suggesting that wind transportable soil grains are the primary driver of bioavailable Pb (Laidlaw, Zahran, Mielke, Taylor, & Filippelli, 2012; S. Zahran et al., 2013). This observation calls for a closer examination of the lead exposure risk associated with fine soil particles that are mobile in the summer months. Not only are urban gardeners more likely to ingest these particles, but they have also been shown to re-contaminate clean raised beds since they are wind transportable (Clark et al., 2008).

The risk associated with these fine particles and the range of growing materials urban gardeners interact with (unamended soil, garden soil, and composts) make urban gardeners’ Pb exposure risk somewhat unique. To better understand Pb mobility and uptake in an urban agricultural setting, this chapter investigates how bioaccessible Pb changes as a function of grain size and growth medium. First, we characterize the geochemical distinctions in urban growing materials collected in Roxbury, MA, ranging from unamended soil to compost. We then examine the driving variables of Pb bioaccessibility and the mobility potential of fine grained, transportable particles across growing mediums. Ultimately, this analysis contributes to developing effective and applicable best management practices for gardening in contaminated soil.
2. Methods

2.1 Sample Collection & Categorization

We collected a range of growing material samples from the Dudley triangle area of Roxbury and Dorchester, MA, a neighborhood of Boston where urban agriculture is common and residents are working to confront a legacy of lead contamination. Dudley demographics reflect national trends for communities with high soil Pb levels: most residents are people of color and over half of residents earn less than $25,000 per year (DSNI, 2014). Sample collection in this neighborhood was made possible through partnership with The Food Project, a Boston based non-profit organization practicing urban agriculture for youth and community empowerment. In addition to collecting discrete samples for laboratory analysis discussed in this chapter, we also performed in-situ soil tests for residents and community gardens. Work that’s conducted in partnership with The Food Project helps inform localized remediation decisions for urban gardeners and formulate new research questions.

The growing materials examined in this study were chosen to represent a realistic range of what Dudley urban farmers are using to grow food. Though each sample is unique, reflecting the spatial heterogeneity of the urban environment, they can be grouped into four categories. Composts are the nutrient-rich product of accelerated recycling of organic matter, primarily food, yard, and park waste (Fitzstevens et al., 2016). We collected samples from compost piles at Roxbury community gardens after they had been brought from the production site. We collected raised bed fills from raised beds, which are initially filled with a low-Pb, nutrient-rich alternative to urban soil (typically compost) and have been used to grow crops. Garden soils are from plots without raised beds where compost is usually mixed with the original soil. We collected unamended urban soil samples from uncultivated areas near garden plots where there was little or no evidence of soil management.

2.2 Sample Processing and Sieving

All samples were dried to a constant mass at 30°C, then sieved to <2 mm. Bulk samples were ground in a Spex CertiPrep 8000M mixermill prior to all analyses. Four samples (two unamended soils, one raised bed fill, and one compost) were sieved post-drying using Chemplex Nylon mesh screens into the following grain size fractions: 2mm–250µm (termed >250),
250µm–149µm, 149µm–74µm, 74µm–37µm, and <37µm. Only the 2mm–250µm fractions were ground prior to analysis.

2.3 Primary Geochemical Characterization

Scanning Electron Microscopy (JEOL VP-SEM0-EDS) backscatter electron (BSE) images provide textural characterization of end members of the growing material spectrum: compost and unamended soil. We examined 2015 Boston municipal compost and Roxbury unamended soil using the SEM, both sieved to <37 µm. Since raised bed fill and garden soils are a mix of compost and soil, these analyses bracket the range of samples examined in this study.

We measured trace element concentrations using energy dispersive X-ray fluorescence (SPECTRO-XEPOS). Ground powder samples were analyzed in Premier Lab Supply XRF analytical cups sealed with 4µm Teflon windows. Three aliquots were prepared for each bulk sample, and one for each sieved grain size fraction. All samples were run in triplicate. We measured percent carbon, nitrogen, and sulfur using a CHNS Element Analyzer (Elementar Vario MICRO Cube). Three aliquots of each sample were analyzed. We measured pH in solution (1g sample – 2ml H₂O) for all bulk samples using a Thermo Electron pH meter. Triplicate analyses of three aliquots were analyzed for each sample.

Two of the sieved samples (one unamended soil and one raised bed fill were also fractionated by density. The <37µm was mixed with Sodium Polytungstate (density = 2.89g/cm³) and allowed to settle. Trace element concentrations of the carbon rich “floats” were analyzed using the SPECTRO-XEPOS and the Pb concentration of the mineral rich “sinks” was calculated since there was not enough material to analyze with x-ray fluorescence.

2.4 In-vitro Bioaccessibility Assays

We performed the EPA’s In-vitro Bioaccessibility Assay for 9 bulk samples and 3 sieved samples (5 grain size fractions for each sieved sample) (US EPA, 2012). Following the standard procedure, 0.1g of sample were digested in 10ml of simulated gastric fluid at 37°C for 1 hour. The simulated gastric fluid was a solution of 0.4 M glycine solution adjusted to pH 1.5 with HCl, and was heated to 37°C before being mixed with samples in acid-washed vials. After the digest, samples were filtered through a 0.45 µm cellulose acetate disk filter. The solutions were
analyzed using Optima 7200 DV inductively coupled plasma optical emission spectroscopy (ICP-OES, Perkin-Elmer).

2.5 Pb Stable Isotope Analysis

Bioaccessible Pb extraction solutions containing bioaccessible Pb were analyzed to determine concentrations of $^{206}\text{Pb}$, $^{207}\text{Pb}$, $^{208}\text{Pb}$ using a VG Plasma Quad ExCell ICP-MS at Boston University’s Department of Earth and Environmental Sciences. Solutions were x1000 diluted with nitric acid prior to analysis.

Sample ratios of $^{207}\text{Pb}/^{206}\text{Pb}$ and $^{208}\text{Pb}/^{206}\text{Pb}$ were compared to known ratios for Pb paint and gasoline to determine relative source contribution along a mixing line. Established $^{207}\text{Pb}/^{206}\text{Pb}$ and $^{208}\text{Pb}/^{206}\text{Pb}$ end member ratios are shown in Table 1.

| Table 1: End member $^{207}\text{Pb}/^{206}\text{Pb}$ and $^{208}\text{Pb}/^{206}\text{Pb}$ ratios for lead-based paint and leaded gasoline (Clark et al., 2006; Rabinowitz, 1986). |
|-----------------|------------------|
|                  | Lead-based paint | Boston leaded gasoline fallout |
| $^{207}\text{Pb}/^{206}\text{Pb}$ | 0.867            | 0.827                           |
| $^{208}\text{Pb}/^{206}\text{Pb}$ | 2.119            | 2.029                           |

We compared the $^{207}\text{Pb}/^{206}\text{Pb}$ ratios for end members and samples to estimate % contribution of lead paint for each sample using the mass-balance equation published by Clark, et al., (Equation 1; 2006).

**Equation 1:**

$$F_{\text{Paint}}\% = \frac{^{207}\text{Pb}/^{206}\text{Pb}_{\text{sample}} - ^{207}\text{Pb}/^{206}\text{Pb}_{\text{gas}}}{^{207}\text{Pb}/^{206}\text{Pb}_{\text{paint}} - ^{207}\text{Pb}/^{206}\text{Pb}_{\text{gas}}}$$

Where the variables are defined as follows:

$F_{\text{Paint}}\% = \%$ Paint sourced Pb

$^{207}\text{Pb}/^{206}\text{Pb}_{\text{sample}} = $ Measured Pb isotopic signature for each sample
207\textsuperscript{Pb}/206\textsuperscript{Pb}_{\text{paint}} = \text{Pb isotopic signature of Pb-based paint as measured by Rabinowitz (1986)}.

207\textsuperscript{Pb}/206\textsuperscript{Pb}_{\text{gas}} = \text{Pb isotopic signature of roadside gasoline fallout as measured by Rabinowitz (1986)}.

2.6 Statistical analyses

Basic statistical analyses were conducted in JMP Pro 11 and MS Excel 2011.

3. Results

3.1 Geochemical Characterization of Urban Growing Materials

Consistent with Fitzstevens, et al, all compost, raised bed, and garden soil samples had significantly lower Pb concentrations than 950 µg/g, the neighborhood average soil Pb in Roxbury (Clark et al., 2006; Fitzstevens et al., 2016). Beyond this important distinction, we found a number of geochemical differences between unamended soil and compost, which are end members of the range of growing materials used in urban agriculture.

Table 2: Key biogeochemical characteristics of urban agriculture growing mediums. All samples sieved to <2mm and ground prior to analysis.

<table>
<thead>
<tr>
<th>Growing Material</th>
<th>Pb (µg/g) Mean (st dev)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unamended soil (n=13)</td>
<td>1337 (928)</td>
</tr>
<tr>
<td>Garden Soil (n=9)</td>
<td>495 (205)</td>
</tr>
<tr>
<td>Raised Bed Fill (n=5)</td>
<td>168 (104)</td>
</tr>
<tr>
<td>Compost (n=3)</td>
<td>244 (52)</td>
</tr>
</tbody>
</table>

Scanning Electron Microscopy (SEM) provides useful textural and elemental characterization of Roxbury soil and Boston municipal compost relevant to material characterization and risk analysis. Backscatter electron (BSE) imaging of unamended soil shows angular bright grains, which indicate high mineral content and the presence of heavier elements (Figure 1a). Alternately, compost BSE imaging shows darker, less uniform particles, indicating high organic matter and lighter elements typical in compost (Figure 1b). The compost also has considerably more carbon and a higher pH compared to Roxbury soil, factors that may limit Pb

These SEM images highlight the range of grains within the <37 µm grain size fraction for both samples. Fine grains are more mobile in the environment: grains <150 µm particles are transportable by sticking to hands, <100 µm particles are transportable by wind, <10 µg/g particles are respirable, and <2 µm can stick to skin even after washing (de Miguel et al., 1997; Kissel, Richter, & Fenske, 1996; Ljung, Selinus, Otabbong, & Berglund, 2006; US EPA, 2015). This characterization shows that both and compost contain <10 µm and <2 µm grains; quantifying these particulates on a percentage basis will improve understanding of Pb exposure risk associated with these materials.

(a) 2015 Un-amended Roxbury Soil

(b) 2015 Boston Municipal Compost (Managed by City Soil)

Figure 1: Backscatter electron (BSE) images of the the urban growing matrix end members, unamended soil (a) and compost (b), sieved to <37 µm. Heavier elements correspond with brighter regions.
3.2 *Drivers of Pb Bioaccessibility*

Total lead concentration is directly proportional and tightly correlated with bioaccessible lead for all growing materials (Figure 2).

![Figure 2](image)

**Figure 2**: Bioaccessible Pb vs. total Pb across the growing matrix spectrum. For the range of samples in this study, total Pb appears to be the primary variable controlling Bioaccessible Pb concentration. Inset graph shows compost samples from Boston and surrounding areas.

This relationship allows us to predict bioaccessible Pb from total Pb for growing material samples collected in Boston. Since the EPA’s *in-vitro* bioaccessibility assay is considerably more time and resource intensive than XRF, predicting bioaccessible Pb allows for faster characterization of lead risk in a given sample.

Percent carbon is indirectly proportional to and well correlated ($R^2=0.62$) with the bioaccessible fraction of total Pb, or percent bioaccessible Pb (Figure 3). This relationship is likely due to increased sorption sites in organic matter that limit solubility. Percent carbon and percent bioaccessible Pb vary significantly by growing material. Unamended soils contain the least carbon and have the highest Pb bioaccessibility, while composts have the most carbon and
lowest bioaccessibility. Garden soils and raised beds have intermediate values for both (Figure 4).

Figures three and four only include 2016 samples of soil, garden soils, raised bed fills, and composts. All of these samples were collected in Roxbury, though the composts were produced nearby and transported.

**Figure 3:** Percent carbon vs. Percent bioaccessible Pb. Carbon content limits the fraction of bioaccessible Pb.

**Figure 4:** Average Percent Bioaccessible Pb by growing material. Error bars show one standard deviation. Composts (n=8) and garden soils/raised beds (n=9) have significantly lower fractions of bioaccessible Pb than soils (n=7) (p-values < 0.005).

### 3.3 Grain Size Analysis Across Growing Media

Smaller grain size fractions of all materials consistently have higher concentrations of lead since the small particles’ high surface area-volume ratio maximizes lead sorption (Cheng et al., 2015; Clark et al., 2008). Comparing the change in lead concentration across grain sizes shows that soils have the widest range in concentrations (Figure 5). The lead concentration in the <37 µm high Pb soil grains is four times that of the >250 µm soil grains. Comparatively, the lead concentration in the <37 µm compost grains is only twice as high as the >250 µm compost grains. Since bioaccessible Pb is directly proportional to total Pb, this trend is the same for bioaccessible Pb.
Figure 5: Lead concentration (µg/g) by grain size (µm) for compost, raised bed soil, and unamended soil. The “transportable” range indicates the grains that can stick to hands (<150µm) but also includes the grain sizes that are transportable by wind (<100µm).
**Figure 6**: Percent contribution by grain size fraction to (a) mass, (b) total Pb, and (c) bioaccessible Pb. Percent Pb contribution is the product of mass fraction and Pb concentration. Soil #2 and Raised Bed samples are from the same yard. The compost sample is 2015 Municipal compost and Soil #1 is unamended Roxbury Soil, the <37μm fraction of which is shown in Figure 1 SEM images.

Sieving results show that transportable grains (<150 μm) represent a greater fraction of total mass in soil than in compost (Figure 6a). Further, because of the steeper Pb concentration gradient across soil grain sizes (Figure 5), the transportable grains contribute more to total lead in soil than in compost (Figure 6b). Since bioaccessible Pb is directly proportional to total Pb, the grain size contributions to bioaccessible Pb (Figure 6c) are comparable to their contributions to total Pb. However, the fine grain fractions’ contributions to bioaccessible Pb do increase slightly compared to their contributions to total Pb. This increase can be attributed to slightly higher percent bioaccessibility Pb in the fine grains compared to larger grains (Figure 7). This difference in percent bioaccessible Pb is greater for compost and raised bed fill than unamended soil.
Figure 7: Bioaccessible lead decreases as a function of grain size. X-axis shows grain size fractions <37µm, 37-74µm, 74-149µm, 250-149µm, 2mm-250µm. For each growing material, percent bioaccessible Pb is greater in the fine-grained fraction than in the course fraction. The difference between the fine and course grains is 6%, 11%, and 12% for the soil, raised bed fill, and compost, respectively.

3.4 Isotopic Signatures of Growing Materials, Bioaccessible Pb, and Grain Sizes

Ratios of \(^{207}\text{Pb}/^{206}\text{Pb}\) and \(^{208}\text{Pb}/^{206}\text{Pb}\) in bioaccessible soil and compost Pb are well described by a two end member mixing line bounded by gasoline and paint sourced Pb signatures, which further implicates them as the dominant sources of urban soil Pb (Figure 8). Garden soil bulk Pb isotopic signatures from the same neighborhood collected by Clark, et al., in 2006 also fall between these two end members, which enables comparison.

Soils, garden soils, and raised beds fall within the same range of \(^{207}\text{Pb}/^{206}\text{Pb}\) and \(^{208}\text{Pb}/^{206}\text{Pb}\), indicating common inputs of gasoline and paint. Composts, however, are isotopically distinct and plot significantly closer to the Pb gasoline end member (Figure 9a). Calculating the percent paint sourced Pb for each growing material using Equation 1 reflects this difference. On average, only 23% of the bioaccessible Pb in compost comes from Pb paint compared to 43% in raised beds/garden soils and unamended soils (Figure 9b).
Figure 8: An isotope ratio plot of $^{207}\text{Pb}/^{206}\text{Pb}$ to $^{208}\text{Pb}/^{206}\text{Pb}$ in Boston soils, garden soils, and unamended soils. Bulk and grain size fractionated samples are all included. Black circles indicate isotopic signatures of bioaccessible Pb measured in this study, open circles indicate total Pb signatures measured in Garden soils by Clark, et al., 2006. Grey and white triangles indicate end member isotopic signatures of Pb gasoline and Pb paint. Three regression lines show how well sample trends fit these end members – one for each study (dashed) and one for all the data (solid). The 2016 regression line and the 2006 & 2016 combined line most closely fit the mixing line between the two end members.

There’s also variation between types of compost. The isotopic signature of Boston municipal compost, which is produced close to the city and made primarily from yard waste, more closely resembles the isotopic signatures of garden soils, raised beds, and soils. Meanwhile, the commercial compost that was also produced close to the city but made primarily from food waste falls closer to the Pb gasoline end member isotopic composition. The sample of suburban yard waste compost has the same isotopic signature as fallout from Pb gasoline (Figure 10).
Figure 9: (a) $^{207}\text{Pb}/^{206}\text{Pb}$ vs $^{208}\text{Pb}/^{206}\text{Pb}$ ratios in the bioaccessible fractions of Pb in composts, garden soils/raised beds, and unamended soils. The end members show the Pb isotopic fingerprint of the two primary sources of lead in the urban environment: leaded paint and gasoline. Composts have the widest range in isotopic ratios, and plot closer to the Pb gasoline end member than garden soils/raised beds and soils. (b) Average percent paint sourced Pb for each growing material, error bars show ± one standard deviation. Compost has significantly lower fraction of paint-sourced lead ($p$-values < 0.0015). Percent paint sourced Pb is calculated for each sample using the $^{207}\text{Pb}/^{206}\text{Pb}$ ratio (Equation 1).
Figure 10: Urban composts fall closest to the paint sourced Pb end member, one sample of suburban compost falls close to the gasoline sourced Pb end member, and commercial food sourced, which is semi-urban, falls in between. These distinct isotopic signatures is reflected in the range of percent paint sourced Pb in municipal and suburban composts.

Clark et al. measured isotopic signatures of total Pb after a total digest of Roxbury garden soils. This study measures the bioaccessible Pb isotopic signature in simulated gastric fluid following the in-vitro bioaccessibility assay. Comparison of these results shows that bioaccessible Pb and total Pb have the same isotopic signature, and therefore the same contribution from Pb paint (Figure 8; Figure 11). Sieved samples have a range of isotopic ratios that are not distinct by grain size. This result shows that neither paint nor gasoline particulates are preferentially concentrated in the transportable or non-transportable fractions (Table 3).
Figure 11: Percent paint sourced Pb for the bioaccessible Pb measured in this study and the total Pb measured by Clark et al., 2006 as calculated from the $^{207}$Pb/$^{206}$Pb using Equation 1. Composts are excluded from this comparison, since they have significantly less paint sourced Pb due to material differences governed by organic waste feedstocks. Bioaccessible Pb and total Pb in garden soils and unamended soils contain the same fraction of paint sourced Pb.

4. Discussion

4.1 Drivers of bioaccessibility

The correlation between bioaccessible Pb and total Pb (Figure 2) is unexpected given the geochemical distinctions between soil and compost. This finding implicates environment and source specific Pb characteristics as the primarily factors controlling the fraction of bioaccessible Pb. The comparable Pb isotopic signatures for Dudley soils, garden soils and raised beds also support this conclusion. The Pb in each of these materials is from the same local source and therefore behaves similarly, resulting in a predictable trend in bioaccessible Pb.

Appleton, et al., also observed a linear trend between total and bioaccessible Pb in United Kingdom (UK) urban and suburban soils, but the slope of the trend varied by location (Appleton, Cave, Palumbo-Roe, & Wragg, 2013). Appleton et al. found smaller slopes for all UK sample locations compared to Roxbury and Dorchester samples (Figure 2). Since the slope provides an estimate for the fraction of bioaccessible Pb in soils from a particular location, this trend can inform measures to prevent Pb poisoning. Quantifying this relationship in more urban areas will provide a rough estimate for bioaccessible Pb for yards in that area, which is essential information for understanding and addressing Pb exposure risk.
While the linear relationship between total and bioaccessible Pb provides a useful snapshot for quantifying Pb bioaccessibility, variation away from the regression line more precisely captures the range of percent bioaccessible Pb within a single city. Results from this study show that carbon effectively binds lead and makes it less soluble in gastric fluid (Figure 3). This lowers Pb bioaccessibility by 19% in composts compared to unamended soils (Figure 4). This reduction has significant for remediation approaches. Working to increase carbon content in gardens and yards can limit Pb bioavailability and lower the Pb health burden.

4.2 Pb Source in Dudley Yards and Boston Composts

Consistent with the results of Clark, et al., the primary sources of Pb in the Dudley neighborhood are Pb paint and gasoline. Based on the ratios of $^{207}\text{Pb}/^{206}\text{Pb}$ and $^{208}\text{Pb}/^{206}\text{Pb}$, the relative contribution from each of these sources is essentially the same for all Boston samples except composts, reflecting shared inputs of Pb over time (Figure 8). Pb-based paint and leaded gasoline were the primary 20th century inputs. Today, Dudley yards still share exposure this contamination through transportable, easily ingested particles containing high Pb that are resuspended and deposited between lots (Clark et al., 2006; S. Zahran et al., 2013).

Composts have a distinct isotopic signature because they are produced differently than soils (Figure 9). Rather than slow in-situ weathering of parent material and organic matter, Composts are produced on a shorter time scale from organic waste (Fitzstevens et al., 2016). The varying isotopic signatures between compost types reflect differences in these feedstocks. The city compost has an isotopic signature that’s similar to soil and garden soil because more of the starting materials (eg. urban yard waste) experienced the same urban contamination trends as yards and gardens. The other compost samples have lower lead levels that are primarily from gasoline emissions rather than paint since their feedstocks – food and non-urban yard waste – were not exposed to the same urban Pb contamination sources (Figure 10).

Sieved isotope data shows that Pb paint and Pb gasoline are present in all grain size fractions. This is expected for leaded gasoline fallout, but it is not typical for Pb paint, which typically enters the soil in chips from houses then weathers over time. However, throughout the 1970s and 1980s, intense disinvestment, redlining, and discrimination left Dudley residents with a declining local economy and deteriorating infrastructure, among other social and environmental challenges. During these decades, arson became incredibly common as property
owners in Dudley burned buildings primarily as a way to sever ties with the neighborhood by displacing residents. In 1981 Roxbury’s Highland park had the highest arson rates in the nation; by the late 80s there were over 850 vacant lots in Dudley, most of which had been vacated through arson (Medoff & Sklar, 1994). This widespread burning deposited large amounts of incinerated Pb paint into the soil.

For Dudley and other neighborhoods with histories of fire, the soil Pb from paint is present as fine particles rather than larger chips. The preliminary work fractionating samples by density separation reflects this history. The fine, mineral rich grains of soil and raised bed fill were highly concentrated with Pb, more than an order of magnitude higher than the carbon rich floating fraction (Figure A1). These particles are likely the remnants of incinerated Pb paint. Although they don’t make up a major mass fraction of the sample, they can contain a significantly higher Pb. As these particles are easily transportable, this finding heightens the known health and recontamination risks associated with urban soil dust.

All urban samples contain a high fraction of bioaccessible Pb (50-75%), and these fraction have comparable isotopic signature to total Pb (Figure 1; Figure 8). Dudley’s intense arson history likely contributed to this, since the Pb in fine particles of incinerated paint is more easily ingested and potentially more bioaccessible than Pb paint chips. In other cities, it’s possible that bioaccessibility would be different for paint and gasoline sourced Pb, which would result in different isotopic signatures between total and bioaccessible Pb. In Dudley, the Pb from each source appears to comparably soluble in gastric fluid.

4.3 Implications for Urban Gardening & Compost use best practices

Previous studies have shown that compost dilutes soil lead concentrations (Chammi P. Attanayake, Ganga M. Hettiarachchi, Sabine Martin, & Gary M. Pierzynski, 2015; Clark et al., 2008; Clarke et al., 2015). Since total Pb is directly proportional to bioaccessible Pb and compost binds Pb more effectively, compost application also reduces urban gardeners’ exposure to bioaccessible Pb through dilution and limiting the fraction of soluble Pb (Table 4). Compost use is easily integrated into the practice of urban gardening because its high nutrient content fertilizes nutrient poor urban soils. With improved city level management schemes, compost can be produced locally by redirecting cities’ organic waste, which would make compost available and affordable for urban communities while reducing greenhouse gas production by diverting the
waste from landfills (Brown, Chaney, & Hettiarachchi, 2016; Fitzstevens et al., 2016; Jones & Healey, 2010).

The grain size analysis in this study shows that compost lowers the prevalence of fine, transportable particles that Zahran, et al., found to be the primary Pb exposure pathway in the urban environment (2013). Compost has a high moisture holding capacity that can limit particle re-suspension into the air (Farrell et al., 2010; Gould, 2015). Taken together, these qualities considerably limit the transport of bioaccessible Pb in the urban environment and, therefore, urban gardener Pb exposure.

Research on the capacity of compost and other amendments to bind Pb and reduce percent bioaccessibility is an important and promising field of research that may eventually provide more methods for cities to reduce Pb exposure (Henry et al., 2015). Compost provides an immediate tool proven to reduce lead exposure in urban gardens.

Table 4: Summary of key differences in compost and unamended soil that highlight the benefits of using compost as an alternative growing medium to Pb contaminated soil. This compilation only includes samples for total and bioaccessible Pb were measured, which accounts for differences in total Pb compared to Table1.

<table>
<thead>
<tr>
<th>Material Characteristic</th>
<th>Compost Mean (SD)</th>
<th>Unamended Soil Mean (SD)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Pb (µg/g)</td>
<td>265 (70)</td>
<td>2450 (1170)</td>
<td>Compost reduces concentrations of total &amp; bioaccessible Pb by an order of magnitude (Figure 2).</td>
</tr>
<tr>
<td>Bioaccessible Pb (µg/g)</td>
<td>144 (55)</td>
<td>1780 (889)</td>
<td>Compost reduces Pb solubility in gastric fluid by 19% (Figure 4).</td>
</tr>
<tr>
<td>% Pb Bioaccessibility</td>
<td>53% (9)</td>
<td>72% (2)</td>
<td>Compost contains 14% more carbon, which increases binding sites for Pb and can improve material quality for cultivation (Figure 3).</td>
</tr>
<tr>
<td>% C</td>
<td>21% (3)</td>
<td>7% (1)</td>
<td>Compost contains a smaller fraction of transportable grains, and the Pb concentration in that fraction is smaller, resulting in 23% less transportable Pb in compost than in soil (Figure 6a and 6b).</td>
</tr>
<tr>
<td>% Transportable Pb</td>
<td>11%</td>
<td>34%</td>
<td></td>
</tr>
</tbody>
</table>
4.4 Recontamination & Neighborhood Scale Remediation

Recontamination of remediated areas by wind transportable particles is still a major challenge in communities with high soil lead contamination (Clark et al., 2008; S. Zahran et al., 2013). Gardeners must annually reapply compost to their raised beds and plots to prevent Pb contamination, which is a considerable investment of time and money for low-income residents. The best way to confront recontamination is capping of contaminated soil with clean fill at the neighborhood scale, though these plans are limited by cost and material availability (Filippelli et al., 2015). Municipal compost, clean sediment, or a mix of these materials have been proposed as local, affordable materials that cities can use for regional remediation (Egendorf, Cheng, & Sutton, 2015; Fitzstevens et al., 2016; Mielke et al., 2006; Mielke, Covington, et al., 2011). Even these plans require a monetary investment from the city, but they are still well below the costs of delayed remediation. Costs associated with healthcare, criminal justice, and human capital losses due to Pb poisoning have been estimated at 10 times the cost of cleaning up Pb contaminated neighborhoods (Drum, 2013).

5. Conclusions

Characterizing the Pb health risk in terms bioaccessible Pb provides a more precise assessment of Pb risk than only studying total lead. Total and bioaccessible Pb are linearly related, indicating that total lead is a key driver of bioaccessible Pb. The slope of this trend varies between cities, so characterizing this relationship in more places will provide an estimate of percent bioaccessible Pb by location. This analysis will also help identify what other variables may play influential roles in limiting bioaccessible Pb.

Pb source is consistent across Dudley unamended soils, gardens, and raised beds, which reflects their shared inputs of Pb over time and the impact neighborhood history has on the present Pb reservoir. While there’s only minor variation in lead source within Boston samples, lead source may vary significantly between cities, which could contribute to the differences in Pb bioaccessibility between UK cities and Boston.

Second, compost is a beneficial tool for lowering lead exposure in urban gardens. Since compost contains less bioaccessible Pb than unamended soils, applying it as a soil cap or amendment in gardens dilutes the bioaccessible Pb concentration in the soil. Further, results from this study suggest that compost binds lead more effectively than soils, likely due to increased
carbon content, which limits the fraction of lead that can be taken up by the body. Compost also has fewer fine, easily transportable grains than soil, which contain high lead and people are easily exposed to. All of these findings highlight the benefits of using compost as an alternative growing medium in urban agriculture and as an amendment tool for lead contaminated lots.
Chapter 3

The Social Ties Between Urban Agriculture and Lead Contamination

1. Introduction

Urban gardens are an important setting to study lead mobility and exposure since they are spaces where residents routinely interact with urban soil, the primary reservoir for lead in cities (Laidlaw, Mielke, Filippelli, Johnson, & Gonzales, 2005; Mielke et al., 1983; Mielke & Reagan, 1998). However, urban gardens represent more than the physical setting of this study. The rise of urban agriculture in the Dudley neighborhood for the past 40 years reflects social trends that are important for understanding the persistence of soil lead contamination into the 21st century. Urban agriculture came as a response to many of the same forces – namely, the synergy between structural racism and economic oppression – that left low-income communities of color with lead contaminated soil and insufficient resources to address it.

While urban geochemists identify empirically that lead primarily impacts urban Black and Latino communities, few discuss why that disparity exists beyond surface level environmental conditions like urban setting and decaying infrastructure (Campanella & Mielke, 2008). These are important factors, but they do not capture a root cause for why communities of color routinely bear a disproportionate share of environmental health burdens (Bullard, 2002). Quantitatively determining the reasons for a particular environmental injustice is complicated, as there are typically a number of causes including siting discrimination, unintentionally biased environmental regulation, unequal enforcement, and low political power in urban Black and Latino communities (S. Diaz, 2016).

However, these factors don’t exist in isolation; they are all related and driven by the institutionalized legacy of racism in the US social, political, and economic systems (Williams, Sternthal, & Wright, 2009). Though not eradicated by the legislative progress made during and since the Civil Rights Movement, racism did change forms - contemporary racism became more implicit (Perry, 2011). Literal and insidious violence against Black and Brown people is still engrained in society, reproduced by denial and justified by various reasons like criminal tendencies, lack of ambition, or other moral and cultural deficits (Perry, 2011; Tolliver, Hadden, Snowden, & Brown-Manning, 2016)
‘Structural racism’ refers to the race based discrimination engrained in societal level political, economic, and social system ideology and operations (Paradies, 2006). Structural racism has concentrated, tangible impacts on neighborhoods of color like Dudley. Disinvestment, redlining, and pollution, which are products of structural racism when they occur disproportionately in communities of color, created the physical and social environments within which lead pollution became a legacy problem. Understanding the social and historical context of soil lead contamination and urban agriculture provides a systems perspective that highlights the need for localized remediation plans for lead contaminated neighborhoods that align with efforts to confront structural racism.

In this chapter, I ask three questions to better understand the social context of urban soil lead contamination: (1) Who bears the majority of the Pb health burden, and why?, (2) How and why did urban agriculture begin in these communities?, and (3) What is the current state of lead contamination and urban agriculture, and what can cities to do address persistent and emerging issues? To answer them, I’ve reviewed literature from a variety of stakeholder perspectives and disciplines including environmental studies, sociology, public health, critical race studies, and human geography, among others. I relate trends in the literature to the Dudley neighborhood through interviews and personal communication with stakeholders in the Boston urban agriculture network: two Food Project employees, Danielle Andrews and Jess Liborio, and a former city government leader, Edith Murnane. By examining these questions together through multiple disciplinary lenses, this chapter provides new, systems level insight into the lead contamination - urban agriculture intersection.

2. Who bears the Lead health burden, and why?

2.1 History of the Dudley neighborhood

The Dudley neighborhood of Roxbury and Dorchester, MA is one example of a low-income community of color with high lead contamination, and the history of the neighborhood informs understanding of urban soil lead in cities across the country. Since the 1960s, the majority of Dudley inhabitants have been people of color, primarily African Americans, Cape Verdean immigrants, and Puerto Ricans (Medoff & Sklar, 1994). By 2014, over 70% of the residents were people of color (DSNI, 2014). Dudley was one of many urban neighborhoods in the US to experience severe disinvestment as White Americans moved from the inner cities to
the suburbs in the 60s and 70s, a process that was further segregated as lending institutions only provided means for white residents to move. As this exodus occurred, insurance companies and the Federal Housing association redlined areas of Roxbury and Dorchester, meaning they refused credit, insurance, and other resources to the residents and businesses. Loans were systematically denied on the basis of race: by 1989, Boston’s biggest lending institutions approved three times as many loans and had 5 times as many offices in white neighborhoods of comparable income than in Dudley (Medoff & Sklar, 1994). This public and private disinvestment systematically restricted jobs, education, housing, and political representation from Black Boston residents. In the 50s, Dudley was full of businesses and residencies, but throughout the following decades businesses failed and housing deteriorated (figure 1). The city blamed the resulting problems – poverty, unemployment, homelessness, and crime – on the Black and Hispanic residents who filled the White flight vacancy instead of identifying the true cause: the extended denial of living necessities from black neighborhoods by the city and lending institutions (King, 1981).

![Figure 1: The decline in privately owned businesses on main Dudley neighborhood streets from 1950 – 1993 (Medoff, 1994).](image)

Throughout the 1970s and 80s, arson became dangerously common, leaving Dudley residents fearing for their homes and lives (Medoff & Sklar, 1994). Absent landlords saw their properties falling below building codes, but renovations weren’t cost effective for current rents. Fires provided a fast mechanism for mass eviction and demolition, allowing landlords to either escape their commitment to depreciating Dudley real estate and collect insurance payback or
rebuild higher-class housing that current residents couldn’t afford. By the 80s, arson and property abandonment had left over 840 lots in the Dudley neighborhood vacant. These sites became spaces for trash dumping and criminal activity, which the city continued to blame on residents (Medoff & Sklar, 1994).

2.2 The demographics of lead contamination

Low-income neighborhoods of color in the US that face disproportionate environmental health burdens; lead contamination fits this pattern (Bullard & Lewis, 1996; Gee & Ford, 2011). In cities around the country, the neighborhoods facing the worst lead contamination are predictably poor inner city communities where the majority of residents are people of color (Aelion et al., 2012; Bernard & McGeehin, 2003; Campanella & Mielke, 2008; McClintock, 2012; Phoenix, 1993). The bulk of soil lead deposits occurred throughout the second half of the 20th century as lead painted houses fell to disrepair and leaded gasoline emissions peaked (Filippelli et al., 2005). Lead poisoning has declined significantly since use of leaded paint and gasoline ceased, but since lead is stable in the soil the pollution persists today (Filippelli et al., 2005). Beyond the gasoline particulates and paint chips that contaminated Dudley yards, burned buildings left vacant lots with unusually high inputs of incinerated lead paint. The systematic disinvestment in Dudley and other urban communities of color across the US that occurred throughout the second half of the 20th century overlaps the primary period of urban soil lead contamination, and these histories are linked. Structural racism present in US economic and political systems produced neighborhoods with failing, arson inflicted infrastructure that exacerbated soil lead inputs. Then, cities upheld structural racism by ignoring the needs of these neighborhoods, which include the need for a remediation plan addressing environmental contamination.
Figure 2: The use of leaded paint and gasoline in the 20th century. The majority of soil lead contamination occurred post 1950; Lead paint deposits into soil were delayed and occurred primarily as houses fell into disrepair, while leaded gasoline emissions were immediately deposited in the soil (Filippelli, 2005).

The environment has a major impact on physical and mental health, so the people living in these disproportionately contaminated neighborhoods face corresponding health consequences (Evans, 2003; Evans & Kantrowitz, 2002; WHO, 2016). Even at low levels of exposure, Pb can cause serious intellectual deficits, especially in children, and increase the likelihood of depression, anxiety, and other detriments (D. C. Bellinger, Stiles, & Needleman, 1992; D. Bellinger et al., 1991; Bouchard et al., 2009; Lanphear et al., 2005; Herbert L Needleman & Gatsonis, 1990).

2.3 Social implications of lead poisoning

These individual neurological effects also have system-level implications. Lead contamination occurs at the neighborhood scale, and therefore has collective social implications for the people living in contaminated areas – in this case, primarily low-income people of color. Bellinger, et al., found that low socio-economic status impacts children’s social and physical environments in a number of ways that can exacerbate the impacts of lead exposure. Children from poor households are more impacted by lower levels of lead poisoning and are less able to recover over time than their middle-income peers. This distinction is due to a number of social,
environmental, and lifestyle factors that distinguish low-income families including co-exposure to contaminants, stimulation and social development, diet, and increased stress (D. C. Bellinger, 2008). Further, since lead poisoning decreases cognitive functioning, it amplifies the challenge of improving socio-economic status throughout a child’s life. Students with high blood lead levels perform worse in school (S Zahran, Mielke, Weiler, Berry, & Gonzales, 2009), which poses additional limitations on post-high school employment opportunities and future income. These outcomes of lead poisoning compound the inter-generational cycle of poverty already present in the affected communities.

Low-income Black neighborhoods have faced restricted educational and employment opportunities for generations (Berlak, 2001). These conditions, coupled with disinvestment, failing infrastructure, and other factors, fueled increased crime rates in these areas, creating violence that is only heightened by policing and mass incarceration (Alexander, 2012). Just as lead poisoning exacerbates cycles of poverty and ineffective education, it also exacerbates the violence in these communities. Lead poisoning lowers self-control, which can lead to impulsivity and aggression, traits that are linked with criminal behavior (Herbert L. Needleman, McFarland, Ness, Fienberg, & Tobin, 2002). This is reflected in societal scale trends: the prevalence of air lead from leaded gasoline emissions corresponds directly with violent crime rates in US cities (Mielke & Zahran, 2012). Lead pollution amplifies cycles of crime, police violence, and mass incarceration in the lives of young, urban Blacks, who are three times more likely to have elevated blood lead than their peers (Bernard & McGeehin, 2003; Sellers & Turner, 2015). Lead amplifies feedback loops supporting structural racism that low income people of color face in their communities: health problems, poverty, insufficient education and employment, and over-criminalization and incarceration (Perry, 2011).

3. How and why did urban agriculture begin in these communities?

3.1 Historical Context of Urban Agriculture

Historically, community gardening has been a mechanism of local resistance to broader social, economic, and political problems (Okvat & Zautra, 2011; Saldivar-tanaka & Krasny). Urban gardens have been important sources of reliable, affordable food since the late 1800’s, particularly during the great depression and after WWII with the rise of Victory Gardens (Lawson & ebrary, 2005) Following redlining and disinvestment in urban communities of color
in the 60s and 70s, residents began gardening to reclaim land that absent owners neglected or exploited (Okvat & Zautra, 2011; Schmelzkopf, 1995). Urban gardening was, and continues to be, a way to resist the forms of structural oppression that communities like Dudley face (Saldivar-tanaka & Krasny; Wiprud, 2015).

3.2 Social Benefits of Urban agriculture

When implemented effectively, urban agriculture can provide affordable, healthy, culturally appropriate food that poor urban residents otherwise struggle to afford or cannot access in conventional supermarkets (Alkon et al., 2013). By growing their own food, gardeners become responsible for the entire food production process and care for their environment. Working in the garden and eating fresh fruits and vegetables supports physical and mental health of gardeners and their families (Ober Allen et al., 2008; Okvat & Zautra, 2011).

Urban agriculture also provides a range of social benefits that are particularly beneficial to urban communities of color. Beyond producing food, urban gardens provide safe green space for community building and organizing, education, and youth leadership (Ober Allen et al., 2008; Okvat & Zautra, 2011; Subica et al., 2015). Urban community gardens provide space for social networking, which is often lacking in these communities when vacant land is polluted and crime is common. When residents clean up lots and create communal green space they are reclaiming their right to a safe, supportive community (Okvat & Zautra, 2011). As residents socialize and build relationships, gardens become safe space to discuss social issues they face as a community and brainstorm collective methods of resistance. This activism frequently spreads beyond the garden, and can take place there through cultural and environmental education (Saldivar-tanaka & Krasny; Subica et al., 2015). As neighborhood youth take part in gardening, they also have opportunities to learn about their cultural heritage and take leadership roles in community activism - healthy, empowering experiences that deter them from criminal activity (Ober Allen et al., 2008).

Dudley has seen all of these positive social benefits, stemming from residents’ campaign to clean up their neighborhood beginning in the 80s. In 1984, a group of residents formed the Dudley Street Neighborhood Initiative (DSNI) to confront the problems they saw their community struggling with (DSNI; Medoff & Sklar, 1994). DSNI leaders did extensive door knocking to hear what residents’ wanted changed in the neighborhood, and common themes that
arose – fear of displacement, crime, and discontent with the physical environment – guided their action. DSNI launched an organizing campaign called “Don’t Dump On Us” to clean up the numerous vacant lots where outside companies and agencies had dumped garbage for decades and were common sites for criminal activity. Residents, many of whom were youth, came together to clean up lots. Collective investment in improving the Dudley environment enhanced social connections and neighborhood pride (Medoff & Sklar, 1994). The lots were used for different purposes, but some were transformed into community gardens and became spaces for cultural and environmental education, organizing, youth empowerment, and social interaction. Residents were motivated to reclaim lots to address social and environmental issues present in their neighborhood, and this form of activism created gardens that have social and cultural benefits beyond food production (Wiprud, 2015). In 2011, youth working with Alternatives for Community and Environment (ACE), a community based environmental justice organization in Roxbury, started the ‘Grow or Die’ campaign to improve food access in Dudley. With the support of neighboring residents but without asking permission from land owners or the city, they reclaimed vacant lots to start community gardens; they called their activism ‘gorilla gardening’. This ACE youth organizers group, called Roxbury Environmental Empowerment Program (REEP), is still active, though their current efforts are focused on resisting gentrification. The Food Project youth crews have taken on aspects of the Grow or Die campaign to form their own model for helping initiate community gardens in Dudley. Their work is still based around what residents want for their community food system, but they site gardens on neighborhood land trust lots rather than reclaiming any vacant land (Liborio, 2016; Wiprud, 2015).

The disinvestment, exploitation, and neglect communities like Dudley face create the socio-political climate that enables unaddressed lead pollution; because of these conditions, these communities have the most to gain from urban agriculture. They’ve been denied the privilege of fresh, culturally appropriate food, equal educational opportunities, access to safe green space, and more. In this context, urban agriculture is a tool for food-sovereignty and land reclamation. Urban gardens become part of an alternative economy that low-income communities of color build to resist the structural oppression harming their communities (Alkon & Mares, 2012; Andrews, 2016; Wiprud, 2015).
4. What is the current state of lead contamination and urban agriculture?

4.1 Urban Agriculture at the Community Scale: Residents, Newcomers, and Local Organizations

Today, urban agriculture is flourishing in Boston. An increasing number of residential, commercial, community, and school gardens have brought tremendous social benefits to the city. Boston urban agricultural leaders are primarily people of color, and most urban farms and gardens are located in Black and Latino neighborhoods (Wiprud, 2015). Following the goals set out by Dudley gardeners in the late 70s and 80s, the majority of urban farming in Roxbury and Dorchester continues to be rooted in resident defined community goals.

This is not the case in many cities, where outsiders, often young Whites, run urban gardening initiatives to promote food access (Anguelovski, 2015; Guthman, 2008; Reynolds, 2015). While well intentioned, this trend can be deeply problematic when residents are not involved in goal definition and decision-making. If residents aren’t consulted, outsiders can’t accurately identify community needs and their solutions can be harmful (Anguelovski, 2015).

This ineffective mode of urban farming creates distrust in the community. Edith Murnane, the former head of Boston’s Office of Food Initiatives encountered this sentiment in Dorchester when she was working to ease policy barriers to urban agriculture. She recalls speaking with one resident who said, “I go to bed hungry, and I am so fearful that my children go to bed hungry. And you’re going to grow food in front of me that I’m not going to be able to afford. How can you even consider that?” (Murnane, 2016). While this was not the case for Murnane’s project, the resident’s fear reflects a common pitfall of alternative food advocates’ interventions in low-income urban communities. Without asking residents, they misidentify barriers to food access as geographic access and insufficient nutrition knowledge, when the true barrier is affordability (Alkon et al., 2013).

Dudley residents identify land security and looming gentrification as a primary community concern, and urban agriculture led by middle-class Whites who are new to the neighborhood, however well intentioned, can cause or exacerbate gentrification (Anguelovski, 2015; Reynolds, 2015). Residents use gardens as a way to reclaim land, so when outsiders claim vacant lots to farm, the garden becomes another form of displacement. Further, as gardens and other community greening projects improve environmental conditions, low-income communities become attractive to higher income people. Long-term residents recognize the danger of this
‘ecological’ or ‘environmental’ gentrification, and make resisting it a priority in all forms of activism, including urban gardens (Anguelovski, 2015; Dooling, 2009).

Many Dudley residents see how linked these issues are and that environmental or food justice only matter as long as the neighborhood avoids displacement, and this mindset is integrated into their activism. In 2014, DSNI and The Food Project partnered to conduct a community food planning process to identify and document the food values in Dudley. The process identified five priorities that center on improving the local economy and income opportunities:

1. Build a resident-owned supply chain for great food in the neighborhood, growing food businesses that create neighborhood wealth and jobs.
2. Permanently secure vacant land for growing by interested residents, so that anyone who wishes to produce food for themselves or the neighborhood can do so.
3. Improve the food in our schools, ensuring that youth eating at school are well-nourished with food they enjoy.
4. Expand access to great food for lower-income residents, building creative new ways to make great food affordable to all.
5. Encourage physical development to support the neighborhood food system, advocating for food interests in planning, building, and community development.

(J. Diaz, Higgins, Hinds, Ngo, & Shepard-Kim, 2015; Farnsworth, Kiplinger, & Rossello-Cornier, 2015)

The top two priorities around food identified by Dudley residents are to own and control the food production process and the land for growing. Community control is, and has always been, a core value in the Dudley neighborhood and urban agricultural endeavors must reflect that to remain a valuable resource for the community.

Resident led decision-making is also reflected in the youth activism in Dudley. The ACE youth program, REEP, is shifting focus from guerilla gardening to anti-gentrification work to resist resident displacement. As the Food Project youth take over managing the community garden initiation process, they are prioritizing residents’ vision. Jess Liborio, The Food Project Programs and Community Outreach Manager explains that the youth are playing leadership roles in the creation of a new community garden on Folsom Street in Dudley Square, but through this process they’re discussing social and environmental injustice and what that means in the Dudley
community. Through door knocking and being present throughout the community food planning process, the youth are learning “how to [take] cues from residents and [make] as much space as possible for residents to be leading the work” (Liborio, 2016).

Although Dudley is being gentrified, the neighborhood has experienced less displacement in recent years than other neighborhoods. This is largely due to DSNI’s long standing focus on ensuring resident control over their environment (Liborio, 2016). In the late 80s, DSNI was the first community-based organization to use Eminent Domain to create a community owned land trust, which gives Dudley residents long-term control over more than 30 acres of land in their neighborhood (Medoff & Sklar, 1994). Community planning processes like the Food Planning process decide how these lots are used. The land trust enabled 220 affordable housing units, the Dudley Greenhouse, multiple gardens, and a playground in Dudley, which are now all under community control. With DSNI and partner organizations, Dudley is organized to keep residents’ voices at the center of neighborhood decisions, including urban agriculture.

4.2 Urban Agriculture at the City Level

The most successful city policies around urban agriculture are created when the city partners with community based organizations (Goldstein, Bellis, Morse, Myers, & Ura, 2011). In recent years, Boston City government has had some important successes with this approach, as there are a number of well-established non-profits and new commercial endeavors related to urban agriculture. In 2011, a new branch of city government, the Office of Food initiatives, was tasked with updating zoning code to accommodate a broad range of urban farms and gardens. Edith Murnane, the head of the Office of Food Initiatives lead this process, the final outcome of which was Article 89: a specified set of laws around urban agriculture. Prior to Article 89 any commercial urban farming was technically illegal, though some organizations were already farming in Dudley. Creating Article 89 was a long process – nearly two and a half years – in part because the city attempted to capture the needs of urban agriculture practitioners in the city. Danielle Andrews, The Food Project Dudley Greenhouse Manager, sat on the planning board for Article 89. She found many of the initial policy proposals prohibitively strict, but the revision process allowed her and other non-government board members to advocate for the needs of aspiring urban farmers. Both Andrews and Murnane described the process of consulting the broad range of urban agricultural constituents beyond those who sat on the board as a time
intensive process, but the outcome seems worthwhile. Article 89 is one of the most comprehensive urban zoning codes around urban agriculture, and accommodates a wide range of agricultural practices (Andrews, 2016; "Article 89 Made Easy: Urban Agricultural Zoning for the City of Boston," 2013; BRA, 2013; Murnane, 2016).

Ultimately, city government decisions should prioritize residents. Historically, this responsibility has not been upheld in Dudley, but seems to be improving. The creation and execution of Article 89 were not perfect, but the board aimed to accommodate the need of urban agricultural constituents, including Dudley farmers. Murnane’s vision for government reflects a resident centered approach: “I am a very strong believer that government of any kind is for people by people and about people. That is especially true for city government - city government is where rubber hits the road...So many people have a stake in Boston. You live here, you work here, you have a stake in this city. And the city should be open and responsive [and] actively listen for what people want” (Murnane, 2016). Achieving this vision for government is challenging, but seeking out residents’ voices to inform city level urban agriculture decisions will enable an urban food system that benefits Dudley.

The Current Lead Exposure Risk in Dudley Gardens

While garden soil lead levels are still a health risk in Dudley, remediation methods like soil barriers, capping yards with fresh soil and compost, and using rasied beds for growing have all contributed to lowering lead exposure (Clark et al., 2006; Clark et al., 2008; Clarke et al., 2015). These successes reflect the effort Dudley gardeners, local organizations, and the city have put into safe soil management practices in gardens (Hynes, Maxfield, & Hillger, 2001; TFP, 2014). The strong network of Dudley gardeners and Boston urban agricultural organizations coupled with academic research has spread knowledge about soil management techniques so that many growers use raised beds and/or reapply compost regularly; these practices decrease lead exposure and compost application also supplies nutrients to support plant growth. Unfortunately, even the current soil lead average represents a serious health risk to gardeners: the EPA benchmark for safe soil lead is 400 ppm, and even that has been criticized as too high (Henry et al., 2015; Stewart et al., 2014). Gardeners need to continue to address soil lead, particularly as more vacant lots are transformed into agricultural space; however, the improvements in many
yards and gardens highlight the success of soil management methods that can be improved and implemented in more yards in the coming decade.

5. Conclusion

To truly understand urban agriculture and lead pollution, we have to understand the impact structural oppression has had and continues to have in urban communities of color. Through this lens, it becomes clear that to effectively address lead contamination cities must do so at a local and systemic scale. Remediating lead locally is crucial to create healthy environments for gardeners and residents, yet without also confronting structural racism lead contamination will likely be replaced by another form of environmental injustice – perhaps a new pollutant or residents’ displacement.

To create healthy environments, we need healthy relationships with each other (Finney, 2008). Addressing environmental problems with strategies rooted in social justice creates long-term solutions that address root problems in urban communities of color (Subica et al., 2015). The Dudley neighborhood land trust is a great example, as it simultaneously resists gentrification while providing space for community gardens and the greenhouse, which have all been tested and managed to lower lead concentrations to a safe level. Addressing the soil lead health burden remains a major challenge in many urban areas. As organizations and cities move to confront it, solutions that build equitable social environments while reducing soil lead will enable long-term, sustainable health outcomes.
Conclusion

Soil lead contamination has yet to be adequately addressed in the urban environment, especially in low-income communities of color. This study offers a current perspective on the remediation process in the Dudley neighborhood of Boston, and situates the geochemical results in the community’s social and historical context.

This analysis reframes the practice and the communication of GeoHealth research on environmental justice issues like soil lead contamination. Understanding the intersection of biogeochemical flows and human health requires an interdisciplinary toolset and community collaboration, which are new approaches for most geochemists. The research model presented in this study provides a strategy to accomplish this by integrating urban geochemistry and participatory action methodologies. This approach enriches the practice of GeoHealth research and leads to applicable solutions that align with long-term community goals.

This study focuses on identifying drivers of lead exposure from the individual to societal scale, which has implications for understanding and acting on the lead health risk. In line with other recent urban geochemistry studies, we focus on bioaccessible rather than total lead to more accurately characterize gardeners’ health risk (Chammi P Attanayake, Ganga M Hettiarachchi, Sabine Martin, & Gary M Pierzynski, 2015; Clarke et al., 2015; Henry et al., 2015). The outcomes from this approach shape gardening best practices that reduce exposure to bioaccessible lead. For example, Food Project employees have used the finding that compost dilutes lead concentration, binds lead in the soil, and limits fine particle transport to make compost sourcing and application decisions in Dudley gardens.

Public health discourse on the lead health risk typically centers on identifying the populations with high blood lead levels. We expand that perspective to also to ask why these populations bear disproportionate impacts. Structural racism is a key root cause of environmental health inequality that explains the pattern of low-income people of color experiencing a higher rate of elevated blood lead levels (Bernard & McGeehin, 2003; Bullard, 2002; Phoenix, 1993). However, identifying social drivers cannot end at the structural level; rather, structural inequality should be traced to the tangible actions of organizations, companies, governments, and individuals. This ensures that local entities are held accountable for their role in upholding a harmful system (Pulido, 1996). Naming racism as a key driver in the persistence of soil lead
contamination encourages systems level understanding that shapes local actions to address the root cause (Subica et al., 2015).

This interdisciplinary, community-based, applied approach to urban garden soil lead contamination highlights solutions that have an immediate impact at the local level that also support long-term community sovereignty. Grassroots organizations like The Food Project, the Dudley Street Neighborhood Initiative, and Alternatives for Community and Environment center their work on the Dudley residents’ vision for their neighborhood. Under this model, remediating lead contamination in urban gardens is part of a larger goal to increase residents’ control over their environment. The most effective pathways to address soil lead contamination will reflect the understanding that social and environmental injustices cannot be separated, and therefore must be addressed synergistically to produce sustainable, equitable outcomes.
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Appendix A:
Supplementary Information

A1: Density Separation Experiment Results.................................................................62
A1. Density Separation Experiment Results

**Figure A1:** Density separation experiment preliminary results. Pb is highly concentrated in the fine, dense particles, likely due to incinerated Pb paint from houses that were burned in second half of the 20th century. Fractionating <37µm samples of soil and raised bed fill from the same yard showed that there are fine, dense particles with high concentrations of Pb (Figure 12). These particles make up approximately 40% of the soil by mass but only 3% of the raised bed, which reflects the benefit of adding compost but highlights the potential for recontamination from fine soil particles.
Appendix B:

Alternate modes of research communication

B1. Infographics for Food Project collaborators..........................................................64
B2. Schedules for Food Project teen crew visits.........................................................67

Note that each of these infographics and schedules were collaborations with:
  Hannah Davelman, ‘16
  Meredith Wade, ‘17
  Hannah Oettgen, ‘17
  Disha Okhai, ‘17
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**B1. Infographics for Food Project Collaborators**

**Brabander Lab Summary of Lead in Boston Compost, Garden Soils, and Soils • August 2015**

*What is the current Pb level in Boston compost and gardens and how does it compare to previous years?*

*How can we confront the additional risk associated with small, mobile particles?*

*What role can compost play in remediation efforts?*

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**Pb in Boston City Compost by Year**

- EPA Soil Lead Benchmark: 400 ppm
- German Compost Lead Benchmark: 150 ppm

**Pb in Rocky Hill Compost**

- 2011 (RH)
- 2015 (RH)

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**Lead Mobility and Intake**

**Bioaccessible Lead:** the fraction of total lead that is soluble in gastric fluid and could be taken up by your body and impact health.

**Transportable Lead:** the fraction of total lead present in soil or compost particles that can be transported by wind or by sticking to hands, which increases exposure risk for people.

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**June 2015 Sample Results**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Lead (ppm)</th>
<th>% Nitrogen</th>
<th>% Organic Carbon</th>
<th>Lead (ppm) in hand portable grains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corner of Langdon St and Dudley St</td>
<td>1971</td>
<td>0.2</td>
<td>6</td>
<td>3346</td>
</tr>
<tr>
<td>Avó’s Garden</td>
<td>720</td>
<td>0.6</td>
<td>10</td>
<td>Being measured</td>
</tr>
<tr>
<td>Barros Raised Bed</td>
<td>345</td>
<td>1.4</td>
<td>20</td>
<td>580</td>
</tr>
<tr>
<td>Barros Soil</td>
<td>1062</td>
<td>0.2</td>
<td>5</td>
<td>Being measured</td>
</tr>
<tr>
<td>City Soil Compost</td>
<td>274</td>
<td>1.6</td>
<td>24</td>
<td>300</td>
</tr>
<tr>
<td>Rocky Hill Compost</td>
<td>184</td>
<td>1.7</td>
<td>21</td>
<td>Being measured</td>
</tr>
</tbody>
</table>

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**Takeaways & recommendations moving forward:**

**General:** Composts have lower lead concentrations than Roxbury soils, so continue amending soil with compost whenever possible.

Raised beds filled with compost are ideal, since compost is the primary growing medium. Compost should be reapplied each year to prevent recontamination from nearby soils blowing into the raised beds. Any soil not used for growing should be covered with mulch or cover crop to prevent re-contaminating exposed growing areas.

**2015 Samples:** Compost application has definitely helped, but Avó’s garden still has high lead levels. Additional compost application there and under the nearby fruit trees and grape vines is a priority.

2015 City Soil Compost contains 1.5 times as much lead as Rocky Hill, confirming that Rocky Hill is still preferable in terms of lead.
B2. Schedule for Food Project Teen Crew Lab Visits

This is a general layout for the two Food Project teen crew (Dirt Crew and Root Crew) visits to the Wellesley College Geoscience lab space to learn about soil lead contamination, testing, and remediation in the Dudley neighborhood context.

[30 Mins] djb team arrives; Set up, check-ins, potentially bagels :)

[30 Mins] Crew arrives; intros and icebreakers (name games, trust-building, get energy up)

[30 Mins] In small groups, generate some questions using lead, urban agriculture, and Dudley as starting points. At this point, anything at all that is interesting or personally relevant, big questions, little questions, complex or simple, etc. Report back to the whole group and pick a few questions to focus on for the day.

[1 Hour] Divide into two groups (4 interns each) and spend half an hour or so on:

1. **Soil Sample Testing with Niton + Discussion**
   We can explain how to use the Niton and XEPOS so they can test their own samples from their yards and Dudley Community gardens. We can then have a discussion on what the results mean. They will already know some stuff about lead in soils, but we could chat about remediation or about urban agriculture as a way to address Pb contamination. If any of the questions we came up with earlier are relevant, we could try and connect to them here, too.
   DJB folks on this: **Rosalie, Ciaran, Hannah O.**

2. **Mapping**
   We will have a hardcopy map of Dudley Triangle posted on the whiteboard in 200, so that interns can mark with Post-it circles where they got their samples from with input data from the soil testing. They can also do some descriptions of the surroundings of the gardens they worked on and we can compare and contrast. Potential discussion questions could be about where Pb comes from, how remediation differs in this range of environments, etc.
   DJB folks on this: **Hannah D., Mer, Idalmis**

[30 Mins] Weather permitting, we will do a tour of the Greenhouses/Farm-in-a-Box, and edible ecosystem garden. The crews are really interested in seeing these other forms of agriculture, and it’s a nice break from thinking about environmental contamination.

[30 Mins] final discussion and closing activities

   **Concept map** -- of what we learned, new questions, what we can do about Pb contamination

   **Next steps** -- a fun and short reflective activity to close out the day
Appendix C:
Conference Presentations

C2. 2016 Ruhlman Conference, Wellesley College, Oral Panel Abstract ......................70
C3. 2015 Summer Research Presentation, Scientific Poster ........................................71
C4. 2013 Ruhlman Conference, Wellesley College, Collaborative Scientific Poster ........72

Note that I worked with co-authors who are listed with each presentation title.

Oral Presentation at the Geological Society of America 2015 Annual Meeting, Baltimore, MD
Session T47. Geology and Health: A Decade of Progress

Abstract: Community driven urban agriculture is an empowering source of affordable, fresh, healthy, and culturally appropriate food in urban neighborhoods. However, in many cities urban soil lead contamination correlates with elevated blood lead levels in children and thus threatens the potential social and environmental rewards of urban agriculture. Lead exposure causes significant neurological damage, especially in children, negatively impacting the individual and society. Compost application is a promising tool for soil lead remediation since low lead compost can dilute and bind lead in highly contaminated soils. This project evaluates the key biogeochemical characteristics of growing matrices in order to gain a comprehensive understanding of the ability of municipally sourced compost as a growth media to support urban agriculture and remediate lead contaminated urban soil. Samples of compost, garden soil, and unamended soil were collected in Roxbury, MA, in partnership with The Food Project, an organization that promotes urban farming for youth and community empowerment. Geochemical fingerprinting coupled with textural characterization using SEM images (JEOL VP-SEM0-EDS) confirms that compost and urban soil are geochemically distinct and constitute end members of the urban growing matrix spectrum examined in this study. Using an Energy Dispersive X-ray fluorescence instrument (SPECTRO-XEPOS), a CHNS Element Analyzer (Elementar Vario MICRO Cube), and performing the EPA in-vitro Bioaccessibility Assay, we examine major physical and chemical properties of bulk, sieved, and density separated samples in relation to Pb concentrations and bioaccessibility. Compared to unamended soils, compost has lower total Pb, a higher fraction of non-transportable grains (>150 µm), higher pH, and higher % organic carbon, all of which are associated with reduced Pb geomobility and bioaccessibility. This research will improve risk assessment of gardening in contaminated soils and shape effective and sustainable remediation recommendations for urban agriculture. This work contributes to a broader goal of optimizing urban carbon cycling to support social, cultural, and environmental sustainability in the urban ecosystem.
C2. Towards Environmental Justice: An Interdisciplinary, Community Based Approach to Address Urban Soil Lead

Ruhlman Conference Panel Presentation, April 2016
Presenters: Rosalie Sharp, ‘16, Meredith Wade, ’17, Idalmis Vaquero, ‘16

Abstract: This panel will discuss three projects in the natural and social sciences that are addressing soil lead contamination in low-income urban communities of color. Environmental justice organizations are working to address lead exposure in urban environments through policy, legal, and organizing strategies. Geochemical analyses of soils and composts inform understanding of lead exposure risk. Our results implicate fine soil grains as the primary cause of elevated blood lead and as a recontamination threat for clean areas. Understanding lead exposure and transport pathways informs sustainable remediation designs. Effectively communicating health risks and remediation strategies requires thoughtful, long-term collaboration with local residents. Partnerships with community organizations like The Food Project come with unique challenges, but ultimately allow for more effective, ethical, and equitable research. Together, these projects examine the social and environmental intersection of lead contamination to identify sustainable solutions.
Urban Carbon Cycle Risks and Resources: Assessing the potential of municipal compost in urban soil lead remediation

Rosalie Sharp, ’16, Environmental Studies; Hannah Oettgen, ’17, Geosciences; Disha Khokh, ’17, Geosciences
Advisor: Dan Brabander, Geosciences

Introduction

Community-driven urban agriculture is an urgent and empowering source of affordable, fresh, healthy, and culturally appropriate food in urban neighborhoods. However, in many cities, urban soil lead contamination has been directly linked to elevated blood lead levels in children. Lead exposure causes neurological damage that varies by the societal scales and the extent and potential social and environmental rewards of urban agriculture. Compost application in urban gardens is growing for soil lead remediation because lead in compost can also be highly contaminated. This project evaluates the key biogeochemical characteristics of growing matrices to understand the ability of municipally sourced compost to serve as a growth media supporting urban agriculture and as a tool for in situ remediation of lead contaminated urban soil.

Methods

All samples were collected in Boston, MA in partnership with The Food Project, an urban agriculture organization practicing urban agriculture for educational and community empowerment. Bulk samples were sieved to <2mm.

Results and Discussion

Figure 1. (Pb) uptake by grain size for compost, raised bed soil, and soil. Smaller and more transportable grain sizes have higher lead concentrations for all samples, with soils showing the greatest range in Pb.

Figure 2. % contribution (Pb mass in each grain size / total Pb mass) to (a) total Pb and (b) bioaccessible Pb by grain size fraction.

(a) Soil and compost Pb show higher lead contribution from smaller, transportable grain sizes, which increases Pb exposure risk associated with these samples. Since Pb in compost is more evenly distributed across grain sizes (Figure 1), nearly 90% of lead in compost is associated with the large >250 µm particle. In comparison, only 40% of lead in soil is associated with the >250 µm fraction.

(b) Contribution to bioaccessible Pb is similar for each sample; the majority of bioaccessible lead is associated with the smallest, highly transportable grain sizes.

Conclusions

This project confirms that unamended urban soil and compost are geochemically distinct. Compost has a significantly smaller fraction of transportable Pb compared to soils, since Pb is more evenly distributed across grain sizes. Highly transportable grains (<250 µm) have higher concentrations of bioaccessible Pb than the larger grain sizes (>500 µm) across matrices. This increases the risk associated with the transportable particles.

• This data suggests that nutrients and sources of lead in this range of urban soil to compost do not influence parent Pb bioaccessibility.

• %C may limit bioaccessibility but this relationship varies by Pb source.

Future Works

• Performed density separation tests on the transportable grain size fractions (<150µm), and test for total and bioaccessible Pb in the different density fractions.

• Test and characterize dissolved organic carbon (DOC) in the remaining SIE solutions to examine the link between bioaccessible Pb and DOC in each matrix type.

• The impact of curing temperature and time on Pb bioaccessibility. This will have implications for optimizing the compost production process.

• Expand the depth of time in the in vitro bioaccessibility procedure. This will help to determine the in situ Pb contamination for the worst and best case Pb ingestion scenarios.

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We originally conducted this experiment to find the source of lead in compost and yard waste from the City of Boston/Dudley Square and the Wellesley RDF. Based on our findings, we concluded that the City of Boston Dudley Square compost yard waste has greater levels of lead than the Wellesley RDF.

The primary source of lead in Dudley Square is leaded paint and the primary source of lead in Wellesley is leaded gasoline emissions.

At both sites, the greatest amount of lead in compost comes from soil.

Natural sources of lead play a larger role in the Wellesley compost yard waste samples than in the Boston samples.

The bulk concentration of lead in the Dudley Square yard waste bag is an order of magnitude greater than the concentrations found in the Wellesley yard waste bag.

The bulk yard waste leads to the bulk compost lead at both locations.

There are additional sources other than yard waste that contribute to lead concentrations in compost.

- Continue collecting samples from Dudley Square, Boston, and Wellesley's RDF. Also collect samples from other locations within each of these areas to examine variability of our results.
- Test these samples once if there are any changes in heavy metal concentrations either over time or across locations and areas.
- This would allow us to see if concentration gradient exists.
- Collect soil, air, and water samples to test for heavy metal concentrations, since these are other exposure pathways for contamination.
- Recommend changes to reduce the amount of pollution that creates and contributes to the concentrations of heavy metals in the yard waste and compost. This is in the hopes of lowering total compost lead concentration in order to allow safe distribution of municipal compost to urban gardeners.
- Bag yard waste for soil particles.

Acknowledgements: Thanks to: Professor Dan Brabander, Maia Fitzstevens, the DJB lab, Town of Wellesley Recycling and Disposal Facility, and to the Residence on North Ave., Dudley Square, Boston, MA.