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Research paper

Assessing the potential contribution of vacant land to urban vegetable production and consumption in Oakland, California

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HIGHLIGHTS

- We identify more than 335 ha of vacant public land with potential urban agricultural value.
- The contribution of vacant land to vegetable requirements depends largely on management practices.
- Committing 40 ha to vegetable production could contribute more than 5% of current needs.

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ABSTRACT

As urban agriculture grows in popularity, researchers are attempting to quantify its potential contribution to local food systems. We present the results of a vacant land inventory conducted in collaboration with the HOPE Collaborative, a multi-stakeholder, community-based initiative in Oakland, CA, USA. Vacant lots, open space, and underutilized parks with agricultural potential were identified using GIS and aerial imagery. Using visual interpretation, we identified 1201 ac (486.4 ha) of public land and 337 ac (136.4 ha) of private land that could potentially be used for vegetable production. Based on USDA loss-adjusted consumption data, we calculated the potential contribution of these sites to the city's current and recommended vegetable needs. Calculations were based on average yields under three different management practices: conventional at 10 tons/ac (22.4 Mg/ha); low-biointensive at 15 tons/ac (33.6 Mg/ha); and medium-biointensive at 25 tons/ac (56.0 Mg/ha). Four different land use scenarios were considered: (1) all identified sites (<30% slope); (2) optimal land (<30% slope excluding north-facing slopes); (3) a high land use scenario of 500 ac (202.3 ha); and (4) a low land use scenario of 100 ac (40.5 ha). We estimate that the most conservative scenario would contribute between 2.9 and 7.3% of Oakland's current consumption, depending on production methods, or 0.6–1.5% of recommended consumption. While an inventory is an important first step, determining how much vacant land should be committed to urban agriculture will ultimately depend on additional site assessment and negotiation of potentially conflicting stakeholder interests.

1. Introduction

Across North America vacant land is taking center stage in the efforts of activists, community members, non-profit organizations, and local governments to increase food production in the city. Dozens of urban agriculture initiatives have taken root on large vacant parcels and in city parks, ranging in scale and scope from small community gardens to urban farms of several acres run by non-profits or commercial market gardeners. Most are launched in collaboration through use or lease agreements with public agencies, private landowners, or land trusts (Hodgson, Caton Campbell, & Bailkey, 2011; Nordahl, 2009). While its impact on urban diets and income creation should not be overstated, urban agriculture has become an attractive land use because of its potential to addresses multiple needs, supplying fresh produce in neighborhoods with limited access to healthy food while offering opportunities for employment, education, and recreation (Hodgson et al., 2011; Hou, Johnson, & Lawson, 2009; Redwood, 2011).

As planners, public health officials, and community groups alike articulate the linkages between food systems, health, and the built environment (Corburn, 2009; Muller, Tagtow, Roberts, & MacDougall, 2009; Pothukuchi, 2009), locating possible sites for urban agriculture has become a priority. Over the past few years, researchers have conducted inventories of vacant land with agricultural potential in Portland (Balmer et al., 2005), Vancouver (Kaethler, 2006), Seattle (Horst, 2008), Cleveland (Grewal &

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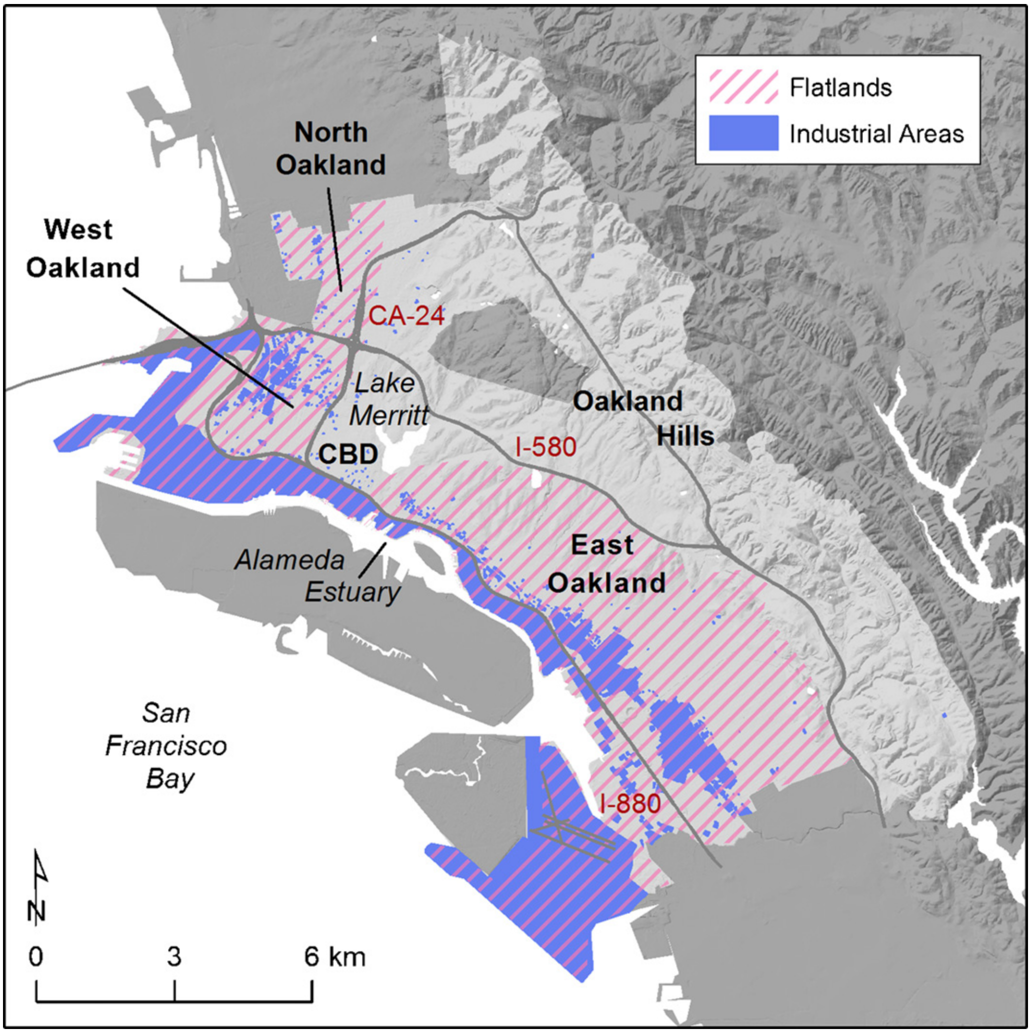

Fig. 1. The hills and flatlands of Oakland, California. Note that the industrial areas (blue) are located in the flatlands along the waterfront. Freeways are labeled in red and downtown (central business district) labeled as "CBD". (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Grewal, 2012; Taggart, Chaney, & Meaney, 2009), Detroit (Colasanti & Hamm, 2010), Toronto (MacRae et al., 2010), Chicago (Taylor & Lovell, 2012), and New York (Ackerman, 2012). Only some of these inventories, however, estimate the potential productivity of the identified land or its ability to meet consumer demands for fresh fruits and vegetables.

To address health disparities in Oakland, California, food justice organizations interested in ramping up urban agriculture have eyed the city's numerous vacant lots. Until the research presented in this article was conducted, the scale of potential production was unknown, both in terms of the spatial extent of vacant land and its potential contribution to the food system. In this paper we detail the development, implementation, and results of a geographic information system (GIS)-based inventory of Oakland's vacant and underutilized public and private land conducted in collaboration with one such food justice initiative, the HOPE Collaborative (hereafter, HOPE). The goals of the inventory, entitled *Cultivating the Commons* (CTC), were to: (1) identify potential sites for urban agriculture on vacant and underutilized public land in Oakland; (2) quantify the spatial extent this land; and (3) estimate its potential contribution to Oakland's food system.

In this article, we present a description of the study site and context before presenting the methods and results of both the CTC inventory and our more recent calculations of urban agriculture's potential contribution to Oakland's vegetable consumption. We conclude by discussing potential limitations of the analysis and possible ways to hone the methodology.

2. Study site and context

2.1. Biophysical landscape

This study was conducted in the city of Oakland, California (WGS84 37.804444, −122.270833). Three primary topographic zones define the city's physical geography: flatlands, foothills, and hills. The flatlands are low-lying areas largely comprised of fill (e.g., dredged sediment, construction debris, quarried rocks), adjacent to the San Francisco Bay to the city's west and Alameda Estuary and San Leandro Bay to the south (see Fig. 1). The foothills are formed on a gentle fan of alluvium spreading downwards from the Oakland hills, a series of undulating, parallel ridges thrust upwards along the Hayward and Moraga faults and which run along the city's eastern portion along a northwest-southeast axis (Sloan, 2006). Soils in the flatlands are a mix of urban land (highly mixed, heterogeneous fill) and complexes of urban land and endogenous soils derived from sedimentary, alluvial parent material, while the complexes in the hills are dominated by a number of excessively drained loams weathered from uplifted conglomerate and ultrabasic metamorphic rock (Welch, 1981). The climate is Mediterranean with wet winters and dry summers with morning fog. Average annual precipitation is 22.9 in (582.7 mm), with 89% of the total rainfall occurring between November and April. September is the hottest month with an average high temperature of 80.6 °F (27 °C); January is the coldest month, with an average high of 58.1 °F (14.5 °C) (NOAA, 2004). Native vegetation includes oak (*Quercus* sp.) woodland, coastal shrub, and coastal terrace prairie, with large redwood (*Sequoia sempervirens*) stands in the drainages (Beidleman & Kozloff, 2003).

2.2. Social landscape

Oakland (pop. 391,000) is one of three core cities in the San Francisco Bay Area, a major American metropolitan region populated by 7.2 million people and comprised of nine counties and 101 municipalities (U.S. Census Bureau, 2010). Oakland's downtown central business district is located immediately west of Lake Merritt, the physical landmark demarcating East Oakland from the rest of the city. Two freeways roughly delimit the flatlands from the hills: CA-24 along the north–south axis west of downtown, and I-580 along the northwest–southeast axis south of the Oakland hills and foothills (see Fig. 1).

From its founding in the early 1850s, the city grew eastwards from West Oakland and downtown. The terminus of the transcontinental railroad in West Oakland led to the city's rapid growth beginning in the late 19th-century, followed by major shipbuilding, automobile manufacture, and food processing during the First World War. For most of the 20th century, industry, commercial transportation, and warehousing were concentrated in the flatlands around the Port of Oakland in West Oakland and along the Alameda Estuary. The remainder of the flatlands and hills developed as residential neighborhoods (U.S. Census Bureau, 2010; Walker, 2001).

Census data reveal a disproportionate concentration of poverty in the flatlands of North, West, and East Oakland, affecting a population that is majority African American, Southeast Asian, and Latino. Most of Oakland's white population lives in the more affluent foothills and hills neighborhoods (U.S. Census Bureau, 2010). The spatial inequities of the socioeconomic landscape are largely due to the historical demarcation of areas where particular ethnic groups were allowed to live as well as where investment capital flowed. During the first half of the 20th century, "redlining" by insurance companies prevented investment in "high risk" low-income areas, while racial covenants prevented people of color from living in white neighborhoods. During the 1960s and 1970s, freeway construction bifurcated the city while deindustrialization prompted the outflow of commercial capital and a declining tax base (McClintock, 2011; Self, 2003; Walker, 2001).

This bifurcation of the socioeconomic landscape into hills and flatlands has also defined access to healthy and affordable food in Oakland. In Oakland, 20% of families live below the federal poverty line. Approximately one-third of Alameda County's residents are food insecure and 87% of Oakland school children receive free or reduced-price lunch (ACPHD, 2008; OFPC, 2010). Areas with limited access to healthy food—so-called "food deserts"—are located in the flatlands and are closely tied to its history of disinvestment (HOPE Collaborative, 2009; McClintock, 2011). Over the last decade, several food justice organizations have attempted to address inequitable access to healthy food through a variety of programs and policy recommendations. Urban agriculture has been central to these efforts and has begun to figure prominently in food systems, public health, and land use planning discussions in Oakland (McClintock, Wooten, & Brown, 2012).

2.3. Study context

Oakland's vibrant food justice movement and a growing body of community-based participatory research in public health (Israel, Eng, Schulz, & Parker, 2005; Minkler & Wallerstein, 2003) and environmental justice (Metzger & Lendvay, 2006; Petersen, Minkler, Vasquez, & Baden, 2006) inspired this research. Developed iteratively with community stakeholders, the project took shape within the following context. In 2006 the Oakland City Council embraced a goal of sourcing 30% of its food locally, and passed Resolution No. 79680 to support a food system assessment for the city. The resulting Oakland Food System Assessment (OFSA) evaluated the existing avenues of food distribution and consumption in Oakland, including food production within a 200 mi (321.9 km) radius from the city (Unger & Wooten, 2006). While the vast majority of food consumed in Oakland comes from outside of this area, local food systems advocates have underscored the importance of food production within the city itself in order to promote education, reduce the distance between production and consumption, enhance green space, and create green job opportunities (Hodgson et al., 2011; OFPC, 2010). While urban agriculture in Oakland is widespread, the contribution of existing gardens to the city's total consumption of vegetables is unknown and difficult to quantify. There are currently more than 100 school gardens in Oakland, 10 community gardens managed by the Office of Parks and Recreation (OPR), and dozens managed by non-profit organizations (Farfan-Ramirez, Olivera, Pascoe, & Safinya-Davies, 2010; OFPC, 2010; Unger & Wooten, 2006). No data on residential gardening exists for Oakland, but national data reveal that almost 40% of Americans grow vegetables in their yards (Marks, 2008).

Because the *potential* contribution of urban agriculture was also unknown, the OFSA's first recommendation regarding local food production was to: "Initiate an inventory of land that is potentially suitable for urban agricultural production. Such an inventory would ideally include both suitable public land (e.g., rights-of-way, easements, parks) and private land (e.g., rooftops, vacant lots, backyard gardens)" (Unger & Wooten, 2006, p. 105). A 2008 meta-analysis of existing data on production, distribution, consumption, and waste recovery in Oakland's food system reiterated the need for a land inventory in order to calculate the city's agricultural potential, noting that "it would be useful to have a better sense of production capacity in order to understand land acquisition and programming needs/costs" (Wooten, 2008, p. 19).

Between October 2007 and June 2009, this paper's lead author (N. McClintock) was involved with HOPE as a participant observer. During this time, HOPE members conducted an assessment of the food system and built environment in six low-income "micro-zones" in the flatlands. The assessment included interviews, inventories, community listening sessions, and *charrettes* that involved mapping and visioning a "healthier, greener Oakland" (Herrera, Khanna, & Davis, 2009; HOPE Collaborative, 2009). Participants repeatedly expressed the need to know the potential for urban agriculture to expand in Oakland. Over the course of 2008, discussions with HOPE members helped to define a specific research question: *To what extent could urban agriculture on Oakland's vacant and underutilized vacant land contribute to the city's food system*? Key sub-questions included: *Where is there available land? Who owns it? How much is there? How much produce could be grown on it*?

In early 2009, HOPE members collectively prioritized the need to move forward with such an assessment as a crucial first step toward the development of a robust food system for low-income flatlands neighborhoods and funded a research assistant (J. Cooper) to help complete the inventory. McClintock and Cooper completed the majority of GIS analysis and mapping between January and June 2009 and released a final report (McClintock & Cooper, 2009) in

October 2009, with hopes that the inventory might help non-profit organizations and city officials identify potential urban agriculture sites and inform food policy decisions.

Over the course of the project we worked collaboratively with HOPE members, city officials, and urban agriculture organizations, establishing a community advisory committee made up of members from these groups to brainstorm criteria for selection of potential sites and provide feedback on what information would be useful in the finished report. Advisory committee members also provided feedback on several drafts of the report before its release. The process of defining the parameters of the research was iterative, a defining characteristic of collaborative or participatory research (Israel et al., 2005; Minkler & Wallerstein, 2003). Moreover, the project itself was iterative, and continued even after the report's release. Extensive ground-truthing of sites was conducted throughout 2010. In Fall 2010, McClintock conducted a finer-grained slope analysis and a research assistant (S. Khandeshi) analyzed a data layer of privately owned vacant land. Building on methods used in assessments of vacant land in Detroit (Colasanti & Hamm, 2010) and Toronto (MacRae et al., 2010), McClintock then calculated the potential contribution of inventoried vacant land to Oakland's estimated current and recommended vegetable consumption. The methods and results of the entire project—the CTC public land inventory, the private land inventory, and productivity calculations—are reported here in detail.

3. Methods

3.1. Vacant land inventory

Following the lead of early vacant land inventories conducted in Portland (Balmer et al., 2005), Vancouver (Kaethler, 2006), and Seattle (Horst, 2008), our goal was to locate vacant parcels that could potentially serve as sites of food production. Upon initial examination, we realized that the amount of actual vacant public land (e.g., land with no existing use, such as a park or lawn or playing field) in Oakland was limited. We therefore chose to broaden the scope of our investigation to include any underutilized public land that could potentially be used for crop production, with the understanding that actual site selection would ultimately depend on additional criteria and community input.

We used ArcGIS 9.3 software to identify, delineate, and catalog areas where crops could potentially be grown, as well as to calculate area, slope, and aspect of the sites. The land included in the inventory belongs to public agencies spanning multiple administrative levels, from municipal to federal (see Table 1). We first used Alameda County Tax Assessor's parcel data obtained from the City of Oakland's GIS database to identify the 2551 publicly owned parcels totaling 10,013 ac (4052.1 ha) of land, or nearly a third of Oakland's total area of 35,703 ac (14,448.5 ha). Zoning and General Plan land use classifications were joined to each site.

We then exported and overlaid the parcel layer onto National Agriculture Imagery Program (NAIP) 1-m satellite imagery (USDA, 2005). Systematically following a 1-km grid overlay, we used visual interpretation to select parcels containing potentially arable land, including parcels that appeared vacant or that contained lawns, fields, and other open spaces within a park or adjacent to a government facility (see Fig. 2a and b). We excluded fully developed parcels and spaces with an apparent use, such as playing fields and parking lots, but in a few cases included parking lots that appeared to have been abandoned, as such sites could be used for food production in greenhouses or raised beds.

We clipped out buildings and developed areas such as roads, playing fields, and parking lots and classified each parcel into one of four ground cover categories: soil/grass (less than 25% coverage by dense vegetation or hard surface); hard surface (>25% asphalt, concrete, or gravel, and <500 ft^2 of contiguous open soil/grass); mixed surface (>25% asphalt, concrete, or gravel, but >500 ft^2 of contiguous open soil/grass), or dense vegetation (>25% dense vegetation and <500 ft^2 of contiguous open soil/grass). Dense vegetation parcels containing <500 ft^2 of contiguous open soil/grass were removed, while those containing >500 ft^2 were modified by clipping out the vegetation. Finally, any parcel with <500 ft^2 (46.5 m^2) of open space was removed from the final inventory.

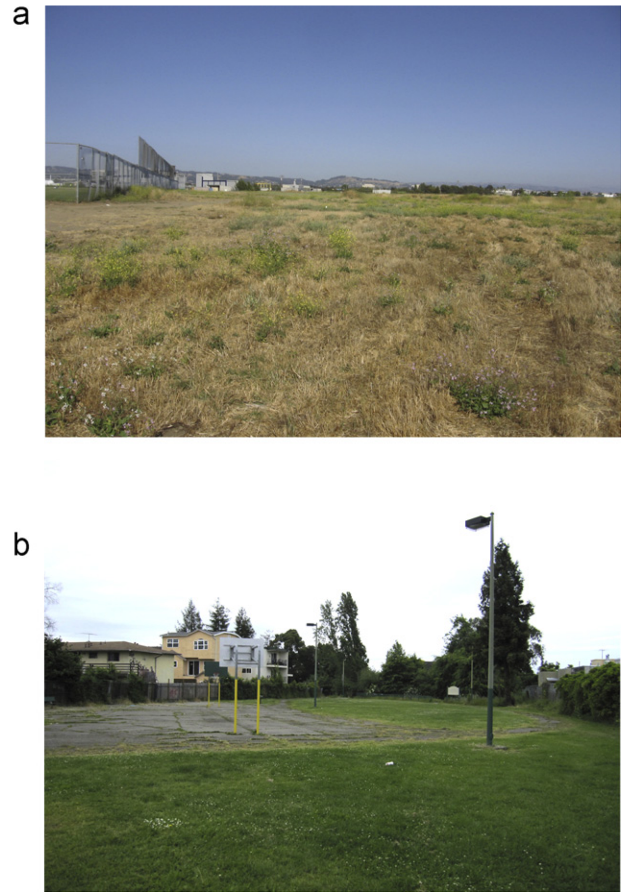

Fig. 2. Examples of (a) vacant land and (b) underutilized parks in Oakland included in the inventory.

The aggregated area that remained (which included soil/grass, hard surface, and mixed surface) formed the total area classified as arable. To calculate slope at each site, we transformed parcel polygons to a raster and calculated average slope for each 100 m^2 raster square using a digital elevation model (DEM). The raster was then reclassified into: slopes <10%; between 10 and 30%; and >30%, a practical threshold slope for cultivation (while agriculture is practiced on slopes greater than 30% in many parts of the world, terracing or other stabilization techniques are generally required). Using the slope raster and DEM, we also created an aspect raster, which we then reclassified as "optimal" (<30% slope and W, SW, S, SE, or E aspect) or "less desirable" (>30% slope and NW, N, or NE aspect). Finally, we spatially joined water meters, schools, and bus stops to the inventory layer, and queried all sites within 10 ft (3.05 m) of a water meter, 0.25 mi (0.40 km) of a school, and/or 0.25 mi (0.40 km) of a bus stop, attributes that were presented in the final database and report.

To account for limitations posed by visual interpretation of the NAIP imagery, we cross-checked all sites with more recent Google

Table 1
Potentially arable vacant or underutilized public land in Oakland, California.

Land type by level of government: Landowner or managing agency	Total public land			Public land w/urban agriculture potential			
	No. parcels	ac	ha	No. parcels	ac	ha	% of total area
Municipal:							
City of Oakland	1167	6659.4	2695.0	206	232.7	94.2	19.4
Oakland Parks & Recreation (OPR)	[a]	[a]		266	629.1	254.6	52.5
Redevelopment Agency	104	32.9	13.3	8	2.1	0.8	0.2
Housing Authority	343	127.9	51.8	13	2.3	0.9	0.2
Oakland Unified School District	165	493.2	199.6	10	5.8	2.3	0.5
County:							
Alameda Co. Flood Control	114	50.9	20.6	25	8.9	3.6	0.7
Alameda Co. Superintendent of Schools	1	1.8	0.7	1	0.6	0.2	0.1
Peralta Community College District	23	188.9	76.4	24	36.5	14.8	3.0
AC Transit District	8	23.8	9.6	1	0.6	0.2	0.1
County of Alameda	29	159.8	64.7	1	8.9	3.6	0.7
Regional:							
Bay Area Rapid Transit (BART)	100	59.4	24.0	8	1.9	0.8	0.2
East Bay Municipal Utilities District	115	405.0	163.9	48	28.0	11.3	2.3
East Bay Regional Parks District	100	835.8	338.2	65	109.0	44.1	9.1
State:							
University of California Regents	19	748.8	303.0	41	92.6	37.5	7.7
State of California	248	195.0	78.9	39	42.7	17.3	3.6
Federal:							
Amtrak	8	19.1	7.7	0	0	0	0
US Postal Service	6	9.2	3.7	0	0	0	0
Other federal land	21	496.7	201.0	0	0	0	0
Total[b]	2551	10,013.0	4052.1	756	1201.7	486.3	100

[a] Oakland Parks and Recreation (OPR) land is included in City of Oakland total listed in the row above.
[b] The sum of individual rows may slightly exceed the total due to rounding.

Maps imagery and visited a geographically representative sample of sites to assess vegetation density and slope. We visited 50 of 495 total sites (10%) in 2009, and an additional 120 sites (24%) in 2010 under the purview of a related soil sampling project (McClintock, 2012). Overall, seven densely vegetated sites (4% of total ground-truthed sites) were removed from the inventory.

Using vacant parcels data obtained from the UC Berkeley Department of City and Regional Planning in Fall 2010, we followed roughly the same GIS protocol to calculate the amount of potentially arable privately owned vacant land. This time we used ArcGIS 10 and a current Bing Maps base layer (rather than NAIP imagery) to visually interpret the 4249 vacant parcels. Given the extensive labor required, we modified the selection criteria, whereby parcels containing >25% dense vegetation were removed from the inventory. Similarly, parcels containing >25% infrastructure (such as outbuildings or pavement) or with a clear existing use (such as parking or junk storage) were removed. Due to the variation in selection criteria between public and private parcels, we have chosen to report the results separately.

3.2. Calculating consumption

To calculate the vegetable needs of Oakland's population, we used population data (sex and age cohorts) from the 2010 US Census, then aggregated cohorts into larger groups based on USDA recommendations for vegetable intake. Recommended consumption for all cohorts was then aggregated into an overall citywide demand (see Table 2). Both the Detroit (Colasanti & Hamm, 2010) and Toronto (MacRae et al., 2010) studies, however, assessed the potential for vacant land to contribute to *actual* consumption rather than *recommended* consumption. Following the Detroit study, we obtained consumption data from the USDA ERS Loss-Adjusted Food Availability Database (USDA, 2010) which calculates average national per capita fresh vegetable consumption from aggregate production, adjusting for losses between production and consumption. Using the national per capita consumption for each fresh vegetable crop (see Appendix A), we extrapolated current and recommended Oakland consumption based on the population data presented in Table 2.

When calculating potential productivity of vacant land, it is important to factor in both the geographic adaptability of a particular crop to the local agroecosystem and its seasonality. Following the Detroit study, we calculated the potential *local/seasonal* share of current and recommended consumption, divided the number of months that a particular crop can be harvested in Oakland by 12 months, then multiplied the coefficient by estimated current and recommended consumption levels for each crop (see Appendix A). Three of the USDA database crops—lima beans, okra, sweet corn, and sweet potatoes—do not grow well in Oakland, requiring warmer and sunnier conditions (sweet corn, for example, rarely produces large ears during the Bay Area foggy summers). They were therefore excluded from the local/seasonal productivity calculations.

3.3. Calculating productivity

No yield data was available from actual urban gardens in Oakland. The Detroit study used three different production scenarios to estimate the amount necessary to meet consumer demands: high-productivity biointensive, low-productivity biointensive, and commercial. Following this logic, we averaged California statewide yield data from 1998 to 2008 for each of the vegetable crops listed in the USDA database as well as low and medium yields using biointensive methods calculated in Northern California (Jeavons, 2002). Vegetable yields under conventional management average 13.2 tons/ac (29.6 Mg/ha). Low biointensive yields, which assume a beginning gardener, are slightly higher at 15.4 tons/ac (34.5 Mg/ha) while medium biointensive yield averages are twice as high (30.8 tons/ac or 69.0 Mg/ha) (see Appendix B). Unlike the Detroit researchers, we used medium biointensive yields for each crop rather than high yields (which many gardeners argue are unrealistic). Finally, we interviewed three organic farmers operating

Table 2
Oakland's recommended vegetable needs.

Oakland population (2010)[a]		Individual				Citywide	
		cups/day[b]	(g/day)	lbs/year	(kg/year)	tons/year	(Mg/year)
Males							
<5 years	13,396	1	(229)	183	(83.6)	1222	(1108.6)
5–9	11,708	1.5	(343)	274	(125.2)	1603	(1454.2)
10–14	10,500	2.5	(571)	456	(208.4)	2395	(2172.7)
15–19	11,293	3	(680)	548	(248.2)	3091	(2804.1)
20–34	46,201	3.5	(800)	639	(292.0)	14,755	(13,385.5)
35–79	91,836	3	(680)	548	(248.2)	25,140	(22,806.6)
>79 years	4585	2.5	(571)	456	(414.1)	1046	(948.9)
Females							
<5 years	12,703	1	(229)	183	(83.6)	1159	(1051.4)
5–9	11,286	1.5	(343)	274	(125.2)	1545	(1401.6)
10–14	10,325	2	(457)	365	(166.8)	1884	(1709.1)
15–19	11,163	2.5	(571)	456	(208.4)	2547	(2310.6)
20–44	79,322	2.5	(571)	456	(208.4)	18,095	(16,415.5)
45–64	51,250	2.5	(571)	456	(208.4)	11,691	(10.605.9)
>64 years	25,156	2	(457)	365	(166.8)	4591	(4164.9)
Total	390,724					90,766	(82,341.5)

[a] Data source: U.S. Census Bureau (2010).
[b] Data source: USDA (2010).

intensive commercial and/or educational operations in other urban or peri-urban areas with Mediterranean growing conditions. Farms were located in Davis and Santa Cruz, California (both approximately 110 km from Oakland, east and south, respectively) and Eugene, Oregon (830 km north of Oakland). They verified that our selected range of yields was realistic, depending on crop choice and management.

While the Toronto study calculated productivity based on Statistics Canada yield data unadjusted for losses, we followed the Detroit study's method of using state and federal data to calculate yields and farm to consumer losses at different stages in the commodity chain. The USDA database reports average estimated post-harvest losses at various stages between farm and table: farm to retail, retail to consumer, and inedible share (i.e., the portion of the raw vegetable, such as stems, that are not actually consumed). These farm-to-table losses are needed to calculate the overall production required to meet both estimated current consumption and recommended consumption levels. Appendix B lists these losses for each crop of interest. On average, there is a 63% loss in weight from farm to table, but these vary considerably by crop.

3.4. *Calculating potential contribution of vacant land*

To estimate the contribution of vegetable production on Oakland's vacant land to the city's estimated current and recommended vegetable consumption, we calculated production under four different land use scenarios. The first two scenarios use total areas calculated during the GIS inventory. A highly unlikely Scenario 1 assumes that all available land with a slope <30% would be used for vegetable production, while Scenario 2 uses only "optimal" acres (i.e., the Scenario 1 total excluding all NW, N, and NE-facing land). Scenarios 3 and 4 represent two more realistic scenarios, where specific (but arbitrary) amounts of land would be dedicated to urban agriculture, for example, by an act of City Council or OPR. Scenario 3 is based on a "High" land use of 500 ac (202.3 ha), while Scenario 4 is perhaps the most realistic, a "Low" land use of 100 ac (40.5 ha). In all Scenarios, we assumed that 75% of a site's arable total land area would be used for crop production, with the remaining 25% taken up by infrastructure and non-productive space (between-row aisles, turning lanes at the end of the rows, etc.). We then calculated the potential contribution under three agricultural management practices: conventional, biointensive (low), and biointensive (medium). For the sake of developing a "back of the envelope" metric for future studies, we rounded down to a slightly more conservative average yield for each of these management practices, using 10, 15, and 25 tons/ac (22.4, 33.6, and 56.0 Mg/ha), for conventional, bio-intensive (low), and bio-intensive (medium), respectively.

4. Results

4.1. *Consumption*

Based on Oakland's 2010 population of 390,724, the recommended annual vegetable consumption by city's population totals 90,766 tons (82,341.5 Mg) (Table 4). According to the USDA Americans annually consume 97.9 lbs (44.4 kg) of fresh vegetables per capita. Assuming that Oakland follows the same pattern, Oaklanders currently consume 19,126 tons (17,350.8 Mg) of fresh vegetables, or only 21% of the recommended total.

We estimate that 28,884 tons (26,203.1 Mg) are needed to meet estimated current consumption levels, and 137,016 tons (124,298.8 Mg) needed to meet recommended levels. Considering the geographic adaptability and seasonality of crops, the overall possible local contribution to production needs is slightly lower (see Table 3).

4.2. *Public land*

Overall, we identified roughly 1200 ac (486.0 ha) of arable land on 495 aggregated sites consisting of 756 individual tax parcels

Table 3
Total and locally possible vegetable production (including losses) necessary to meet estimated existing and recommended consumption needs in Oakland.

	Production needed to meet:	
	Estimated current consumption, tons (Mg)	Recommended consumption, tons (Mg)
Total production needed (including losses)	28,884 (26,203.1)	137,016(124,298.8)
Possible local/seasonal share of total production (including losses)	23,954 (21,730.7)	113,630(103,083.4)

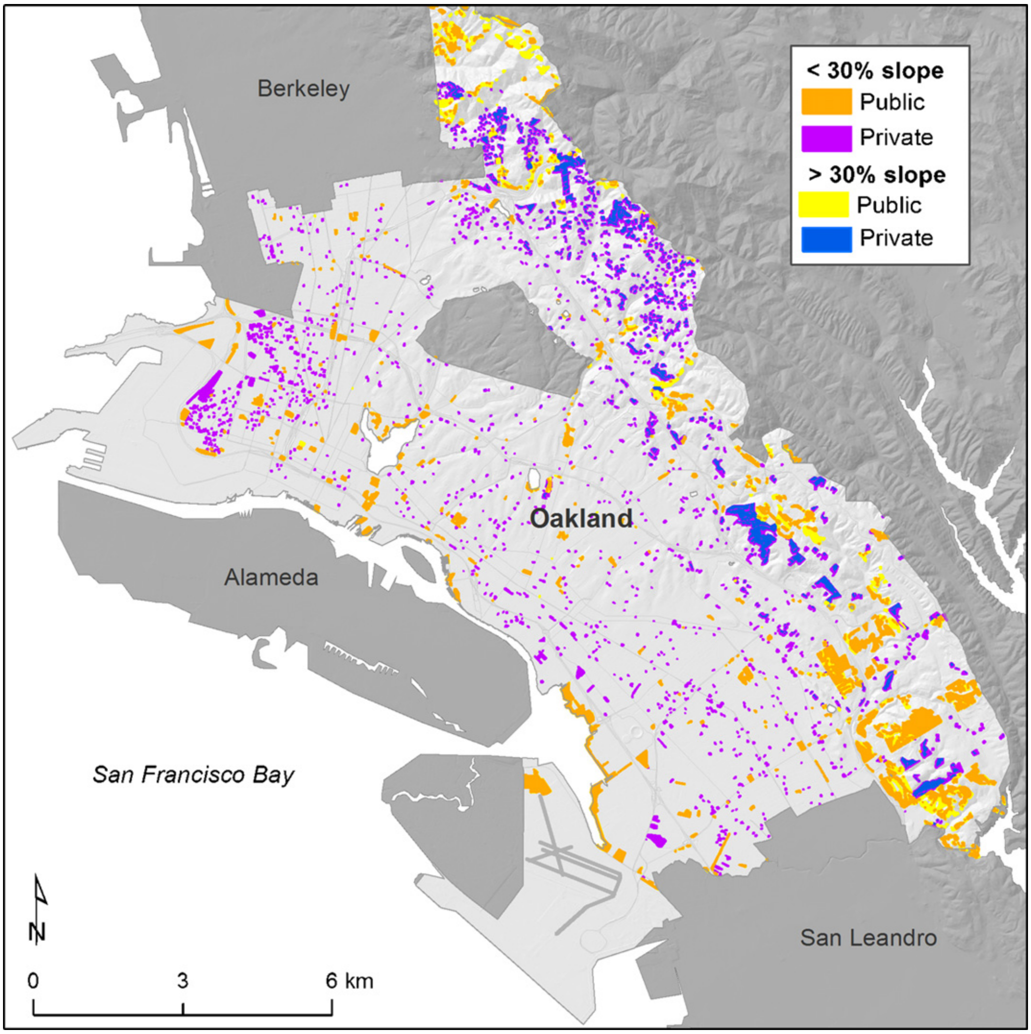

Fig. 3. Vacant or underutilized public and privately owned land in Oakland. Sites with the greatest agricultural potential are those with slopes less than 30% (orange and purple). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

(see Fig. 3). Slightly more than half (629 ac, or 254.5 ha) of land identified in the inventory is currently owned or managed by OPR. The sites are distributed relatively evenly across the city, but the vast majority of arable public land is located in East Oakland, with another large number of sites located in the West Oakland flatlands. While a significant amount of open space is located on public land in the Oakland hills, much of this land is fragmented, located on slopes >30%, and inaccessible by road.

More than one-third of the sites are small parcels >0.25 ac (0.1 ha), which, based on size alone, would be best suited for community gardens. Another one-third of the sites are between 0.25 and 1 ac (0.1–0.4 ha) and might be best used as community gardens or small market gardens run by urban agriculture organizations. A final one-third of the sites are between 1 and 5 ac (0.4–2.0 ha) and could be developed as large market gardens or "mini-farms" run by urban agriculture organizations or leased to individual commercial urban farmers. Finally, 45 sites are >5 ac (2.0 ha) and could be used as urban farms managed by urban agriculture organizations or leased to commercial farmers for large-scale urban production.

Most of the identified land (1078 ac, or 436.3 ha) has soil or grass as ground cover, while 26 parcels totaling 30 ac (12.1 ha) are covered with an impermeable ground cover such as gravel, concrete, or asphalt. Such sites would be suitable for greenhouses or raised beds (or used for compost processing, distribution centers, and/or storage). The land is almost evenly divided between level (<10% slope), sloping (10–30%), and steep land (>30%). More than a third of the land (nearly 410 ac or 165.9 ha) is level (see Fig. 3). Parcels with the most level terrain would be optimal for community gardens. Aspect, or directional exposure to the sun, is another key consideration when considering crop production, particularly on moderate to steep slopes. Overall, roughly 12% of the total area faces NW, N, or NE. Our "optimal site" calculation yielded a total of 730 ac (295.4 ha), or 62% of the total area (see Table 4).

Table 5 summarizes the potential contribution of urban agriculture on public land to vegetable consumption in Oakland under three different production systems. Under ideal growing practices, even the Low land use scenario, which commits 100 ac (40.5 ha) to vegetable production, could yield more than 5% of the city's estimated vegetable consumption, while the High use scenario which commits 500 ac (202.3 ha) could produce roughly a third of the estimated current consumption needs. More modest yields under conventional management would result in 2.9 and 14.5% under the Low and High land use scenarios, respectively. Because *recommended* consumption is so much higher than *current* consumption, the vacant land's potential to meet these recommendations is lower. The Low land use scenario would contribute as little as 0.6–1.5% to the city's food recommended consumption needs, while the High land use scenario could deliver as much as 7.7%, depending on management practices.

Table 4
Public land area disaggregated by slope and aspect.

	Area[a]		% total	Description
	ac	(ha)		
Slope				
Under 10%	409.6	(165.8)	34.1	Flat terrain to gradual slope (<5.7°)
10–20%	211.0	(85.3)	17.6	Gradual to moderate (5.7–11.3°)
20–30%	207.2	(83.9)	17.2	Moderate to steep (11.3–16.7°)
Over 30%	374.1	(151.4)	31.1	Very steep (>16.7°)
Total	1201.9	(486.4)	100.0	
Aspect				
NW–N–NE	140.0	(56.7)	11.6	Often shaded
W–SW–S–SE–E	1061.9	(429.7)	88.3	Receives more direct sunlight
Total	1201.9	(486.4)	100.0	
Aspect + Slope				
Optimal	730.1	(295.5)	60.1	Western, southern, or eastern exposure, slope under 30%
Less desirable	471.8	(190.9)	39.9	Northern exposure, slope greater than 30%
Total	1201.9	(486.4)	100.0	

[a] Total difference in area (0.2 ac) is due to conversion from vector to raster data. Total % may exceed 100 due to rounding.

4.3. Private land

Overall, we identified 3008 privately owned vacant parcels, totaling 864 ac (349.6 ha) (see Fig. 3). The vast majority of this land (2484 parcels totaling 289 ac, or 117.0 ha) consists of lots <0.25 ac (0.1 ha). Fifteen large parcels >5 ac (2.0 ha) account for roughly a third of the land (see Table 6). A slope analysis reveals that only 40%, or 337 ac (136.4 ha) of the overall area is located on slopes <30%. Many of the largest parcels are located on steep slopes in the Oakland hills, likely the reason that they have not been developed.

Using the methods described above to calculate potential contribution of vacant land to Oakland's vegetable consumption, private vacant could contribute an additional 3370 tons (3057.2 Mg) of vegetables under conventional farming practices, equaling 2.1 of Oakland's current consumption or 9.8% of recommended consumption. Low-yield biointensive could produce 5055 tons (4585.8 Mg), 14.7% of current consumption or 3.1% of recommended consumption. Medium-yield biointensive could produce 8425 tons (7463 Mg), 24.5% of the city's current consumption needs or 5.2% of recommended needs.

5. Discussion

5.1. Strengths of the study

This study identifies potential sites of production in Oakland and provides a preliminary assessment of the capacity of this vacant land to contribute to the city's vegetable consumption. Moreover, the analysis also reveals that a majority of arable sites are located in the flatlands, where urban agriculture advocates are most active and the need for healthy produce the greatest.

Clearly, urban agriculture should not supplant all other uses of urban green space; public open spaces must serve multiple purposes. The spectrum of land use scenarios therefore ranges from the improbable Scenario 1 (where all land would be used) to the potentially possible Scenario 4 where only 100 ac (14% of the total optimal vacant land) would be devoted to urban food production. Even under this scenario and the most conservative yield estimate, as much as 3% of the city's current consumption needs could be met. This contribution may seem insignificant when weighing costs and benefits on production alone, but when considering urban agriculture as only one (albeit spatially disparate) node in a network of

Table 5
Potential contribution of urban agriculture on public land to Oakland's estimated and recommended vegetable needs under three management types and four land use scenarios.

Consumption level	Agricultural management practice	Avg. yield	Area needed	Land use scenario[a]			
		tons/ac (Mg/ha)	ac (ha)	1 All 828 ac (335.1 ha)	2 Optimal 730 ac (295.4 ha)	3 High 500 ac (202.3 ha)	4 Low 100 ac (40.5 ha)
				% contribution to vegetable needs[b]			
Current (estimated)	Conventional	10 (22.4)	2582 (1044.90)	24.1	21.2	14.5	2.9
	Biointensive – Low	15 (33.6)	1722 (696.9)	36.1	31.8	21.8	4.4
	Biointensive – Med	25 (56)	1033 (418)	60.1	53	36.3	7.3
Recommended	Conventional	10 (22.4)	12,250 (4957.40)	5.1	4.5	3.1	0.6
	Biointensive – Low	15 (33.6)	8167 (3305.10)	7.6	6.7	4.6	0.9
	Biointensive – Med	25 (56)	4900 (1983.00)	12.7	11.2	7.7	1.5

[a] Scenario 1 includes all identified publicly owned vacant or underutilized public land with a slope < 30%. Scenario 2 removes NW, N, and NE-facing slopes from the Scenario 1 total area. Scenarios 3 and 4 are based on arbitrary values (high and low, respectively) of land area that might be converted to crop production via a municipal policy or initiative.
[b] Assumes that 75% of land in each scenario will be used for crop production.

Table 6
Size distribution of privately owned vacant land in Oakland.

Parcel size		Potential use	No. parcels	Total area	
ac	(ha)			ac	(ha)
100 ft^2 to 0.25 ac	(9.3 m^2 to 0.1 ha)	Community garden	2484	289	(117.0)
0.25–0.5 ac	(0.1–0.2)	Community garden/market garden	338	113	(45.7)
0.5–1 ac	(0.2–0.4)	Market garden	115	81	(32.8)
1–5 ac	(0.4–2.0)	Urban farm	56	119	(48.2)
>5 ac	(>2.0)	Urban farm	15	262	(106.0)
Total			3008	864	(349.6)
Total (<30% slope)				337	(136.4)

local and regional production, 3% is considerable, especially in a built environment as dense as the Bay Area. Similar to our findings, vacant land in New York City could contribute to 2% of the city's vegetable consumption under conventional methods (Ackerman, 2012), whereas in Detroit, where vacant public land alone totals 4848 ac (1961.9 ha) and the population is shrinking, one-third of current consumption levels could be met by farming vacant lots (Colasanti & Hamm, 2010), while Cleveland's 3413 ac (1381.1 ha) of vacant lots could contribute 22–48% to the city's produce (Grewal & Grewal, 2012).

Beyond providing Oakland urban agriculture practitioners and policy makers with data, this study helped to foster collaboration between researchers and the public. The project was initially inspired by a broad range of stakeholders, many of whom also contributed to the land inventory in an advisory capacity. Such integration of community participation is common in environmental justice research and policy advocacy (Costa et al., 2002; Metzger & Lendvay, 2006; Petersen et al., 2006), reflecting the broader collaborative turn in planning (Innes & Booher, 2010). It also gives primacy to the co-production of science for healthy city planning, what Corburn (2009, p. 11) describes as a "polycentric, interactive, and multipartite sharing of information" bringing together researchers, government agencies, and lay publics. On a more immediate level, as Mendes, Balmer, Kaethler, and Rhoads (2008) concluded in their comparative study of the Portland and Vancouver land inventories, the success of moving from land inventory to successful implementation of urban agriculture projects relies on the successful integration of stakeholders into the inventory and planning process. Indeed, the preliminary GIS inventory of public land that emerged from this project has played a role in ongoing efforts by city officials in Oakland to update urban agriculture zoning (McClintock et al., 2012).

Furthermore, this study has both informed and built on other efforts to assess urban agriculture's potential on vacant and underutilized land in North American cities. The original CTC report provided methodological insights for several inventories that were conducted in other cities (Ackerman, 2012; Colasanti & Hamm, 2010; MacRae et al., 2010; Taggart et al., 2009; Taylor & Lovell, 2012). Two of these studies, in turn, helped us refine our own consumption and productivity calculations.

5.2. *Limitations to the methodology*

This project solely sought to provide a rough, "back of the envelope" estimate of urban agriculture's potential contribution to the food system. While the inventory was comprehensive, there are several limitations worth noting.

5.2.1. *Data availability*

A primary limitation was the availability and currency of geospatial data. Even though the tax assessor data file was updated quarterly, there was a lag time before shape files were updated to reflect the tax assessor data. Because of the dynamic nature of development plans and real estate transfers, each site would ideally be crosschecked with managing agencies and the online tax assessor database; time and labor constraints prevented us from doing so. As outside researchers without access to the tax assessor database, it was only possible to provide this "snapshot" of vacant land at the time that the inventory was completed. A searchable Web GIS version of the inventory, ideally linked to the existing tax assessor database and updated immediately as sites are sold or transferred, could make current information available to the public in a more user-friendly fashion.

The currency of aerial imagery was also an obstacle. When the CTC inventory was completed, only 2005 NAIP imagery was available, thus the visual record of land use was already four years old. To account for this, we crosschecked all sites using Google Maps to see if they had been developed in the interim. While we were able to then delete newly developed sites from the inventory, we were unable to account for slight changes in vegetation. New NAIP imagery, flown in Summer 2009, was released after we had completed the majority of the GIS analysis of the public land. The release of ArcGIS 10, which includes up to date Bing base map imagery, greatly expedited our analysis of private land. For analysts using Quantum GIS, GRASS, or other open source software, NAIP imagery is a free alternative, but may have slightly lower resolution than Bing or Google imagery.

5.2.2. *Visual interpretation*

The study also revealed the limitations of visual interpretation. Even with 1-m resolution, what appears to be arable in an aerial or satellite-photo may not hold up to ground-truthing. The annual grasses of the Bay Area turn a golden brown color during the dry season, making it difficult to distinguish them from bare dirt or concrete at some sites. While ground-truthing of 34% of the publicly owned sites confirmed that our estimates were 96% accurate, further comprehensive assessment of sites should be conducted to determine if all of them are actually viable for food production. Indeed, ground-truthing ultimately prompted us to hone the slope analysis in 2010 to better identify slopes that might be too steep to farm.

Another major drawback of our approach was its labor intensiveness. Visual assessment of each parcel was incredibly time consuming, and clipping out vegetation and buildings and other reshaping of polygons added a significant level of precision to the project. The HOPE mini-grant funded 140 h of GIS work, but we easily spent twice this amount of time inventorying the publicly owned land. The private land inventory was completed much more quickly because the Bing base map allowed us to eliminate the extra step of cross checking each site against Google Maps. The use of remote sensing software to process aerial imagery could certainly speed up the process, but would be complicated by shading from buildings and differentiating dry vegetation from other surfaces. Using higher resolution imagery for the entire city would also require significant data processing capabilities. Indeed, recent land inventories using remote sensing have extrapolated their results from small sub-sections of the city (Nipen, 2009; Welty, 2010).

5.2.3. Estimating production and consumption

There are limitations to calculating vegetable consumption (and by extension, necessary production) at the city- or neighborhood-scale. Interpolating consumption based on national averages is clearly problematic, especially when the demographics of poverty, race, and ethnicity—all of which factor into food consumption patterns—differ between the municipal and national scale. Vegetable consumption is closely correlated to education and income, with significant differences in consumption between races and/or ethnic groups (Casagrande, Wang, Anderson, & Gary, 2007). Given the socioeconomic disparity between the flatlands and hills, consumption patterns are surely even different *within* Oakland (hence the activism that has emerged to address these inequities). Considering that 22% of Oakland's population lives in poverty relative to 15% nationally (U.S. Census Bureau, 2010), the quantity of vegetables actually consumed is likely lower than aggregate USDA data suggests.

Furthermore, the USDA averages likely do not reflect Oakland's ethnic—and culinary—diversity; the culinary traditions and diets of the city's large Asian and Latino populations (17% and 25% of the city's population, respectively, versus 5% and 16% of the US population) are rich in many vegetables that are not represented in the USDA dataset. A more accurate estimate would require finer grain, in-depth consumption surveys stratified along socioeconomic lines. This would also help to reveal the full spectrum of crop varieties that people actually consume in Oakland.

In terms of production, estimates of the local/seasonal share of crop production should be fine-tuned using crop yield data specific to East Bay urban agroecosystems. No such data currently exists in any comprehensive form. Moreover, not all vegetables would grow equally well at every site, given site-specific soil quality and microclimatic conditions. Such variability would need to be considered once actual sites were selected. Because existing soil maps are too coarse to capture such variability at the site scale, we did not include a soil assessment in our GIS analysis.

Moreover, our three yield scenarios are realistic only if gardens were to be managed with a level of professional attention to spacing, planting, weeding, irrigation, pest control, and harvest. Community and school gardens that are not tended with the same level of care are unlikely to attain such yields. Scenario 4 (100 ac devoted to urban agriculture) is arguably the most realistic in that it represents a scale that City of Oakland officials might consider given conflicting stakeholder needs (an issue we address in Section 6) and/or the difficulty they might face in securing potential commercial or non-profit farm managers to farm a larger area.

Finally, our production estimates incorporate USDA loss estimates that are likely higher than what might occur in a localized food system. Indeed, they reflect the average losses for vegetables that travel more than 1000 miles on average from farm to plate (Weber & Matthews, 2008). Under a localized production system where more produce is sold at farm stands and farmers' markets and less weight loss to processing, we might assume lower rates of loss between retail and consumer. For this reason, our overall production estimates are likely conservative.

5.3. Future directions

This study represents only a preliminary step in an ongoing effort to expand urban agriculture in Oakland. The next step would be to prioritize site suitability. The sites identified in this inventory were categorized based on size, slope, and aspect. While information on ground cover, presence of a water meter, accessibility to public transportation, and proximity to schools were included with each site listed in the original report, these factors (selected by the advisory committee) were not used to rank site suitability; rather, they were simply presented as relevant data to help guide such decisions in the future. A prioritization or ranking of sites for suitability should include some or all of these factors, as well as others such as soil quality, tenure, access, and waste disposal (Unger & Wooten, 2006).

Soil quality, in particular, is an issue in urban areas. Many urban soils have high levels of lead (Pb) and other contaminants. This project led to the assessment of Pb at more than a hundred sites identified in this inventory. Results indicated that Pb levels are lower than expected across the city, but that levels are highly variable at each site and are dependent on a number of variables including soil type, density of pre-1940s housing, distance to major roads, and levels of soil carbon and soil phosphorus (McClintock, 2012). These data, along with EPA Brownfields and California Department of Toxic Substances Control data, should figure centrally in future site suitability assessment. Other indicators of soil quality, such as soil organic matter, cation exchange capacity, clay content, and nutrient availability would also be useful. In many cases, however, construction of raised beds and/or the importation of soil and compost may mitigate many soil quality issues.

Since the completion of the CTC inventory in 2009, several other land inventories have been released. Each of these inventories includes additional variables that could be incorporated into a finer grain analysis and that could help to narrow the overall suitability of a particular site. Some of these analyses are more dependent on high-resolution geospatial data than others. The Halifax inventory, for example, uses LiDAR data to model potential sun exposure at different times of day in potential backyard gardens in several sample neighborhoods, and reports an additional 22% loss of available space due to shading (Nipen, 2009). A Somerville (Massachusetts) inventory includes soil type and population density in the analysis (Bickerdike, DiLisio, Haskin, McCullagh, & Pierce-Quinonez, 2010). One Cleveland inventory, conducted by the Cleveland-Cuyahoga County Food Policy Coalition, includes presence of hydrological features and soil, as well as proximity to community gardens greenhouses and other consumer markets (Taggart et al., 2009). Furthermore, it excludes industrial and Brownfields sites, as does the New York assessment (Ackerman, 2012).

With the exception of a recent Cleveland study (Grewal & Grewal, 2012), vacant land inventories to date have not included economic variables. A suite of economic indicators such as parcel values, crop values, job creation, and infrastructure costs would be necessary to conduct cost-benefit analyses to compare urban agriculture to other land uses. At the same time, such an econometric analysis would likely fail to capture the multiple—but difficult or impossible to quantify—attributes that make parks and other green space valuable in urban landscapes, notably the esthetic, recreational, educational, and health benefits offered by such spaces.

6. Conclusion

Despite the methodological limitations outlined above, mapping vacant land is an important step in an ongoing process to bring urban agriculture's potential to fruition in Oakland and other cities. It will surely take a long time for cultivation to reach the 100 or 500 ac as envisioned in the Low and High land use scenarios presented above. Ultimately, the delineation of polygons is only a preliminary step in the long process of mapping the agricultural potential of a city such as Oakland. Indeed, the politics of negotiating competing uses of vacant land is far more complex than identifying potential sites of production. The real work in planning for urban agriculture lies in identifying and negotiating the varied interests of multiple stakeholders.

As in any case of multiple land uses, such conflicting interests may hinder urban agriculture at a particular site. For example, people who use the site for walking dogs, playing Frisbee, flying kites, or picnicking would likely object to its conversion to agricultural use. Similarly, "not-in-my-backyard" (NIMBY) sentiments from neighbors concerned over noise, human or vehicle traffic, odors from compost or manure, or impact on property values may prove a challenge to cultivation at particular sites. These conflicting interests and concerns must figure centrally into public discussions over how much and which land to devote to urban agriculture. In Oakland, all projects proposed on OPR land, for example, are required to go through a lengthy approval process that includes several public comment periods where such conflicts are heard.

The cultivation of private land ultimately depends on the will of the landowner. Municipalities have little control over how a vacant parcel is to be used other than easing zoning and permitting restrictions on urban agriculture (McClintock et al., 2012) or incentivizing landowners to convert their property to agricultural use. A municipal government could waive blight fines or provide property tax credits, for example, for vacant property owners allowing cultivation on their property, a policy exemplified by Maryland House Bill 1062 (Property Tax Credit: Urban Agricultural Property) signed into law in May 2010.

While negotiating stakeholder interests ultimately determines how much vacant land is used for urban agriculture, a vacant land inventory can help not only to identify possible locations and posit their potential contribution to the food system, but can also help to embed the socioecological landscape with alternative possibilities, a first step in realizing a vision of what an alternative food system might look like. St. Martin (2009, p. 494) describes such an approach as "a cartography of the commons that can effectively recast space as a site of multiple economic possibilities and resources as the basis of community livelihoods." How this vision is ultimately interpreted and mobilized—and by whom—will also necessarily become part of this process. Additional analyses, as described above, may help stakeholders prioritize sites, but the prioritization process itself will depend on how well differing views of land use are negotiated and integrated and on how such spaces are valued.

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Appendix A. Estimated and recommended vegetable consumption in Oakland and possible local/seasonal share

Crop	US per capita consumption (USDA, 2010) (lbs/year)	Oakland		Annual months of production	Possible local/seasonal availability (%)	Possible local/seasonal share of:	
		Estimated current consumption (tons/year)	Recommended consumption (tons/year)			Estimated current consumption (tons/year)	Recommended consumption (tons/year)
Artichokes	0.2	42	197	10	83	35	164
Asparagus	0.3	57	269	5	42	24	112
Bell peppers	4.6	908	4308	7	58	530	2513
Broccoli	1.8	360	1710	12	100	360	1710
Brussels sprouts	0.1	27	129	12	100	27	129
Cabbage	3.9	761	3611	12	100	761	3611
Carrots	5.5	1067	5062	12	100	1067	5062
Cauliflower	0.2	47	225	10	83	39	187
Celery	3.8	737	3498	9	75	553	2624
Collard greens	0.1	28	132	11	92	26	121
Sweet corn	0.3	64	304	0	0	0	0
Cucumbers	2.9	570	2703	6	50	285	1352
Eggplant	0.3	60	284	4	33	20	95
Escarole/endive	0.1	18	83	12	100	18	83
Garlic	1.3	253	1198	12	100	253	1198
Head lettuce	11.4	2226	10,559	12	100	2226	10,559
Kale	0.1	15	70	12	100	15	70
Leaf lettuce	4.9	961	4556	12	100	961	4556
Lima beans	0.0	2	8	0	0	0	0
Mushrooms	1.6	316	1501	12	100	316	1501
Mustard greens	0.2	29	140	6	50	15	70
Okra	0.2	31	149	0	0	0	0
Onions	9.3	1821	8637	12	100	1821	8637
Potatoes	27.0	5271	25,001	11	92	4831	22,918
Pumpkins	1.9	362	1716	4	33	121	572
Radishes	0.3	51	241	12	100	51	241
Snap beans	1.0	201	953	12	100	201	953
Spinach	0.6	126	599	12	100	126	599
Squash	2.2	423	2009	5	42	176	837
Sweet potatoes	1.4	281	1332	0	0	0	0
Tomatoes	10.2	1997	9473	6	50	999	4737
Turnip greens	0.1	22	106	7	58	13	62
Fresh vegetables	97.9	19,134	90,766		83	15,869	75,274

Appendix B. Average conventional and biointensive yields and farm-to-table losses

Crop	Average yields			Average losses			
	Conventional[a] (tons/acre)	Biointensive (low)[b] (tons/acre)	Biointensive (medium)[b] (tons/acre)	Farm to retail[c] (%)	Retail to consumer[c] (%)	Inedible share[c] (%)	Total farm to table loss[c] (%)
Artichokes	6.1	nd	nd	7	19	60	49
Asparagus	1.5	2.1	4.1	9	9	47	57
Bell peppers	15.0	7.8	15.7	8	8	18	73
Broccoli	7.5	5.7	11.3	8	12	39	59
Brussels sprouts	9.0	15.5	30.9	8	19	10	71
Cabbage	20.0	20.9	41.8	7	14	20	68
Carrots	15.0	21.8	43.6	3	5	11	83
Cauliflower	9.0	9.6	19.2	8	14	61	50
Celery	36.5	52.3	104.5	7	5	11	80
Collard greens	8.5	20.9	41.8	12	38	43	45
Cucumbers	12.0	34.4	68.8	8	6	27	69
Eggplant	10.0	11.8	23.5	10	21	19	63
Escarole/endive	7.8	nd	nd	10	47	14	54
Garlic	8.5	13.1	26.1	19	7	14	69
Head lettuce	18.0	16.3	32.7	7	9	16	74
Kale	10.0	16.6	33.1	12	39	39	46
Leaf lettuce	11.5	29.4	58.8	7	14	21	68
Mushrooms	35.9	nd	nd	6	13	3	81
Mustard greens	7.5	39.2	78.4	12	63	27	43
Onions	22.5	21.8	43.6	6	10	10	78
Potatoes	18.5	21.8	43.6	4	7	0	90
Pumpkins	12.0	10.5	20.9	10	11	30	63
Radishes	11.5	21.8	43.6	3	21	10	73
Snap beans	5.0	6.5	13.1	6	18	12	71
Spinach	8.0	10.9	21.8	12	14	28	61
Squash	10.0	10.9	21.8	10	13	17	69
Tomatoes	15.0	21.8	43.6	15	13	9	70
Turnip greens	nd	5.4	10.9	12	41	30	49
Fresh vegetables	13.2	15.4	30.8	9	18	24	63

[a] Data source: USDA (2010).

[b] Data source: Jeavons (2002).

[c] Data source: USDA 201.

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