Landscape and Urban Planning xxx (2012) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Mapping public and private spaces of urban agriculture in Chicago through the analysis of high-resolution aerial images in Google Earth

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HIGHLIGHTS

- ▶ Extraction of urban agriculture sites from Google Earth images is highly accurate.
- ▶ Urban agriculture is an extensive land use type in Chicago.
- ▶ Much of the production area has been previously undocumented.
- ▶ A small percentage of Chicago sites reported to be community gardens produce food.
- ▶ Home gardens constitute the majority of existing food production area in Chicago.

ARTICLE INFO

Article history:
Received 22 December 2011
Received in revised form 28 July 2012
Accepted 6 August 2012
Available online xxx

Keywords:
GIS
Chicago
Urban agriculture
Mapping
Food system
Photointerpretation

ABSTRACT

Although always a part of city life, urban agriculture has recently attracted increased attention from diverse groups in the United States, which promote it as a strategy for stimulating economic development, increasing food security and access, and combatting obesity and diabetes, among other goals. Developing effective policies and programs at the city or neighborhood level demands as a first step the accurate mapping of existing urban agriculture sites. Mapping efforts in major U.S. cities have been limited in their focus and methodology. Focusing on public sites of food production, such as community gardens, they have overlooked the actual and potential contribution of private spaces, including home food gardens, to local food systems. This paper describes a case study of urban agriculture in Chicago which used the manual analysis of high-resolution aerial images in Google Earth in conjunction with ArcGIS to identify and map public and private spaces of food production. The resulting spatial dataset demonstrates that urban agriculture is an extensive land use type with wide variations in the distribution of sites across the city. Only 13% of sites reported to be community gardening projects by nongovernment organizations and government agencies were determined, through image analysis, to be sites of food production. The production area of home gardens identified by the study is almost threefold that of community gardens. Study results suggest opportunities may exist for scaling up existing production networks—including home food gardens—and enhancing community food sovereignty by leveraging local knowledges of urban agriculture.

1. Introduction

For the purposes of this study, urban agriculture is broadly defined as the growing of food in the city. As a practice, it encompasses a wide range of actors, activities, and sites, from recreational food production in the home garden to outdoor for-profit farms to indoor aquaponic production systems housed in industrial lofts. While long recognized as an integral component of food systems in developing countries, urban agriculture has been characterized (and often dismissed) as a cyclical phenomenon in the United States—a temporary response to crisis that waxes and wanes with the country's fortunes (Bassett, 1981; Lawson, 2005; Moore, 2006; Pudup, 2008). With the recent economic downturn, government interest in and support for growing food in the city has experienced a predictable resurgence, with the federal government providing funding for a wide range of urban agriculture-related programs and a number of U.S. cities considering or passing zoning ordinances and other policies intended to foster urban food production for recreation, subsistence, or profit. Urban agriculture and community-based food systems have further attracted the attention of planners and landscape architects, with the American

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http://dx.doi.org/10.1016/j.landurbplan.2012.08.001

Planning Association recently publishing a guide to planning for local food production in the city (Hodgson, Campbell, & Bailkey, 2011) and the American Society of Landscape Architects promoting urban agriculture as an element of sustainable city and community planning (ASLA, 2011). Local nongovernment organizations (NGOs) have also played a significant role in the recent renaissance in urban agriculture. New NGOs devoted to the promotion of urban agriculture have proliferated in recent years, and NGO-sponsored projects have sprouted across the urban landscape, vying for public interest and the financial and political support of government agencies, foundations, and other potential benefactors.

Actors in the urban agriculture movement have tended to privilege public and semi-public forms of food production, including urban farms and school and community gardens. In contrast, home gardens and other informal provisioning practices have usually been overlooked in food systems planning, and their contributions to local food systems have been difficult to measure or have remained unmeasured (Martinez et al., 2010). Home gardens in particular may be a significant source of local food in urban areas, but in the United States and in the Global North as a whole their actual and potential impact on household and community food security and resiliency has largely gone unremarked and unstudied, particularly in economically disadvantaged communities (Gray, 2011). In the Global South, on the other hand, the social, economic, and health benefits of home food gardens are well documented for marginalized and economically disadvantaged populations (Kortright & Wakefield, 2011; Reyes-Garcia et al., 2012). Home gardens are reported to diversify diets (Cabalda, Rayco-Solon, Solon, & Solon, 2011), to increase the food security of households and communities (Buchmann, 2009; Kumar & Nair, 2004), and to strengthen household and community resilience (Aguilar-Stoen, Moe, & Camargo-Ricalde, 2009; Buchmann, 2009). They also support urban livelihoods and provide informal sources of income for households (Drescher, Holmer, & Iaquinta, 2006; Kumar & Nair, 2004; Méndez, Lok, & Somarriba, 2001)

In the small number of studies conducted in the Global North, home food gardens have been found to reduce household expenditures on food and to provide a source of income through the sale of excess produce (Airriess & Clawson, 1994; Domene & Sauri, 2007; Reyes-Garcia et al., 2012). By increasing the accessibility of fresh, nutritious produce, home food gardens increase the overall consumption of vegetables and improve the nutritional quality of diets (Airriess & Clawson, 1994; Kortright & Wakefield, 2011). They further support ethnic foodways (Airriess & Clawson, 1994; Head, Muir, & Hampel, 2004; Nazarea, 2005), provide valuable ecosystem services (Calvet-Mir, Gomez-Baggethun, & Reyes-Garcia, 2012) and may be sites of agrobiodiversity and cultural reproduction (Calvet-Mir, Calvet-Mir, Vaque-Nunez, & Reyes-Garcia, 2011; Domene & Sauri, 2007; Galluzzi, Eyzaguirre, & Negri, 2010; Gaynor, 2006; Gray, 2011; Nazarea, 2005). Through home food production, urban and rural home gardeners may participate in economies of reciprocity and redistribution (Morton, Bitto, Oakland, & Sand, 2008), and scaling up private food production at the level of the home garden may be one way to build community food security (Gray, 2011). Clearly, home food gardens could play an important role in urban agriculture and may already do so.

1.1. Mapping urban agriculture

Developing coherent and effective urban agriculture policies and programs at the city level demands as a first step the accurate mapping of both public *and* private forms of urban agriculture, including food production at the parcel level. Such mapping should be an integral part of a larger foodshed or food systems analysis (Hodgson et al., 2011; Kremer & DeLiberty, 2011). Knowing where urban agriculture is currently occurring and in what forms can help planners, government officials, and advocates identify gaps in the spatial distribution of existing sites—where urban agriculture is not occurring but possibly should be because of poverty, lack of food access, or public health problems such as obesity, diabetes, and heart disease. Mapping can also help to identify valuable local resources for the development of new sites and the enhancement of existing sites. Existing gardens and farms, for example, can function as nucleation points for the creation and expansion of urban agriculture networks, with gardeners and farmers and their locally adapted knowledges serving as information resources for novice practitioners. In addition, knowledge of the distribution of existing urban agriculture sites and the physical and sociodemographic characteristics of the surrounding areas can help planners, advocates, and educators tailor outreach programs to address the needs of specific populations of gardeners and farmers as well as the particular environmental conditions, e.g., potentially contaminated former industrial sites, in which they are growing food in the city. Finally, maps that accurately document the extent and diversity of food production sites can demonstrate to city officials and others that urban agriculture is a valid and productive use of urban land.

1.1.1. Mapping through lists and voluntary reports

NGOs, public agencies, and other groups recognize the potential value of mapping sites of food production to their advocacy and community planning work. However, mapping efforts in major U.S. cities—and in cities in other developed countries—have been limited in their narrow focus on identifying only existing public sites and/or by their methodology, which has largely been limited to the collection of institutional lists or voluntary reports of sites. In Chicago, New York, Philadelphia, and other cities, mapping projects have concentrated almost exclusively on documenting community gardens, urban or periurban farms, and other publicly accessible sites. A recent effort to map urban agriculture sites in Philadelphia did include in its scope single-plot "squatter" gardens but not residential food gardens (Vitiello & Nairn, 2009). In Chicago, GreenNet, a coalition of NGOs and public agencies, compiled its 2005 map of more than 600 community gardens from self-reports and from lists of urban greening and gardening projects obtained from NGOs and city programs. The organization's current map—which includes approximately 120 sites that may or may not support food production—relies solely on self-reports from urban gardeners and farmers (GreenNet, 2011). The U.S. Forest Service's New York and Chicago STEW-MAP projects have also adopted a participatory approach to identifying and mapping urban stewardship sites, including community gardens, urban farms, and private sites as small as residential yards, flowerboxes, and planters (U.S. Forest Service, 2011). Though the participatory approach of these efforts is laudable, particularly because the maps they yield are publicly accessible and are intended to foster networking between stewardship or community groups, the quality of the maps depends on the active participation of the targeted groups or individuals in the mapping process. Consequently, the maps may suffer from significant undercoverage of even the limited range of sites they seek to inventory.

1.1.2. Mapping through image analysis

A more inclusive approach to mapping urban agriculture based on manual or automated classification of aerial or satellite images potentially overcomes the methodological exclusion of particular spaces of production such as the home garden. It has, however, been applied only infrequently to mapping existing urban agriculture sites. The majority of applications have been exploratory in nature and have focused on the identification of agricultural sites—typically farms—in open space in periurban and urban landscapes in developing countries (Appeaning Addo, 2010). The reported accuracy of classification varies by method and study area. For a limited periurban area of Hanoi, Vietnam, for example, an object-oriented classification method for high spatial resolution satellite data was applied to the classification of agricultural sites. The average farm size was reported to be 0.22 ha, almost eight times the size of a standard residential lot in the city of Chicago. With an overall accuracy of 67%, the classification of the QuickBird image with spatial resolutions of 0.5 m (panchromatic bands) and 2 m (multi-spectral bands) was considered to be satisfactory (Forster, Buehler, & Kellenberger, 2009). Remote sensing with satellite imagery was also applied to the identification of urban agriculture sites in a small (64 ha) area of Lisbon, Portugal. At 52%, the overall accuracy of the semi-automated extraction of urban agriculture sites from the VHR QuickBird image (spatial resolution of 0.61 m) was deemed to be relatively low. The authors acknowledged that extraction was complicated by the heterogeneity of the vegetative cover of production sites, including the presence of different crops and different phenological stages of the same crop within a single site. Average garden or farm size was not reported (Freire, Santos, & Tenedório, 2009).

In contrast to these exploratory efforts using remote sensing technology, a systematic inventory of sites in open spaces greater than 1000 m^2 in area in Dar es Salaam, Tanzania, was conducted through the manual interpretation of relatively high-resolution black-and-white analog aerial images (1:12,500). Extracted sites were groundtruthed and subsequently digitized in GIS for further analysis. The level of accuracy of the manual classification was not reported, nor was the average garden size (Dongus & Drescher, 2006).

As objects, urban food gardens exhibit high levels of internal heterogeneity, complicating classification efforts. They are composed of patches within patches, or sub-objects, at often very fine scales, and the density and size of sub-objects may change as crops develop and senesce (Forster et al., 2009). The results of the Lisbon and Hanoi studies suggest that the intra- and inter-object heterogeneity and temporal variability of urban food gardens may preclude the use of automated or semi-automated extraction in mapping urban agriculture. While manual feature extraction and classification from aerial imagery—the technique employed in the Dar es Salaam study—may be tedious and subjective (Kampouraki, Wood, & Brewer, 2008), it may have practical and methodological advantages over automated or semi-automated extraction techniques using aerial or satellite imagery. If very high quality, orthorectified aerial images are available on-line, as they were in Google Earth for the study described in this article, no other data sources (e.g., multi-spectral satellite images) need be procured. The spatial resolution of the aerial images in Google Earth is typically higher than that of free satellite imagery. The technique may be performed by individuals with minimal training in GIS or other techniques of spatial analysis, such as interns, students, or volunteers, using only a computer with a high quality monitor.

Despite advances in automated and semi-automated classification such as geographic object-based image analysis (GEOBIA), manual photointerpretation still remains “to a good extent... the method of choice for producing fine-scale forest and land-cover maps” (Castilla, Hay, & Ruiz-Gallardo, 2008). It may be the only suitable strategy for identifying such a diverse and fine-scale urban land use as urban agriculture, particularly at the scale of the home garden. Manual photointerpretation has the advantage of identifying real world objects rather than the image objects extracted in object-based classification approaches. The image interpreter may be better able to identify and to discriminate between real world objects based on context, relationships to neighboring objects, and complex variations in tone, color, and pattern (Kampouraki et al., 2008). The image interpreter may also be able to make inferences based on historical imagery, e.g., about the meaning of seasonal variations in the composition or extent of vegetation (Lillesand, Kiefer, & Chipman, 2008), that cannot be made in automated extraction.

1.2. Mapping urban agriculture in Chicago

This mapping approach—manual interpretation of high-resolution images in Google Earth—was applied to a case study of urban agriculture—including home food gardens—in the city of Chicago. Like many North American cities, Chicago has a long history of local food production. During World War II, the city was reportedly home to more than 1500 community gardens and 250,000 home gardens, led the nation in wartime urban food production, and served as a model for victory garden programs in other cities. Chicago’s North Park neighborhood was home to the country’s largest victory garden (1945–1947), which was resurrected in 2010 on part of the original site as the Peterson Garden Project (Library of Congress, 2011). The Rainbow Beach Community Garden in the city’s South Shore neighborhood was founded as a victory garden during World War II and has been continuously gardened ever since.

Building on this rich history, interest in urban agriculture in Chicago has blossomed over the past decade. An advocacy group for regional urban agriculture, Advocates for Urban Agriculture, boasts over 400 members, and the Chicago Food Policy Action Council recognizes urban agriculture as a multipurpose strategy in its 2008 policy report (Allen, Clawson, Cooley, deCoriolis, & Fiser, 2008). Diverse groups in the city—from home gardeners to neighborhood development advocates to for-profit indoor and rooftop farmers—have coalesced around the common interest of growing food in the city. A decade-long effort by the city and advocacy groups to recognize urban agriculture as a land use by right culminated in 2011 in zoning ordinances expanding the permitted size of community gardens in residential neighborhoods and allowing commercial indoor, outdoor, and rooftop farming in certain nonresidential zoning districts. In the summer of 2011, the Departments of Housing and Economic Development, Public Health, and Family Support and Services began actively collaborating with the Mayor’s Office, community groups, and other stakeholders to develop a comprehensive food space plan for Chicago that seeks to integrate local food production, processing and distribution, with the overall goal of increasing the availability of healthy food across the city (Healthy Places, 2012). Yet despite the growing interest in urban agriculture and in local food systems in Chicago, little attention has been given to production in the home garden.

1.3. Research goals and objectives

In this context, the project described in this article had the overall goal of creating a dataset and sampling frame for future qualitative and quantitative research on the social, cultural, and biophysical dimensions of urban agriculture, including home food gardens. The project also sought to characterize the spatial distribution of existing urban agriculture sites in Chicago, to measure the relative contribution of the different forms of urban agriculture to urban space, and to begin to assess the implications of the extent, character, and distribution of existing sites for food systems planning.

The project had several specific objectives:

1. To identify and measure the production area of private forms of urban agriculture seldom captured by mapping efforts in U.S. cities, through a novel approach based on the manual interpretation of high-resolution aerial images in Google Earth.

2. To determine the proportion of documented community gardening projects producing food, and to measure their production area.
3. To identify previously undocumented food-producing community gardens and other public forms of urban agriculture, and to measure their production area.

2. Methods

2.1. Study site

The project focused on the city of Chicago, IL. Covering more than 606 km^2, Chicago is the third most populous city in the United States, with a population of almost 2.7 million human inhabitants (U.S. Census Bureau, 2011). The population of the city has declined dramatically—by more than 25%—since the middle of the twentieth century, from a high of over 3.6 million inhabitants in 1950.

The current number of urban agriculture sites is unknown, though the media, food policy analysts, and urban agriculture advocates have circulated estimates of between 600 and 700 food-producing community gardens. These estimates apparently derive from GreenNet's 2005 list of more than 600 unconfirmed "community" gardens, which does not describe the gardens' form or function. Furthermore, no attempt has been made to estimate the extent of home food production in Chicago. In fact, we have not identified any study in any region that has attempted to map and quantify home production at a large scale.

2.2. Mapping urban agriculture sites

The study used two strategies for characterizing urban agriculture in Chicago: (1) the visual analysis of aerial images of previously documented community gardens and (2) the manual extraction and classification of undocumented sites from high-resolution aerial images of the city in Google Earth. As part of the first strategy, GreenNet's 2005 list of over 600 community garden sites was entered into an Excel spreadsheet, which was subsequently formatted as a KML file using a freeware program, KML Geocode (http://ctasgis02.psur.utk.edu/credapopulation/freeware.htm). When the file was opened in Google Earth, the program automatically geocoded the garden sites by street address. Over 600 additional community gardening sites were identified by comparing the 2005 GreenNet list with lists from other NGOs and with a list compiled from multiple sources by a graduate student at Chicago State University, John Owens. These additional sites were also geocoded using the same process as for the 2005 GreenNet list. Fig. 1 summarizes the workflow for the entire mapping and analysis process, from the original lists of documented community gardens to the final maps of urban agriculture sites created in ArcMap 10.

A set of urban agriculture reference images was developed from Google Earth aerial images (June 30 and July 1, 2010) of known food production sites in Chicago. The reference images included community gardens, vacant lot gardens, urban farms, school gardens, and home food gardens (Fig. 2). The sites were visited in July and August 2010 for groundtruthing. Visual indicators of food gardens were determined to include combinations of the following: an orthogonal garden layout, vegetation planted in rows or in beds separated by paths, and bare earth or mulch between individual plants or rows of plants. Vegetation height was estimated from shadow length to distinguish between groundlayer vegetation and taller shrubs. High-resolution historical imagery from fall 2007 and spring 2008 was also available in Google Earth and was used to identify changes in garden layout, plant composition, or plant size indicating the presence of food gardening on a site. The presence of extensive arbors—bare in the summer 2010 images but covered with vines in the fall 2007 images—around the periphery of residential lots was determined, through fieldwork, to be an indicator of vegetable gardens of Chinese-origin households.

Using the 2010 Google Earth imagery, documented community gardens (from the geocoded lists) were visually analyzed at a scale of approximately 1:300 for evidence of food production based on the visual markers abstracted from the reference images. The 2010 imagery for the entire land area of the city was then methodically analyzed at the same scale, and previously undocumented food gardens were extracted and digitized as points based on the presence of visual markers of urban agriculture (Fig. 2). The city was divided into approximately 10 km^2 sections, with major highways and streets defining each section. Borders were drawn using the polygon and path tools in Google Earth, which can be used to create lines of user-defined color and width on the aerial image. Each section was then methodically reviewed in an east-west direction, screen by screen. After reviewing the first screen-sized area of the section, the operator moved to the next area, overlapping slightly with the previously reviewed area to ensure no areas were missed. At the western edge of the section, the operator moved to the row below, again with a slight overlap with the previously reviewed row above. This process continued, back and forth, until the entire section had been reviewed.

A preliminary classification system was developed, and possible production sites were assigned to a category based on their appearance and context:

- *Residential garden*: A single-plot garden on the same lot as a single-family or multi-family building.
- *Vacant lot garden*: A garden on a vacant lot, on a double lot, or in a right-of-way that appeared to be gardened by a single person or household. (Differentiating between vacant lots and double lots based on aerial image interpretation—and through fieldwork—proved to be highly subjective, and parcel data, which could have been used to differentiate between the two, was unavailable. Consequently, vacant and double lot gardens are grouped together in the vacant lot category in this study.)
- *School garden*: A garden on the grounds of a school.
- *Urban farm*: A large garden comprising more than one vacant lot, with no apparent internal divisions except those created by crops, suggesting unified management by a single gardener/farmer or group.
- *Community garden*: A garden apparently divided into individual plots.

The size of residential and vacant lot gardens was estimated using the ruler tool in Google Earth, and gardens were further classified by size based on this estimate: small (<20 m^2), medium (20–49 m^2), large (50–100 m^2), and very large (>100 m^2).

After the initial analysis, a second pass was made of the entire land area of the city. To simplify photointerpretation and to facilitate the identification of additional gardens in the second pass, each previously delineated section of the aerial image was further divided into areas of relatively similar structure, e.g., blocks of houses with an east-west orientation, using the path feature in Google Earth. In total, the initial mapping of urban agriculture sites required approximately 400 h of part-time work by one of the authors over an eight month period, at a rate of 40 min per square kilometer of land area.

At the completion of point digitization, all sites were re-examined in Google Earth to ensure that the identification and size criteria had been applied uniformly across the entire city. All very large residential gardens, all vacant lot gardens, and all documented and undocumented school gardens, urban farms, and community gardens were digitized as polygons in Google Earth, and the

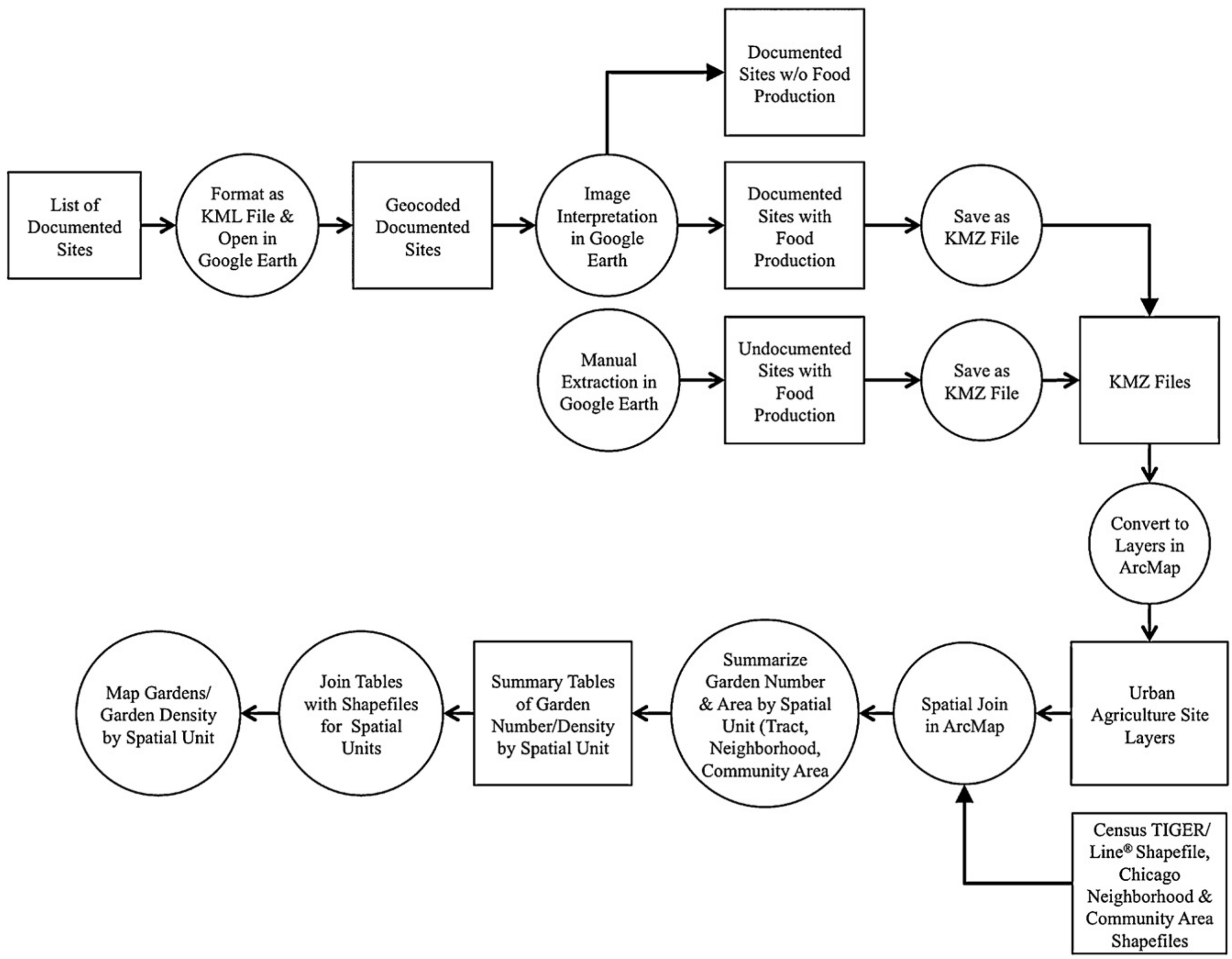

Fig. 1. Flowchart illustrating the methodology for mapping urban agriculture sites in the city of Chicago using Google Earth and ArcMap 10.

polygons were imported into ArcMap 10 for calculation of area. In addition, random samples of small, medium, and large residential gardens were selected for digitization as polygons. For each size class, the sample size was set to ensure a maximum margin of error of 5% at a 95% confidence level. These polygons were also imported into ArcMap 10. Average garden area was calculated for each size class and was used to estimate the total area for each class.

In late June and early July 2011, all undocumented community gardens ($N=44$), all undocumented urban farms ($N=22$), and a sample of very large vacant lot gardens ($n=54$) from across the city were visited to confirm that that they were, in fact, sites of food production. In October 2011, a second sample of previously undocumented sites ($n=74$) was groundtruthed to obtain a better estimate of classification accuracy for a wider range of garden sizes. This sample included all small to very large single-plot vacant lot gardens in an approximately 40-km^2 area on the city's south side. Residential gardens were not groundtruthed because of the limited visual access to sites from streets and alleys due to buildings and fences. Groundtruthing the 194 sites required 40 h of fieldwork.

The classifications of the selected, groundtruthed sites were adjusted based on the results of groundtruthing, but no attempt was made to extrapolate the results of groundtruthing to sites that were not groundtruthed. In addition, no attempt was made to assess through fieldwork the probability of false negatives, of sites that were not classified as food gardens but were in fact sites of food production. Consequently, study estimates of the number and area of community gardens, farms, and vacant lot gardens are relatively conservative.

2.3. Spatial analysis

The results of the visual analysis of documented community garden projects, of the manual extraction and classification of undocumented sites of food production sites, and of groundtruthing were combined to create a final dataset of points and polygons for urban agriculture sites (Fig. 1). KMZ files for these features were imported into ArcMap 10 from Google Earth. To support analysis at multiple spatial levels, the resulting point and polygon shapefiles were spatially joined with a 2010 Census tract shapefile and shapefiles of the city's 77 community areas and 228 neighborhoods obtained from the city's GIS portal. At each spatial level—Census tract, neighborhood, and community area—and for each garden type, the number of gardens and aggregate garden area were calculated; these summary variables were joined with the original Census tract, community area, and neighborhood shapefiles. The tract shapefile was subsequently joined with five-year estimates of Census tract demographic and housing characteristics from the Census Bureau's 2005–2009 American Community Survey (ACS). Community areas represent aggregations of entire Census tracts. Neighborhoods do not; they frequently overlap tract boundaries. ACS tract-level estimates were aggregated by community area and merged with the community area shapefile. No attempt was made to aggregate ACS estimates by neighborhood.

Fig. 2. Examples of Google Earth reference images used to identify sites of food production in the city of Chicago: (A) community garden on the city's far south side and (B) residential garden on the near south side.

Point data for public sites—community gardens, urban farms, and school gardens—and multi-plot vacant lot gardens were subsequently mapped onto community areas. Data for home gardens, including single-plot vacant lot gardens, were mapped and analyzed at finer scales, at the Census tract and neighborhood levels. Home garden counts and aggregate area were standardized by the number of households in the spatial unit to account for the large variation in the number of households by neighborhood and by Census tract.

3. Results

3.1. Verification of previously documented sites

The results of the classification of previously documented community garden sites are presented in Table 1. Of the 1236 sites identified from existing lists of community gardening projects, only 160 sites (12.9%) were determined to have a food production component based on the presence of visual recognition elements derived from the reference images of known food gardens; 99 of these sites were community gardens, 37 were school gardens, 17 were urban farms, and seven were miscellaneous sites, including demonstration gardens. Based on garden layout and vegetation patterns, 615 sites (49.8%) were determined to be ornamental gardens, playlots, parks, or park-like spaces dominated by trees and turfgrass. A smaller number of sites ($N = 130$, 10.5%) appeared to be streetscaping projects, including medians, traffic circles, and tree lawns with ornamental plantings. Of the total number of sites, 331 (26.8%) appeared to be vacant lots or building sites, to have been abandoned, or possibly to have never existed.

Table 1
Classification of previously documented community gardening sites in the city of Chicago based on the visual analysis of high-resolution aerial images in Google Earth.

Classification	*N* (%)	Food production area (m^2)
Food garden	160 (12.9)	58,077
Ornamental garden/park	615 (49.8)	N/A
Streetscaping project	130 (10.5)	N/A
No garden	331 (26.8)	N/A
Total	1236 (100.0)	58,077

Please cite this article in press as: Taylor, J. R., & Lovell, S.T. Mapping public and private spaces of urban agriculture in Chicago through the analysis of high-resolution aerial images in Google Earth. *Landscape Urban Plan.* (2012), http://dx.doi.org/10.1016/j.landurbplan.2012.08.001

Table 2
Previously undocumented urban agriculture sites in Chicago identified through the manual extraction and classification of features from high-resolution aerial images in Google Earth (prior to groundtruthing).

Classification	*N* (%)	Area in m^2 (%)	Margin of error (+/−)
Community food garden	44 (1.0)	13,133 (6.3)	NA
Urban farm	22 (0.5)	41,047 (19.7)	NA
School garden	13 (0.3)	1431 (0.7)	NA
Single-plot vacant lot garden	413 (9.2)	33,345 (16.0)	NA
Small (<20 m^2)	25 (0.6)	419 (0.2)	NA
Medium (20–49 m^2)	145 (3.2)	5084 (2.4)	NA
Large (50–100 m^2)	138 (3.1)	9676 (4.6)	NA
Very large (>100 m^2)	105 (2.3)	18,166 (8.7)	NA
Residential garden	4001 (89.0)	119,269[a] (57.3)	5606
Small (<20 m^2)	1852 (41.2)	29,076[b] (14.0)	1454
Medium (20–49 m^2)	1729 (38.5)	59,132[b] (28.4)	2957
Large (50–100 m^2)	359 (8.0)	23,909[b] (11.5)	1195
Very large (>100 m^2)	61 (1.4)	7152 (3.4)	NA
Total	4493 (100.0)	208,225[a] (100.0)	5606

[a] Totals include actual and estimated areas and have a margin of error associated with the latter.
[b] CI 95%, 5% margin of error.

3.2. Identification of undocumented sites

Table 2 provides the results of the manual extraction and classification of undocumented urban agriculture sites, which yielded a total of 4493 additional possible sites, including 44 community gardens, 22 urban farms, 13 school gardens, 413 gardens on vacant land, and 4001 residential gardens. The largest number of residential gardens (N = 1852) were categorized as "small" (<20 m^2). The average areas of small, medium, and large gardens were estimated to be 15.7 m^2, 34.2 m^2, and 66.6 m^2 (CIs 95%, 14.9, 16.5; 32.5, 35.9; 63.3, 69.9, respectively). These average areas were used to calculate total production area for each size category. The smallest site digitized as a polygon was 4 m^2; the largest site was 23,778 m^2.

3.3. Methodological accuracy

Through fieldwork, 166 (85.6%) of the 194 sites selected for groundtruthing were confirmed to be sites of food production in July or October 2011 (Table 3). Only three sites (1.5%) were misclassified as sites of food production—one possible community garden and two vacant lot or double lot gardens with solely ornamental plantings. A total of five sites could not be groundtruthed because they were not visible from public land; all of these sites had strong aerial signatures in the 2010 Google Earth image indicating they were sites of food production in 2010. Over 9% of the sites (N = 18) appeared to have been abandoned between 2010 and 2011. These sites also had strong aerial signatures in the 2010 image. All but three (13.6%) of the 22 sites that were initially classified as possible urban farms were determined, in fact, to be single- or multi-plot vacant lot gardens on private or public land. Of the 44 sites originally classified as possible community gardens, 36 (81.8%) were determined to be previously undocumented community gardens; five sites (11.4%) appeared to be single-plot vacant lot food gardens, one site (2.3%) was a private ornamental garden, and two sites (4.5%) appeared to have been community gardens in the past but had apparently been abandoned by 2010. Note that, because the probability of false negatives was not assessed in the project, the overall accuracy estimate reflects only the probably of false positives, of features that were classified as food gardens but were not. The accuracy estimate is further limited to vacant lot and community gardens and farms; residential and school gardens were not groundtruthed.

Table 3
Results of groundtruthing of previously undocumented community gardens and urban farms and a sample of vacant lot gardens identified through the visual analysis of high-resolution aerial images of the city of Chicago in Google Earth.

Groundtruthed status	*N*	Percent
Ornamental garden	3	1.5
Vegetable garden	166	85.6
Abandoned between 2010 and 2011	18	9.3
Abandoned prior to 2010	2	1.0
Undetermined	5	2.6
Total	194	100.0

3.4. Extent and spatial distribution of urban agriculture

When combined, the results of the visual analysis of aerial images of documented community gardens, the manual extraction/classification of sites, and groundtruthing yield a final, total number of 4648 urban agriculture sites with a combined production area of 264,181 m^2 (±5606 m^2, 95% CI) (Table 4). The combined area of residential gardens and single-plot gardens on vacant land, 158,876 m^2 (±5606 m^2, 95% CI), is almost threefold the food production area of community gardens, 54,518 m^2 (Table 4).

When mapped onto Chicago's 77 community areas, community gardens, farms, multi-plot vacant lot gardens, and school gardens appear to be highly unevenly distributed across the city (Fig. 3). Home garden density also varies widely by neighborhood (Fig. 4) and by Census tract (Fig. 5).

4. Discussion

This case study demonstrates that urban agriculture is currently an extensive land use type in Chicago, with much of the production previously undocumented. The extraction, classification, and quantification of urban food production sites in the city of Chicago yielded a total of 4648 sites, including 4001 residential gardens, 428 single-plot gardens on vacant land, seven multi-plot gardens on vacant land, 135 community gardens, 50 school gardens, 20 urban farms, and seven miscellaneous sites, including demonstration gardens. Gardens and farms were found in a wide range of places, including residential lots, vacant lots, railroad and utility rights-of-way, public parks, parking lots, rooftops, and even nature preserves. The total area of home food production—including single-plot gardens on vacant lots, which appear to be gardened by the residents of adjacent dwellings—was estimated to be 158,876 m^2 (±5606 m^2, 95% CI). The total production area of all other urban agriculture sites, including community gardens and farms and school gardens, was estimated to be 105,305 m^2. Of the 1236 gardens reported to be community gardening projects by GreenNet, the City of Chicago, and other organizations, only 160, or 12.9%, appear from aerial

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Table 4
Final summary table of urban agriculture sites in the City of Chicago identified through the visual analysis of high-resolution aerial images in Google Earth.

Classification	*N* (%)	Area in m^2 (%)	Margin of error (+/−)
Community food garden	135 (2.9)	54,518 (20.6)	NA
Urban farm	20 (0.4)	12,352 (4.7)	NA
School garden	50 (1.1)	4385 (1.7)	NA
Miscellaneous	7 (0.2)	1731 (0.7)	NA
Multi-plot vacant lot garden[a]	7 (0.2)	32,319 (12.2)	NA
Single-plot vacant lot garden[b]	428 (9.2)	39,607 (15.0)	NA
Small (<20 m^2)	25 (0.5)	419 (0.2)	NA
Medium (20–49 m^2)	145 (3.1)	5084 (2.0)	NA
Large (50–100 m^2)	138 (3.0)	9676 (3.7)	NA
Very large (>100 m^2)	120 (2.6)	23,951 (9.1)	NA
Residential garden	4001 (86.0)	119,269[c] (45.1)	5606
Small (<20 m^2)	1852 (39.8)	29,076[d] (11.0)	1454
Medium (20–49 m^2)	1729 (37.2)	59,132[d] (22.4)	2957
Large (50–100 m^2)	359 (7.7)	23,909[d] (9.0)	1195
Very large (>100 m^2)	61 (1.3)	7,152[c] (2.7)	NA
Total	4648 (100.0)	264,181[c] (100.0)	5606

Note: This table reflects corrections to site classification based on groundtruthing. School gardens and residential gardens were not groundtruthed. The level of classification error for these gardens is unknown.

[a] A vacant lot garden comprising multiple plots.
[b] A vacant lot garden consisting of a single plot, apparently gardened by a single individual or household.
[c] Totals include actual and estimated areas and have a margin of error associated with the latter.
[d] CI 95%, 5% margin of error.

images to have a food production component. A large number of sites (*N* = 130) reported to be community gardening projects appear to be streetscaping projects, at most.

4.1. Spatial distribution of urban agriculture in Chicago

Urban agriculture appears to be highly unevenly distributed across the city due to complex and interacting demographic, cultural, economic, infrastructural, and historical factors. Home food garden density varies widely by Census tract, with the highest densities on the city's south side and far northwest side. Two neighborhoods on the near south side, Chinatown and Bridgeport, appear to be home garden hot spots for demographic and cultural reasons. Both neighborhoods have large Chinese-origin populations. Aerial image interpretation in Google Earth and fieldwork indicate that many of the back yard gardens in these neighborhoods feature arbors constructed of branches and salvaged lumber, which support vining food crops and are characteristic of Chinese vegetable gardens.

Home food gardens are also concentrated on the city's far northwest side. In neighborhoods such as Belmont Heights, Big Oaks, and Schorsch Forest View, which have high densities of gardens, the housing stock consists primarily of newer, owner-occupied single-family detached houses, which may afford greater opportunities for home food gardening than the older, more densely populated residential areas closer to the city center. All three neighborhoods also have large white ethnic populations of Eastern or Southern European origin, and the Census tracts that overlap Schorsch Forest View and Belmont Heights have some of the highest percentages of foreign-born Polish residents of any tracts in the city. These populations may, for cultural reasons, participate in home food gardening at higher rates than other groups. Not surprisingly, the highly developed city center (the Loop) and the densely populated neighborhoods along Lake Michigan to the north of the Loop are largely devoid of home food gardens.

Vacant lot food gardens are concentrated in the economically disadvantaged neighborhoods of the city's south and west sides. These gardens may be a response to the greater availability of vacant land or, alternatively, to food insecurity, which is higher in these neighborhoods than in the more affluent neighborhoods of the north side, the far northwest side, and the southwest side. One multi-plot garden on vacant land on the city's far south side, in the Riverdale community area, accounts for one-third (23,778 m^2) of the total vacant lot production area in the city. Riverdale has been categorized as a food desert and has the highest rate of food insecurity, 40.8%, of any community area in Chicago (Greater Chicago Food Depository, 2011).

Community gardens appear to be concentrated on the south and west sides, possibly due to lower development pressures and the greater availability of vacant land or because of the activity of nonprofit groups promoting community gardening in lower income neighborhoods as a means of improving food security and promoting community development. Fewer food-producing community gardens are found in the densely populated community areas along the lakefront. On the north side lakefront, the ratio of community gardens to households ranges from one garden for every 8093 households in Rogers Park to one for every 55,854 in Lakeview. On the south side, the South Shore community area has a community garden to household ratio of 1:6087, while its less densely-developed neighbor to the north, Woodlawn, has one of the highest densities of community gardens per household in the city, 1:1193. North Lawndale on the west side has the highest garden density of any Chicago community area, with one community garden for every 1128 households. Community gardens are almost entirely absent from the community areas on the far northwest and southwest sides. Owner-occupied, single-family homes are the predominant form of housing in many of these areas, and the availability of on-lot space for food gardening may result in minimal demand for community gardens. The absence of community gardens may also reflect market pressures and a lack of vacant—particularly city-owned—land in these areas for development as community gardens by community groups and NGOs.

Community gardens in Chicago do, however, appear to be more evenly distributed across higher and lower-income Census tracts than in Philadelphia, the only other city for which comparable data are available. Kremer and DeLiberty (2011) report that more than 50% of community gardens in that city are located in tracts with a median 2000 household income of less than $18,000, compared to a city average of $42,000. In Chicago, more than 50% of community gardens are located in Census tracts with a median household income of $33,000 or more, compared to a city average of almost $47,000 (U.S. Census Bureau, 2010). Regardless of income level, the vast majority of Chicago residents—over 2.4 million—live in a Census tract with no community garden. Of the 746 such tracts, 341

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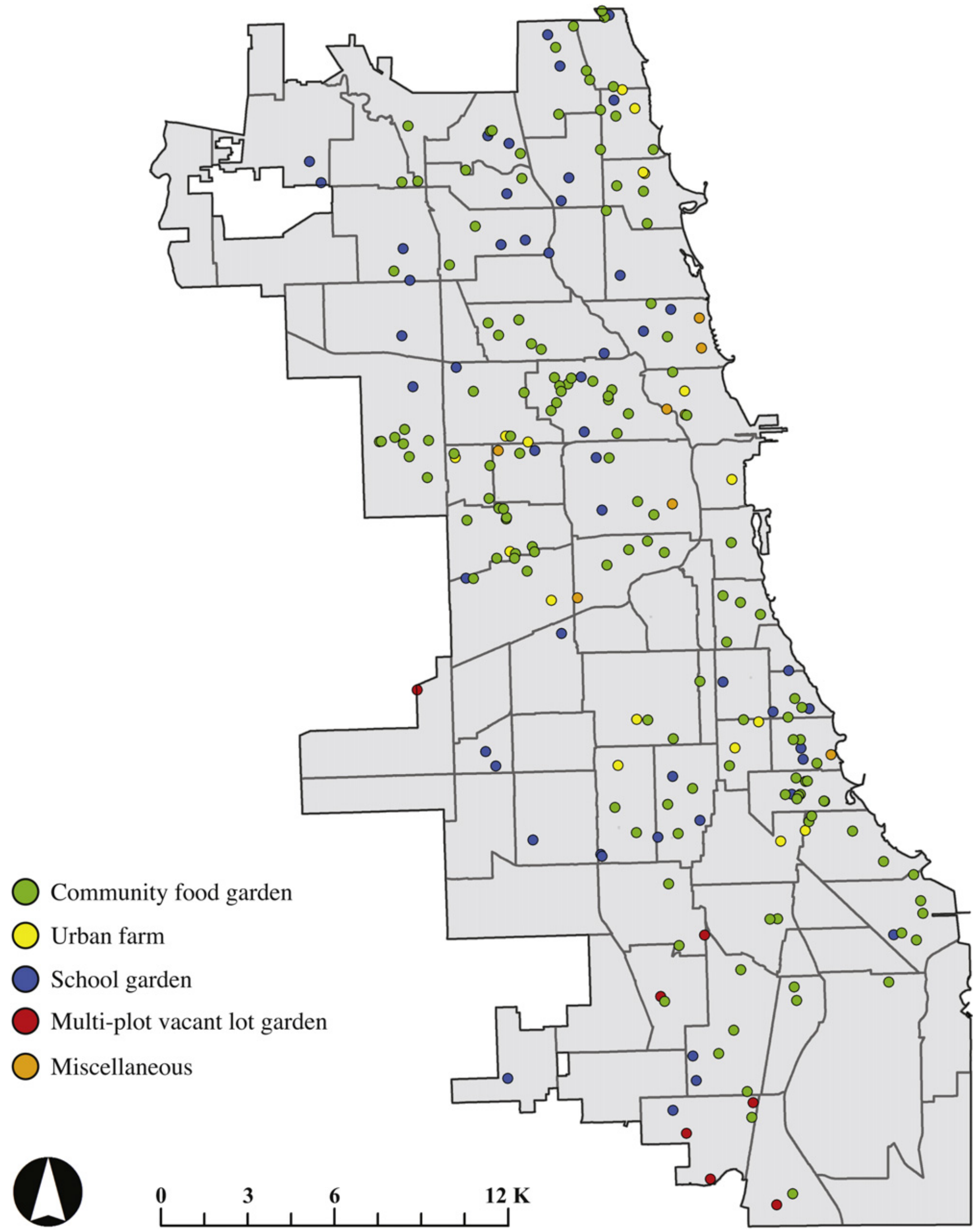

Fig. 3. Map of Chicago showing public and semi-public urban agriculture sites (community and school gardens, urban farms, multi-plot vacant lot gardens, and miscellaneous sites) identified through visual analysis of high-resolution aerial imagery in Google Earth superimposed on Chicago's 77 community areas.

(45.7%) have a poverty rate that exceeds the city average of 20.6% (U.S. Census Bureau, 2010), and the majority of these low-income tracts lacking community gardens are located on the city's south and west sides.

Finally, Chicago has relatively few formally identified urban farms, and nonprofit organizations operate the majority of these sites. Two apparently commercial farms—possibly managed by the same individual or group—are located on vacant land in the densely developed Uptown community area on the city's north side. Gardeners at other sites may participate in the market economy through the sale of products from their gardens, but these sites could not be identified with the methodology employed in this case study.

4.2. Implications for planning

Study results indicate that both residential gardens and usufruct/squatter food gardens on vacant land make a substantial contribution to the total food production area of the city. These "invisible" sites of urban agriculture, however, have attracted limited attention from policymakers, NGOs, or academics, who have overlooked their potential contribution to household and community resiliency in the face of economic crisis and ongoing urban disinvestment. While some of Chicago's more than 400 vacant lot food gardens are already in private hands or are the focus of land conservation efforts by city government agencies and by NGOs such as NeighborSpace, many others remain vulnerable to development. Mapping vacant lot gardens, as in this project, can be a first step toward identifying priorities for land conservation for urban agriculture.

Spatial datasets of existing sites such as the one created in this research project can also serve as a framework for expanding urban agriculture, particularly when combined with maps of potential production spaces created through automated or semi-automated image analysis (e.g., Kremer & DeLiberty, 2011) or manual photointerpretation (e.g., McClintock & Cooper, 2009). The knowledges

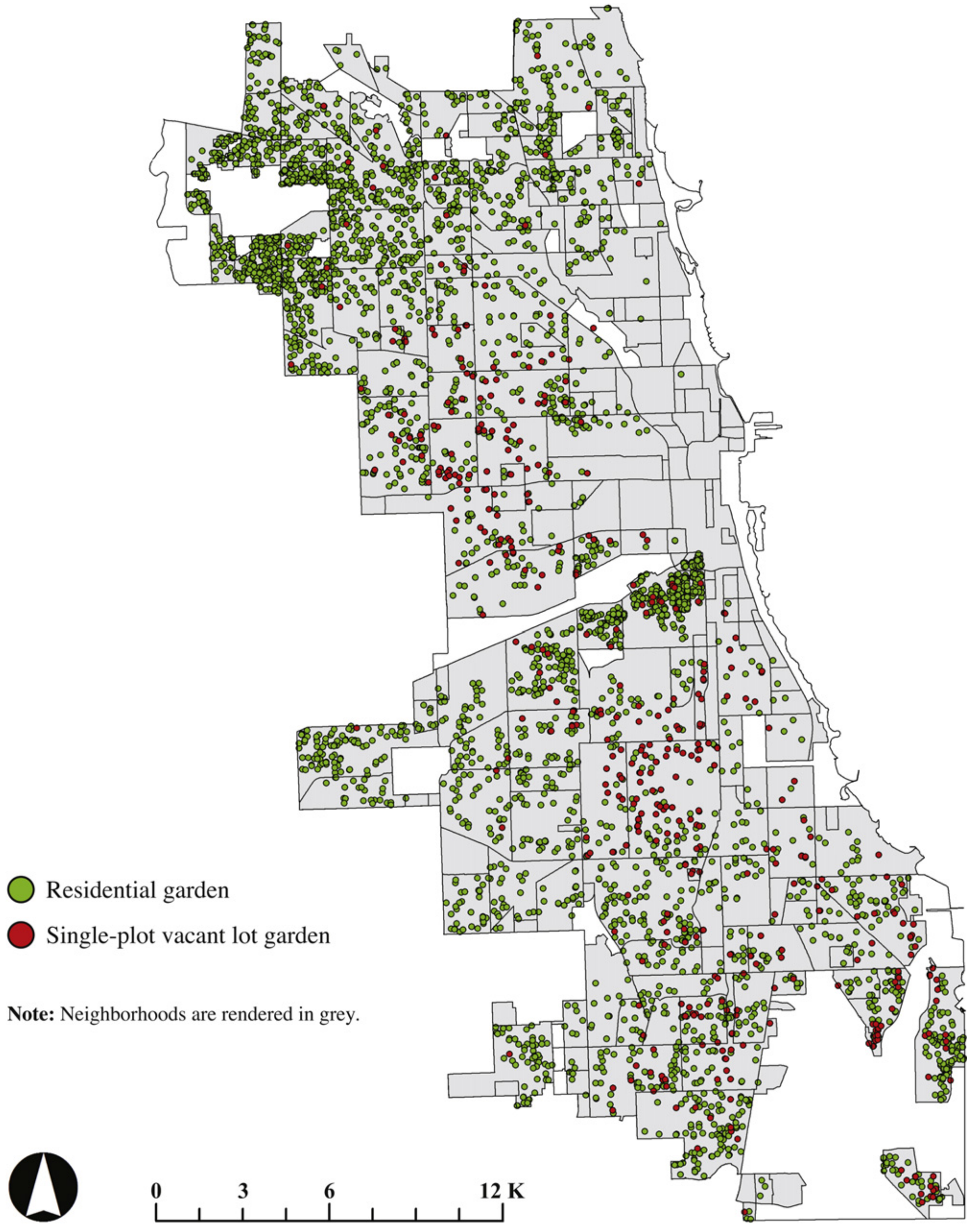

Fig. 4. Map of Chicago showing home food gardens (residential and single-plot vacant lot gardens) identified through manual interpretation of high-resolution aerial imagery in Google Earth superimposed on the city's 228 neighborhoods.

of urban food production and the material resources—such as the traditional plant varieties of ethnic communities—that are associated with existing sites offer an alternative to wholly top-down approaches to promoting urban agriculture, which have often been unsuccessful in the past in the United States because they have failed to cultivate local leadership (Bentley, 1998; Lawson, 2005). In particular, participatory approaches to scaling up home production—on residential and vacant lots—by capitalizing on existing resources could be an effective strategy for addressing a wide range of policy issues, including household and community food insecurity, limited access to fresh, healthy food, and public health problems such as obesity, diabetes, and heart disease. However, while a limited number of grassroots or NGO-sponsored programs to promote home gardening have been implemented in North American cities, no studies evaluating their effectiveness have been published. Even in the Global South—where home gardens have long been recognized and lauded for their contribution to household food security and livelihoods—home gardens have not been promoted as part of either international or local development agendas (Nair, 2006), and no studies have been conducted to determine how best to promote them. Clearly, additional research and the development and evaluation of innovative and participatory approaches to promoting home gardening and community farming through the leveraging of existing assets are needed.

These assets include land, and low-income Census tracts in Chicago largely coincide with the spatial distribution of city-owned vacant land. The city owns more than 11,000 vacant parcels covering over 550 ha (City of Chicago, 2011), and ways to develop at least part of this land safely for food production have been a topic of discussion in the city's food plan workshops. Outside of disinvested neighborhoods, in areas where development pressures are higher, permanent or even usufruct access to land for urban agriculture is more problematic. Study results suggest the increasing densification of development and the trend toward

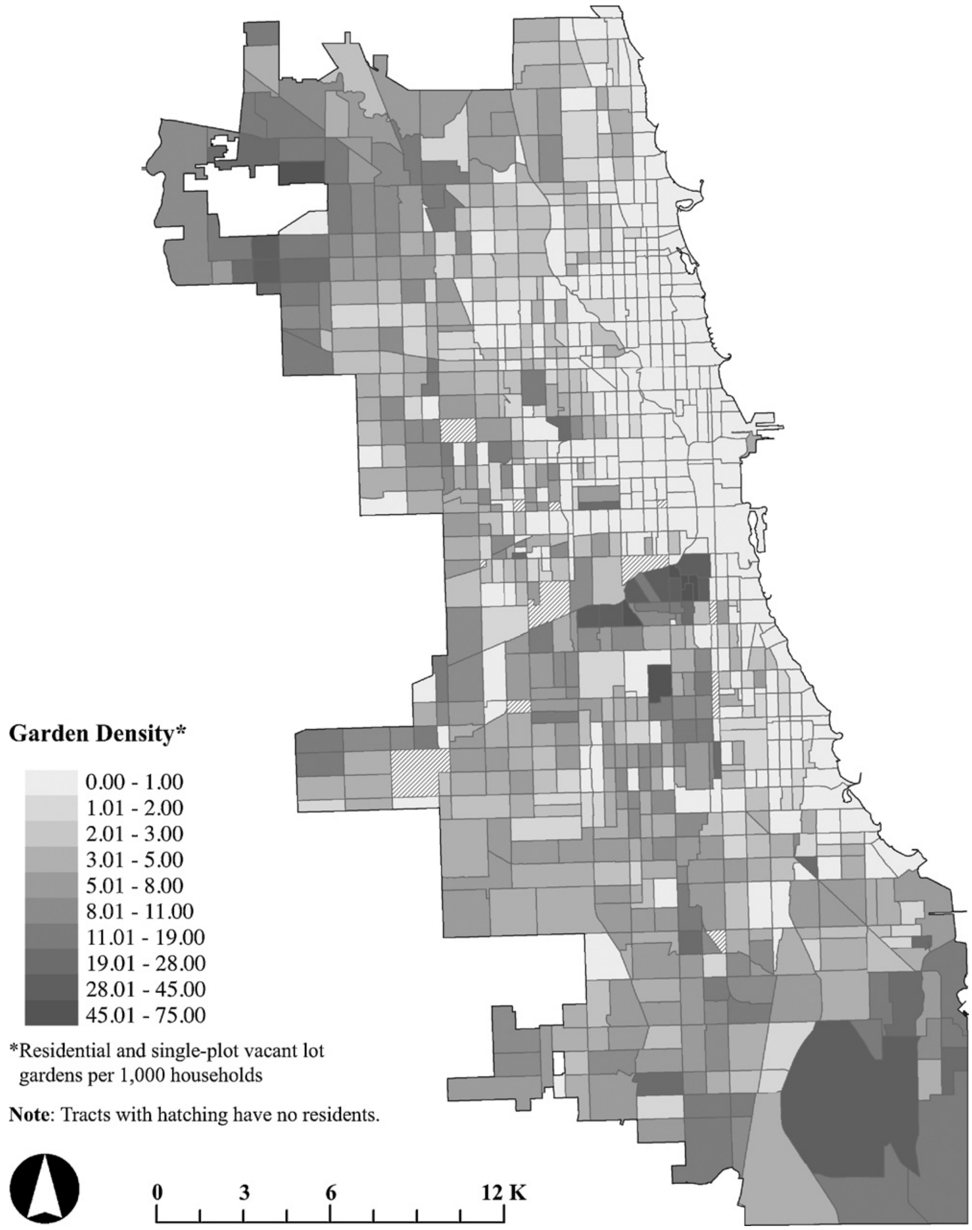

Fig. 5. Map of Chicago showing home food garden density (residential and single-plot vacant lot gardens per thousand households) by 2010 Census tract.

the complete build-out of residential lots in the city center and lakefront neighborhoods may reduce opportunities for developing new urban agriculture sites. Residents of these neighborhoods do have access to local and lakefront parks, but food gardening—as a productive activity—may afford other benefits. By participating in the de-commodified production of food in their backyards or in community gardens, gardeners may become reintegrated with both their labor and nature, with attendant mental and physical health benefits (McClintock, 2010). Creating new opportunities for residents in densely developed neighborhoods to engage in civic forms of urban agriculture will require the increased acquisition of land—or the redevelopment of underutilized park spaces—for community gardens and farms. It will also demand the implementation of novel strategies for ensuring access to gardening, such as the development of analogues to in-ground community gardens, e.g., subirrigated rooftop food gardens and vertical gardens, for the residents of multi-family buildings, midrises, and highrises.

4.3. Mapping methodology

For food systems planning, the approach to mapping and quantifying urban agriculture sites employed in this case study addresses some of the limitations of other commonly used methodologies. It permits the confirmation of food production on sites included on existing lists of community gardens, reducing the problem of overreporting. The method also allows the direct identification and measurement of sites—including residential food gardens, gardens on vacant land, and gardens in utility and transportation rights-of-way—not captured by other methods. It obviates the need for surveys or voluntary reporting and reduces underreporting. The method is highly accurate in terms of the identification of sites with food production, with 85.6% of groundtruthed sites found to be sites of food production. If abandoned and undetermined sites are excluded from the denominator used to calculate the rate of accuracy, the rate rises to 95.4%. However, because only urban agriculture sites were extracted and classified, the study did not assess the probability of false negatives, of features that were not extracted and classified but were in fact sites of food production. In addition, residential gardens were not groundtruthed.

Fieldwork suggests that the visual markers developed for the study—orthogonal garden layout, vegetation planted in rows or in beds separated by paths, bare earth or mulch between individual plants or rows of plants—are accurate indicators of the presence of in-ground food production in Chicago. The popular, practical literature on fruit and vegetable gardening suggests these markers may be expected to apply to most in-ground food gardens in the United States, with modifications that take into account local gardening cultures. In this study, for example, fieldwork revealed extensive backyard arbors with abundant seasonal foliage to be indicative of Chinese vegetable gardens.

Fieldwork also suggests that the taxonomy developed for the study is appropriate to the classification of urban agriculture sites. Only two minor categories, “miscellaneous” and “multi-plot vacant lot gardens,” were added to the taxonomy as a result of groundtruthing. As spaces of collective gardening, multi-plot vacant lot gardens appear to function much like community gardens but lack the communal areas and possibly the formal organizational structure of community gardens. As the name suggests, “miscellaneous” is a catchall category that includes demonstration gardens and other minor forms of urban agriculture. Fieldwork did reveal a number of gardens initially categorized as urban farms because of their very large size to be single-plot or multi-plot vacant lot gardens. In the absence of any evidence that these gardens were market gardens, they were assumed to be for off-lot household production. Survey work would be needed to clarify their function and ownership.

Manual photointerpretation of high-resolution images in Google Earth is the key process in this mapping methodology, and while manual image analysis may be the oldest form of remote sensing, it has the advantage of being amenable to participatory and community-based forms of food systems planning. It can be implemented by community stakeholders, activists, and planners to map sites of local food production and to develop strategies for leveraging community assets, including material resources and local knowledges of growing food in the city. While automated and semi-automated methods of image classification require high levels of technical expertise and sophisticated software, the method described in this paper requires only personnel training in photointerpretation, minimal training (at most) in GIS, Internet access, and a computer with a relatively high-resolution monitor. The purchase of multi-spectral imagery or high-resolution aerial imagery is not required, nor are experts in remote sensing. Though it facilitates spatial analysis, ArcGIS need not be used. Maps can be constructed entirely in Google Earth. Groundtruthing can also be a participatory process, with fieldwork by community stakeholders coordinated through web-based social media.

Manual image analysis can be tedious, but it is not inordinately time-consuming, particularly if performed for a single neighborhood, a town, or a small city. In this study, feature extraction and classification required approximately 40 min per square kilometer of land area, and mapping the entire city of Chicago required approximately 400 h of effort. While at present manual photointerpretation may be more appropriate to the fine-scaled features extracted in this study, future advances in remote sensing—such as computer-assisted photointerpretation and geographic object based image analysis—may allow for faster and accurate automated or semi-automated classification of sites at scales as fine as the residential garden (Blaschke, 2010; Castilla et al., 2008) Manual photointerpretation will still have the advantage of being accessible to non-academic stakeholders, empowering them to shape local food systems.

Users of the methodology described in this paper must be cognizant of its potential limitations. The quality of the result is limited by the quality of the Google Earth aerial image of the area of interest (e.g., resolution, sun angle, cloud cover). Feature extraction and classification can be subjective. The use of more than one interpreter of aerial imagery will require systematic training and reliability testing to ensure consistency in image interpretation and feature extraction and classification across personnel. Trees, buildings, or shadows may obscure gardens in aerial images. Groundtruthing of particular kinds of gardens can be difficult to perform. In this project, although previously undocumented community gardens and urban farms and gardens of diverse sizes on vacant land were groundtruthed, residential gardens—which are almost always located in backyards—were not groundtruthed because of limited visual access from streets and alleys.

The method may fail to capture very small sites of urban agriculture, e.g., container gardens, very narrow sites such as single rows of plants along fence lines, mixed plantings of ornamentals and food plants, individual fruit and nut trees, and other sites that do not display the characteristic patterns of food gardens identified from the reference images. For these reasons, study results may underestimate participation in home food gardening. A total of 4429 on- and off-lot home food gardens were identified in the study, representing 0.4% of all households in the city of Chicago. A survey conducted by the National Gardening Association indicates that approximately 21% of households nationally were involved in in-ground home vegetable production in 2008 (National Gardening Association, 2009). Participation in home food gardening in Chicago—where 70% of housing units are located in multi-family buildings and 27% of housing units are located in buildings of ten or more units (U.S. Census Bureau, 2010)—may be much lower. However, the disparity between the national statistic for participation in home gardening and the percentage based on manual extraction and classification of gardens in Google Earth is large and warrants exploration. The smallest residential garden extracted and measured in the study was 4.1 m^2, and the smallest groundtruthed garden was 6.5 m^2. The average size of residential gardens classified as “small” was 15.7 m^2 (CI 95%, 14.9, 16.5), and the average size of small single-plot vacant lot gardens was 16.8 m^2. Nationally, almost 60% of home food gardens are less than 9.3 m^2 (100 ft^2) (National Gardening Association, 2009). Home food gardens may reasonably be expected to be even smaller in the city. Such small food gardens would not be captured by the methodology described in this paper. Instead, the home food gardens extracted and classified in this project may represent larger gardens, which may be expected to make a relatively large contribution to the food budgets of the associated households.

4.4. Future work

As this case study of urban agriculture in Chicago demonstrates, the methodology described in this article can be used to develop a spatial dataset of existing public *and* private sites of urban food production that supports the more sophisticated spatial geographic analyses necessary for, but largely absent from, food systems planning (Kremer & DeLiberty, 2011). The dataset can also serve as a framework for fieldwork that explores local production practices and identifies ways to promote local food sovereignty through the leveraging of existing social and material resources. Few studies in the Global North have attempted to describe these practices, particularly at the household level, or to characterize or quantify the contributions they make to family and community food security and resiliency, household nutrition, local agrobiodiversity, and the functioning of urban socionatural systems. Results from this study suggest that home food production makes a substantial—but overlooked—contribution to Chicago’s urban food system and that

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ethnic and immigrant communities may be responsible for much of that production. Using the spatial dataset created for this case study as a guide and a sampling frame, future qualitative and quantitative research will focus on the food gardening practices of these communities in Chicago. We anticipate that the results of this research will inform the development of urban land use policies, educational programs, participatory community development plans, and initiatives to promote the development of safe and sustainable urban home food gardens. For community food activists, research findings will suggest ways for local food policy councils, urban agriculture groups, and other stakeholders to leverage existing local knowledges of urban food production and to network small-scale sites to create greater community food security.

Acknowledgments

The authors would like to thank John Owens for sharing his carefully compiled list of community gardening projects in the city of Chicago and the three anonymous reviewers who provided constructive comments on earlier drafts of this paper.

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Please cite this article in press as: Taylor, J. R., & Lovell, S.T. Mapping public and private spaces of urban agriculture in Chicago through the analysis of high-resolution aerial images in Google Earth. *Landscape Urban Plan.* (2012), http://dx.doi.org/10.1016/j.landurbplan.2012.08.001