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Research Paper

Growing fresh fruits and vegetables in an urban landscape: A geospatial assessment of ground level and rooftop urban agriculture potential in Boston, USA

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A B S T R A C T

Urban parcels can potentially be leveraged for developing a local urban food system by growing high yield food crops. Here, a remote sensing and GIS-based modeling framework was developed to locate and quantify available area for urban farming, including both rooftop and ground level areas in the city of Boston, MA, USA. Geoprocessing and spatial analysis tools were used to process geographic data layers for zoning, ownership, slope, soil quality, and adequate light availability. Surface slope (roof pitch) was determined for all buildings in the city through the creation of a digital surface map from remotely sensed LiDAR data. Potential parcels from ground level public and private vacant lots and underutilized residential and commercial areas were mapped using publicly available datasets. Approximately 922 ha of rooftop and 1,250 ha of ground level parcels have been identified, representing 7.4% and 10% of the total land area in Boston, respectively. Finally, food yield values for common urban agricultural crops were used to estimate the city's food production potential from the identified parcels. Despite Boston's density, the mapped areas have potential to produce enough fresh fruits and vegetables for Boston's population, while providing both environmental and economic co-benefits. The study outcome was compared with mapping and inventory results from other North American cities.

1. Introduction

1.1. Urban agriculture

Food and energy security are pressing concerns for municipalities in the face of growing global urban populations. Large-scale industrial agriculture, while economically efficient, has incurred significant environmental costs that are not internalized in food prices, including from deforestation, erosion, depletion of water resources, pollution of waterways from surface runoff, and loss of biodiversity (Knudsen et al., 2006; Nellemann, 2009). The geographical and psychological disconnect between producers and consumers is also a concern, with food traveling an average of 1500 miles in the United States (Halweil, 2002). In contrast, food grown in urban areas is coincident with demand centers. Although dense cities may not be able to provide either the quantity or variety of food that its residents consume, urban food farming of selected crops could increase food resilience and help to address various urban environmental, economic, and social challenges. However, producing significant quantities of food in dense urban areas has important trade-offs, particularly potential uptake of toxins from contaminated soils and competition with other economically and socially valuable potential land uses.

Urban agriculture can enable cities to become partially self-sufficient and improve the resiliency of food and energy systems through diversification of supply, and can bring multiple co-benefits including enhanced food access and security, greater food variety, enriched landscapes, local economic development, and improved environmental quality (Hodgson, Campbell, & Bailkey, 2011). Urban agriculture can also benefit the local environment through improvements to urban air quality, increasing rates of carbon sequestration, modulation of urban heat islands, and mitigation of water pollution problems associated with stormwater runoff (Lovell, 2010). Producing food locally can also avoid environmental impacts associated with long-distance food distribution and losses (Kulak, Graves, & Chatterton, 2013). At the same time, potential economic and social benefits can include employment and local economic activity; redevelopment and productive use of blighted, marginal urban areas that are frequently located in low-income, underserved communities; and, depending on the area of the country, noise abatement, food access and nutrition, and community education (Hendrickson & Porth, 2012; Lovell, 2010; Zhao, Monnell,

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Niblick, Rovensky, & Landis, 2014).

An important preliminary step of planning for local food system development is to estimate the total available area and potential production volumes for urban agriculture. Urban food farming can be implemented using both ground level and rooftop areas. Especially in densely built-up areas where vacant parcels are scarce and much of the non-road area is taken up by building footprints, rooftop farming can be an attractive supplement to more conventional urban farms and community gardens, but is still a niche form urban farming that has yet to gain popularity on a large scale. In estimating potential, however, there exists lack of consensus in defining the geographic boundaries of a local food system. According to one US Department of Agriculture (USDA) definition, a local urban food system may consist of an area as large as 644 km^2 (Clancy & Ruhf, 2010), but this is smaller than the geographic extents of many US cities. Many municipalities consider their administrative boundaries for delineation of their local food systems. Another useful concept is that of the 'foodshed', which considers food production, distribution, and consumption at a regional scale (Kloppenburg, Hendrickson, & Stevenson, 1996).

Though urban agriculture has existed in many forms in North American cities throughout their history (Kurtz & Lawson, 2007), there has been a recent resurgence in efforts to integrate urban agriculture and land use planning (World Bank, 2013), with notable progress in New York, San Francisco, Portland, and Vancouver (Mendes, Balmer, Kaethler, & Rhoads, 2008). Boston is a comparative latecomer in this regard, though up until the 20th century it was one of the largest agricultural centers in Massachusetts (Neyfakh, 2014), in addition to being the state capital (Fig. 1). Following the establishment of the Mayor's Office of Food Initiatives in 2010, the city has made significant efforts in focusing attention on land use planning that includes agricultural uses, stating that urban agriculture "improves access to fresh, healthy, and affordable food, with decreased transportation costs and lower carbon emissions. Furthermore, new farming endeavors can bring communities together, empower small entrepreneurs, and improve access to fresh food for all Bostonians." (Boston Office of Food Initiatives, 2015) To support commercial-scale urban agriculture, the City in 2013 passed Zoning Article 89 for urban agriculture, providing necessary guidelines about urban farming implementation and municipal support for local food distribution (Boston Redevelopment Authority, 2013). This was followed by a city-wide visioning document based on extensive stakeholder engagement (Northbound Ventures, 2015).

1.2. Geospatial analysis of urban agriculture potential

Geospatial analysis is a critical tool in mapping and evaluating the potential yields of local food systems. On the supply side, geospatial analysis has primarily included urban food system mapping and land suitability studies. Notable efforts have been taken in assessing food system mapping under the title of foodshed analysis in various locations over the last several decades (Horst & Gaolach, 2015; Peters, Bills, Wilkins, & Fick, 2009; Thompson et al., 2008). Different analytical, numerical, statistical, and artificial intelligence approaches have been investigated to assess urban agriculture viability and potential extent. Table 1 summarizes the characteristics for studies conducted in different cities across North America. Geographic Information System (GIS)-based analysis using tax assessor or land use layers has been most commonly employed, occasionally coupled with remote sensing data products for further screening or validation.

Remote sensing imagery has typically been processed manually rather than through automated means, either to detect existing urban agriculture activity (Taylor & Lovell, 2012) or to identify potentially suitable parcels (Berger, 2013; McClintock, Cooper, & Khandeshi, 2013). For example, on ground level suitability, Kremer & DeLiberty (2011) analyzed the city of Philadelphia by integrating remotely sensed land cover data with GIS administrative data layers. The authors used a supervised pixel-based classification method and discussed the importance of comparing it with object-based classification methods for detecting residential lots. Richardson and Moskal (2016) examined existing public and private grassland throughout Seattle using object-based image analysis of aerial LiDAR and imagery and estimated food production potential to support the local population on a vegetarian diet. Uniquely, they also tested the effects of tree shading on urban agriculture potential. On rooftop suitability, Berger (2013) looked at potential site suitability of rooftop agriculture in New York City, using public data to identify suitable buildings (including structural considerations) for different modes of farming, combined with aerial imagery for validation and estimation of usable area. While not focused on food, Kodysh et al. (2013) used LiDAR data and GIS to conduct a rooftop suitability study for PV solar installation, considering screening parameters such as elevation, slope, and shadow effects. Such LiDAR-based tools developed for the solar energy industry have also been applied to consider suitability for rooftop agriculture, such as the NYC Solar Map used by Berger (2013).

1.3. Connections to self-sufficiency and resilience

Resilience is now a central concept in city planning; Boston was one of the first cities in the United States to appoint a Chief Resilience Officer in 2015. Also in 2015, the City released the first Boston Food System Resilience Study, describing in mostly qualitative terms some of the potential risks facing the city's residents in the case of disruptions

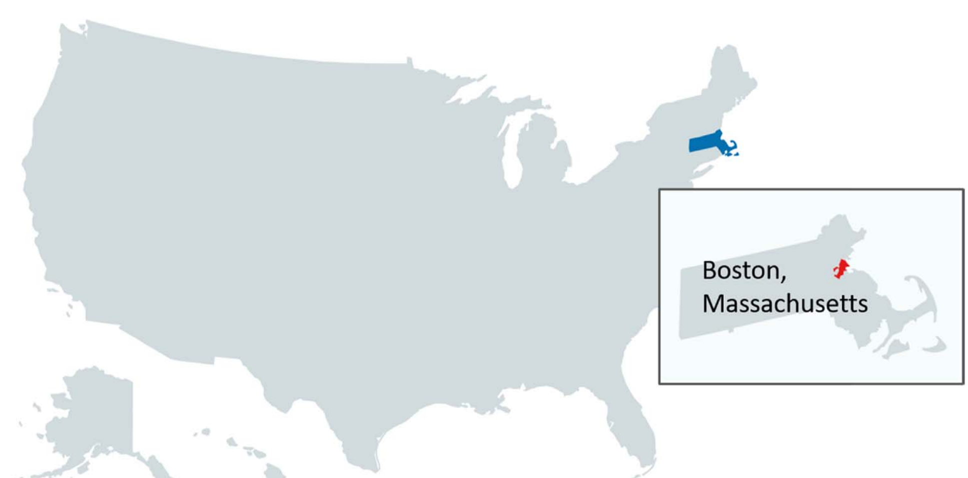

Fig. 1. Locator map for Boston, Massachusetts, USA.