The Role of Urban Agriculture in a Secure, Healthy, and Sustainable Food System

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Investments in urban agriculture (UA) initiatives have been increasing in the United States, but the costs and benefits to society are poorly understood. Urban agriculture can link socioeconomic and health systems, support education and societal engagement, and contribute to a range of conservation goals, including nutrient recycling and biodiversity conservation. Urban agriculture is spatially dispersed and small scale, creating opportunities to redirect underutilized land, water, and nutrient resources. Urban agriculture reduces water and carbon footprints when it replaces lawns. Labor and time requirements, potential for environmental and nutrient pollution, and scarce water resources are challenges that UA must address. Based on our review of the literature, it is unclear whether UA provides economic or nutritional benefits to urbanites, but our case study shows that UA can provide some benefits when replacing other land uses.

Keywords: water resources, nutrient cycling, agriculture production, conservation, urban ecology

Investment in urban food production systems has increased with growing consumer interest in where and how food is produced and increasing pressure on agricultural lands to provide food with fewer environmental impacts. Urban agriculture (UA) may play an important role in sustainable food systems through a diverse array of potential benefits. Although UA is unlikely to provide most of the world's food, food systems that include some production in urban areas may help achieve society's health, economic, and conservation goals. Urban gardens can produce a substantial amount of food (e.g., Ghosh 2014, Eigenbrod and Gruda 2015), and indeed, during the Second World War, households produced approximately 40% of the United States' demand for fresh vegetables as part of the Victory Garden movement (Brown and Jameton 2000).

The US government shapes food systems today as it did during the Victory Garden movement. Government policies and subsidies have far-reaching impacts on the type of agriculture we practice in both urban, periurban, and rural areas. For example, the US Department of Agriculture (USDA) provided almost $57 billion in subsidized crop insurance payments between 2009 and 2015 that primarily supported the production of major commodity crops (USDA RMA 2016). In this same period, the USDA also invested more than $1 billion in activities related to local food systems, including UA initiatives (Vilsack 2016). Most recently, Senator Debbie Stabenow introduced the Urban Agriculture Act of 2016. The program extends the availability of support from many existing USDA programs into urban areas and is purported to create new economic opportunities for urban communities, provide new financial tools and support for urban farmers and gardeners, increase urban consumer's access to healthy food, and create a healthier environment.

Despite growing interest in UA, its impacts are poorly understood. There is a need to assess the potential for UA to provide the multiple food production, community development, and societal benefits that these investments and community initiatives seek. In this article, we discuss the benefits and challenges of UA as part of a broader food system. Our definition of UA includes community, home, and market gardens located within urban areas and includes the production of vegetables, fruits, and livestock (most commonly, chickens kept for eggs; figure 1). We take a multidisciplinary approach, highlighting the economic, sociological, human health, and conservation impacts of UA (table 1). Using a case study and spatial analysis, we quantify the potential impacts of UA in a midsized city of Fort Collins, Colorado,
on nutritional, land-use, and economic outcomes and also quantify the potential for rainwater collection in different climatic regions to support UA without supplemental irrigation.

**Sociological impact**

Urban agriculture has received attention from planners, policymakers, practitioners, institutions, activists, and community residents as a way to improve urban communities,
Table 1. Potential benefits and challenges for urban agriculture as part of sustainable food systems.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Benefits</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social</td>
<td>Promote food education and awareness</td>
<td>Time and knowledge constraints in both growing and preparing food</td>
</tr>
<tr>
<td></td>
<td>Foster civic engagement</td>
<td>May perpetuate inequality and cultural insensitivities</td>
</tr>
<tr>
<td>Economic</td>
<td>Reduce household food expenses through food production</td>
<td>Although high value, urban production is often limited to fruits and vegetables</td>
</tr>
<tr>
<td></td>
<td>Creation of jobs</td>
<td>Underpaid labor supports many urban agriculture efforts</td>
</tr>
<tr>
<td></td>
<td>Improved property values</td>
<td>Limited impact in some studies</td>
</tr>
<tr>
<td>Human health</td>
<td>Contribute to human nutrition, particularly nutrients, and chicken flocks can contribute to filling protein needs</td>
<td>Most human nutrition does not come from produce common in urban gardens</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Possible pathogenic risk from poultry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Limited data to assess impacts</td>
</tr>
<tr>
<td>Conservation</td>
<td>Reduce land conversion for agriculture and reuse of currently irrigated lawns in some regions</td>
<td>More arid climates require supplemental water inputs</td>
</tr>
<tr>
<td></td>
<td>Increase nutrient recycling opportunities</td>
<td>Potential for nutrient pollution if nutrients overapplied</td>
</tr>
<tr>
<td></td>
<td>Increase biodiversity and habitat for some species</td>
<td>Fear of bees and acceptance of urban beekeeping. Potential for pathogen spread into wild bees</td>
</tr>
<tr>
<td></td>
<td>Reduce transportation and storage GHG emissions</td>
<td>Increased emissions for climate-controlled local food production</td>
</tr>
<tr>
<td></td>
<td>Offset of agricultural water use if captured rainwater can meet garden needs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conserve genetic diversity</td>
<td></td>
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</tbody>
</table>

as well as their connection to broader social and natural processes. As a result, UA is a component of many urban community development efforts, commonly with a focus on fruit and vegetable production for urban dwellers. In addition, UA efforts can educate urban dwellers about food while encouraging civic engagement and increasing social involvement, all of which contribute to overall societal health and well-being (Hale et al. 2011, Carolan 2016).

Emerging evidence from studies approaching UA with a more critical lens reveals that some projects perpetuate inequality and cultural insensitivities. For example, UA may unfairly burden farmers and farm labor (Jarosz 2008) and may not grow culturally appropriate food (Guthman 2008). Alkon and Mares (2012) showed that many local food efforts relied heavily on creating alternative food markets rather than engaging in direct efforts to build civil society and civic capacity. Differing objectives of various municipal agencies and supporting partners also create challenges for UA. City officials often prioritize economic viability, but UA initiatives frequently rely on grants from government and local foundations, donations, and typically low-paid, young, and enthusiastic workers.

Time can be either a barrier or a social network benefit of UA. Issues of food access and poverty are important for understanding who participates in UA. The tacit skills needed to garden, raise chickens, and prepare fresh fruits and vegetables are no longer widely held among average households and cannot be simply conveyed via “how to” documents and instructional videos. Acquiring skills for UA requires hands-on training (Carolan 2011), and it is difficult to convey this knowledge among populations that are time poor and as such requires careful thought and well-directed policy. Conversely, time spent gardening is identified as helping to build social networks and pass on cultural practices (Calvet-Mir et al. 2012).

**Economic impact**

Urban agriculture affects local economies when it (a) creates jobs; (b) strengthens local economic linkages, including attracting new capital and opportunities for business development; and (c) improves property values and therefore the local tax base. However, there are very few studies that rigorously assess the economic impacts of UA (Hodgson et al. 2011).

Part of the challenge is that the overall volume and value of food produced in urban regions is unclear. USDA data are based on metropolitan areas, which include suburban and exurban as well as urban areas. Although over one-half of all farms with local food sales were located in metropolitan counties in 2008 compared with only one-third of all US farms, the extent to which these farms are located in urbanized environments is unknown (Low and Vogel 2011, Johnson et al. 2013, Jablonski and Schmit 2016).

Studies of economic impacts of UA show mixed results. Dimitri and colleagues (2016) provided the most comprehensive, peer-reviewed national study of UA operations that includes financial information. In total, 370 farmers responded to their 2015 survey, with 315 self-reporting operating an urban or periurban farm, 89 operating a community garden, and 34 operating both an urban farm and community garden. The respondents were located all across the country and reported average farm sales of $54,000
Fruit and vegetable consumption is important for meeting public health nutrition guidelines, and our case study suggests that UA can contribute to meeting these guidelines at a household level (box 1). However, recent evidence supports that daily total fiber intakes from staple foods such as whole grains and legumes are also critical indicators of overall health when compared with fiber that is primarily derived from fruits and vegetables (Park et al. 2011). Methods used for receiving and assessing nutritional intakes across the spectrum of UA activities warrant continued attention in public health because of potential inaccuracies and recall bias, including heavy reliance on self-reporting. Finally, there is a lack of reliable data on overall macronutrient (i.e., carbohydrates, protein, and fat) and micronutrient (e.g., iron, zinc, calcium, and phosphorus) intake from vegetables grown under different agricultural practices.

Environmental health is another facet of public health that can include but is not limited to measures of food safety (i.e., microbial and chemical contaminants). An emerging body of literature highlights the importance of comonitoring emerging environmental chemicals of concern, both agrochemicals and heavy metals such as lead (Pb) and cadmium (Cd). Determining the soil levels for Pb has raised concerns in multiple settings to date, and that could pose health risks, particularly if ingested by young children. Although growing garden crops in contaminated soils may increase dietary metals, the specific claims about health risks from urban soil concentrations for growing food are not always accurate because various chemical forms may have limited bioavailability and uptake by plants (Brown et al. 2016). In a study of 96 samples of produce from seven urban farms, three suburban farms, and three grocery stores in the San Francisco Bay Area in 2011–2012 (Kohrmann and Chamberlain 2014), Cd and Pb concentrations in produce from urban farms were not significantly different from produce from suburban farms or grocery stores. Although many urban garden soils may not have high levels of heavy metals and other toxins (Hough et al. 2004), the installation of raised beds with imported soils could be considered a limited exposure reduction method (Clark et al. 2008). Although raised beds may be a common strategy in areas with contaminated soils to avoid human health risks, this is not classified as a remediation technique. Testing soils for contaminants prior to establishing urban gardens or measuring toxicant loads in food can be expensive, leading to increased consumer costs. Practitioners of UA must balance the need for assessments of macronutrient and micronutrient quality (i.e., protein, vitamins, or minerals) and food safety (i.e., pathogen screening and contaminants).

Food safety measures, including postharvest processing and handling, can pose unintentional risks to public health and vary by food types in different urban locations. Producer education has gained increased attention over enforcing regulations. Practices to enhance food safety for fruits and vegetables, which are the most common food products from UA, may become more complicated if livestock rearing is integrated into the system. Given that food...
We conducted a case study of home gardening impacts in Fort Collins, Colorado, USA. We utilized gardening trend data (CoDyre et al. 2015) to design a typical 3.05 by 3.05 meter (10 by 10 feet; 9.3 square meter) raised bed garden. We then estimated productivity, yield, and nutritional value. We also estimated the capacity for land within city limits to supply residents’ entire fresh vegetable and egg intake.

Fort Collins has a population of 161,000 and a total of 36,222 single-family homes. Our example garden used common spacing guidelines (Rabin et al. 2012) and crop varieties predicted to have the best yield in Fort Collins (Shonle 2014). The crops selected were tomato, cucumber, musk melon, cabbage, potato, sweet potato, squash, peppers, bush peas, lettuce, spinach, kale, carrots, onions, and beets. High and low costs for seeds were approximated using prices listed by a major retail store and seed supplier (Home Depot and www.Burpee.com). The high and low costs of raised bed construction were calculated using information from Alabama Extension fact sheet no. ANR-1345 (supplemental table S1; Harris et al. 2012). The value of crops produced was gathered from the US Department of Agriculture’s Economic Research Service (Todd and Scharadin 2016), which tends to quote the lower end of price ranges, and multiplied by the estimated approximate yield for each crop grown in a home garden (Rabin et al. 2012). We did not include labor requirements in our economic estimates.

Our estimates suggest that the small garden plot could yield 18 kilograms of produce per season, or 16% of the recommended minimum of 110 kilograms of annual fruit and vegetable for a single person (Martellozzo et al. 2014, citing FAO/WHO). This quantity of produce translated to approximately $70 saved per year by not purchasing this produce at the supermarket (table 3). The cost of setting up a raised bed varied from (a) only the price of seeds if a homeowner used existing garden soil, homemade compost, and scrap building material to (b) $270 if basic materials were purchased new. Using our estimated yield of 2.8 kilograms per square meter, 100% of each Fort Collins resident’s minimum recommended vegetables could be met if 18% of the total unimproved land area of all the single-family residential home lots (34 million square meters) in the city were to be cultivated.

A single garden plot and a few hens contributed to an individual’s annual nutritional needs, providing 9.2% of protein, 23% of vitamin K, 20% of vitamin C, and smaller amounts of other nutrients and vitamins (see table 2). A family keeping a small flock of chickens could easily produce all their egg needs. To supply all of Fort Collins’ egg needs, each of the single-family residential homes in Fort Collins would need to keep approximately 5 laying hens. Including chickens in our calculations not only improved the potential for household gardens to provide nutritional benefits, it did so economically. We calculated initial purchase cost of a 6-month-old laying hen, replacement costs to ensure highest productivity, bedding, and feed costs, resulting in a cost of producing a dozen eggs to $2.75 and $3.92 for non-organic and organic varieties respectively (table 3; supplemental material). A survey of local retailers and farmers’ markets revealed prices for a dozen eggs from $1.25 for concentrated egg operations to as high as $8 for free-range organic. Although backyard chicken keepers could sometimes save money producing their own eggs, they typically choose to keep chickens for other reasons, such as to “establish sustainable backyard agro-ecosystems, build sociability, resist consumerism, and work simultaneously to improve the life and health of animals, humans, and the urban environment” (Blecha and Leitner 2014).

Conservation impact
Urban agriculture, in aggregate, has potentially large impacts, both positive and negative, on the conservation of biodiversity, water, and land. Agriculture (i.e., the land area and resources allocated to food and fiber production) contributes between 20% and 33% of global greenhouse gases (GHGs; IPCC 2007, Vermeulen et al. 2012), uses 70% of global freshwater supplies (FAO 2015) and 90% of mined phosphorus (Jasinski 2006), and is a major contributor to the more than 400 marine hypoxic zones worldwide (Diaz and...
Rosenberg 2008). These effects, in turn, have large impacts on biodiversity (Green et al. 2005). Urban agriculture could have an impact on carbon and water footprints, climate resilience, nutrient recycling and loading into surface waters, habitat value of urban landscapes for pollinators and other wildlife, and demand for land for food production elsewhere. These effects will depend on the location and methods of production. Despite these myriad effects, UA has been widely ignored by the conservation community.

Climate change and urban agriculture. Projected changes in climate, especially extreme weather events, threaten food security. Specifically, climate change can disrupt food availability, access, processing, storage, and consumption, especially for time-poor populations (Brown et al. 2015). Urban agriculture provides an alternative production source and diversifying food sourcing options can serve as a buffer to climate change variability that may disrupt trade and global food markets (Ostrom 2010).

In a thorough life cycle assessment of GHG emissions of urban household gardens, Cleveland and colleagues (2017) found that although producing vegetables in home gardens does create some GHG emissions, these emissions are more than offset by reducing the GHG footprint of consumers buying produce through the conventional agribusiness system. In addition, further GHG savings were realized when researchers accounted for lawn replacement, recycling gray water, and recycling organic household waste. However, home composting can produce methane and nitrous oxide, which are strong GHGs (Cleveland et al. 2017). Other studies that performed similar analyses for urban community farms also demonstrated reductions in GHG emissions compared with conventional systems, especially when vegetable production replaced lawns (Kulak et al. 2013, Fisher and Karunanithi 2014). In developed countries, postproduction processes such as storing, refrigerating, and transporting produce over long distances can contribute as much to the GHG emissions as do the actual production processes (Vermeulen et al. 2012). These postproduction emissions are reduced or eliminated when vegetables are grown where they are consumed, as in the case of UA.

Water impact. Agriculture accounts for the majority of current freshwater withdrawals (Scanlon et al. 2007, FAO 2015). The immense demands for water by agriculture impacts freshwater biodiversity through many mechanisms, including dam construction, dewatering of wetlands and rivers, reduced river flow to coastal areas, changes in the timing and intensity of flows, and aquifer depletion (Gordon et al. 2010). In dry climates, local agricultural production could have significant negative impacts on

### Table 2. Nutritional contribution of a 9.3-square-meter garden and 264 eggs for an average adult with a daily recommended intake of 2000 calories per day. See complete nutritional contributions in the supplemental material.

<table>
<thead>
<tr>
<th></th>
<th>Garden produce</th>
<th>Produce + 264 eggs</th>
<th>Percentage annual recommended of produce only</th>
<th>Percentage annual recommended of produce + egg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitamin K (µg)</td>
<td>6763</td>
<td>6789</td>
<td>23.2%</td>
<td>23.2%</td>
</tr>
<tr>
<td>Vitamin C (mg)</td>
<td>4571</td>
<td>4571</td>
<td>20.9%</td>
<td>20.9%</td>
</tr>
<tr>
<td>Vitamin A (IU)</td>
<td>259,052</td>
<td>321,884</td>
<td>14.2%</td>
<td>17.6%</td>
</tr>
<tr>
<td>Riboflavin (mg)</td>
<td>11</td>
<td>64</td>
<td>1.8%</td>
<td>10.4%</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>220</td>
<td>1680</td>
<td>1.2%</td>
<td>9.2%</td>
</tr>
<tr>
<td>Phosphorus (mg)</td>
<td>6044</td>
<td>29,012</td>
<td>1.7%</td>
<td>7.9%</td>
</tr>
<tr>
<td>Folate (µg)</td>
<td>5171</td>
<td>10,715</td>
<td>3.5%</td>
<td>7.3%</td>
</tr>
<tr>
<td>Vitamin D (IU)</td>
<td>0</td>
<td>9504</td>
<td>0%</td>
<td>6.5%</td>
</tr>
<tr>
<td>Vitamin B6 (mg)</td>
<td>27</td>
<td>47</td>
<td>3.7%</td>
<td>6.4%</td>
</tr>
<tr>
<td>Saturated fatty acids (g)</td>
<td>8</td>
<td>371</td>
<td>0.1%</td>
<td>5.1%</td>
</tr>
</tbody>
</table>

### Table 3. Potential costs, savings, and quantity produced in home gardens.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Annual production</th>
<th>Nutrition contribution</th>
<th>One-time costs</th>
<th>Annual production costs</th>
<th>Cost to buy at store</th>
<th>Annual savings or spending</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetables</td>
<td>9.3 m²</td>
<td>18 kg</td>
<td>16% of 1 person's annual vegetable needs</td>
<td>$0–$260 to set up garden bed</td>
<td>Approximately $20 for seeds</td>
<td>$70</td>
</tr>
<tr>
<td>Eggs</td>
<td>4 hens</td>
<td>900 eggs</td>
<td>340% of 1 person's annual egg consumption</td>
<td>$50–$300 to build basic coop</td>
<td>$252 for feed and bedding</td>
<td>$115</td>
</tr>
<tr>
<td>Organic eggs</td>
<td>4 hens</td>
<td>900 eggs</td>
<td>340% of 1 person's annual egg consumption</td>
<td>$50–$300 to build basic coop</td>
<td>$360 for feed and bedding</td>
<td>$600</td>
</tr>
</tbody>
</table>
limited local water resources, thereby arguing for importing water-intensive produce from wetter regions. Irrigation needs for conventional agriculture will only continue to grow, whereas UA has the potential to depend largely on collected rainwater in some regions (see box 2 below) and, furthermore, to reduce the use of water for processing, packaging, and transporting food. Collected rainwater, although generally of high quality (Bakacs et al. 2013), has some potential for introducing pollutants into the food supply (Lye 2009).

**Nutrient conservation and pollution.** Phosphorus (P) and nitrogen (N) fertilizer use has increased dramatically in the past century and is predicted to continue to do so (Tilman et al. 2001). The global nature of agricultural trade means that some soils are becoming P depleted, whereas excess P and N application is polluting water bodies in other regions. There is therefore a need to increase the recycling of nutrients to contain them within the systems in which they occur, thereby closing nutrient loops (Schipanski and Bennett 2011). The feasibility of food waste recycling is highly dependent on the distance between production and consumption activities because of the logistics and cost of transporting heavy food waste or composted materials. Urban agriculture can contribute to closing nutrient loops by composting and feeding vegetable wastes to animals and then applying animal (e.g., chicken) manures back to garden areas. Household food waste recycling also prevents such wastes from entering landfills. Distributed UA with chickens could improve nutrient recycling efficiencies relative to concentrated poultry operations that are often too far from a sufficient land base to economically distribute chicken manure at recommended rates to avoid nutrient pollution (Ribaudo et al. 2003).

The environmental impact of nutrient management practices in home gardens has not been extensively studied. Fertility management was rated as the most important management challenge for urban gardeners in New York City (Gregory et al. 2016), highlighting the need for collaborative research and education on urban garden

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**Box 2. Potential for rainwater collection to supply home gardens.**

Growing food locally is often touted as ecologically friendly, but how much water does a home garden require? We mapped the amount of additional water needed by a 9.3-square-meter vegetable garden if the owner collected rainwater and used it to water the crops. We determined the potential capacity of rainwater collection barrels to water a home garden on the basis of spatially explicit precipitation and evapotranspiration data. Using the Simplified Landscape Irrigation Demand Estimation method developed by the University of California Extension (Kjelgren et al. 2016) to determine the water need of a typical 9.3-square-meter home vegetable garden, we modeled the amount of supplemental water that would be needed by that garden using daily time steps. We used a water recharge model with a 0.42-cubic-meter (110-gallon) storage capacity (2 typical, home-use rainwater collection barrels) and a modest roof collection area of 93 square meters (1000 square feet). We used monthly precipitation (PRISM 2004) and evapotranspiration (IWMI 2016) data at daily time steps for 1 year.

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**Figure 2. Total water required to be added to garden from January to June (a) and from January to December (b). Only the western United States is shown because no water in addition to precipitation is needed in the rest of the country.**
nutrient management practices. Home garden effects on nutrient recycling and nutrient losses to the surrounding environment depend on the quantity, quality, and timing of manure and compost applications. Urban gardens and lawns can be a net sink of nutrients and carbon, particularly during early conversion from more degraded soils (Kaye et al. 2005). However, urban gardens can also become a nutrient pollution source if compost, manure, and other fertilizer applications exceed nutrient removal in harvested produce resulting in elevated soil P levels and N leaching losses (Dewaelheyns et al. 2013, Cameira et al. 2014). For example, average annual household food waste in the St. Paul–Minneapolis region of Minnesota contained approximately 300 grams of N and 36 grams of P (Baker et al. 2007). Applied to a 3-meter-by-3-meter raised garden bed as used in our case study (box 1), this would represent annual application rates of 337 kilograms of N per hectare and 39 kilograms of P per hectare, which would far exceed nutrient removal by harvested produce. Home gardens are often considered to have minimal impact on overall urban nutrient cycling and losses because of their limited spatial extent (Lin et al. 2014); however, this could shift with increased conversion of urban areas to fertilized gardens. Consequently, urban food waste nutrient recycling would benefit from (a) increased infrastructure, awareness, and education to reduce food waste, as well as (b) municipal
Biodiversity. Urban food gardens could contribute positively to conservation of biological diversity by increasing and improving habitat within urban areas, averting habitat loss elsewhere, contributing to crop diversity, and reducing pollution and nutrient loading. Replacing lawns with gardens increases habitat heterogeneity, which would be expected to increase wildlife diversity (Benton et al. 2003). These green spaces also provide seminatural habitats in the extensive human altered landscapes (Lin et al. 2015), especially for pollinators and species that benefit from small, patchy resources. For successful and sustainable UA, it is vital to maintain essential ecological processes such as pollination, nutrient acquisition and flow, and biological control of pests. Although leveraging the habitat value of large numbers of small plots can be a challenge, this can be overcome with effective, coordinated management (Goddard et al. 2010).

Home gardens in developing countries have long been considered hotbeds of crop diversity, with known links to dietary diversity and quality, but less is known about the contributions of urban gardens in more developed countries (Taylor and Lovell 2014). Widespread availability of stable cultivars in small seed packs removes the need to save seed from year to year or experiment with novel crosses. Despite the lack of incentive, novelty is a coveted trait in home garden products, and amateur plant breeders have formed organized groups and seed exchanges. Immigrant populations contribute to a unique form of germplasm conservation; for example, novel crosses between grocery store varieties of sweet corn and landrace maize cultivars have been found in the home gardens of Mexican immigrants residing in southern California (Heraty and Ellstrand 2016).

The problem of hunger is more one of poverty and access than of sufficient food produced (Schipanski et al. 2016). In addition, we do not efficiently use the food that we currently grow: One-third is wasted, and one-third becomes animal feed (Tscharntke et al. 2012). But a growing world population will necessitate additional land be converted to agriculture (Tilman et al. 2001), and converting lawns in urban areas rather than biodiverse habitat in developing nations could reduce agriculture's negative impact on biodiversity. Researchers predict that large amounts of land will be converted to agricultural uses from 2001 to 2050, a net projected increase of $5.4 \times 10^8$ hectares for pasture and $3.5 \times 10^8$ hectares for cropland (Tilman et al. 2001). Most of the associated habitat loss ($10^8$ hectares by 2050) will be in developing countries, whereas $1.4 \times 10^8$ hectares of land is projected to be removed from agriculture in developed nations (Tilman et al. 2001). Much of the food demand by developed nations results in losses to biodiversity in developing nations (Lenzen et al. 2012), with each dollar spent on agricultural products estimated to displace between 0.1–1 individual birds or mammals (Kitzes et al. 2016).

Furthermore, analyses suggest that many developed nations have enough land within urban areas to meet much of their food needs; for example, Martellozzo and colleagues (2014) found that the United States would need to use less than 10% of its urban land to meet all vegetable needs, and see our case study (box 1). Growing more food in urban areas of developed countries is also positively correlated with increased awareness of the environmental impacts of food production (Martinez et al. 2010).

Conclusions

This review indicates that UA could serve as part of a sustainable food system despite challenges and knowledge gaps. Carefully designed UA can provide conservation benefits, especially when it replaces lawns (e.g., box 2), but other conservation impacts are poorly understood and require more research. Although our Fort Collins case study (box 1) demonstrates that home gardens provide limited contributions to nutrition and money saving, the majority of farmers engaged in UA are motivated by social goals in addition to food production (Dimitri et al. 2016). Barriers to UA include access to suitable land for growing and gardening knowledge (Kortright and Wakefield 2011), time, and expense. Urban agriculture can also contribute to food security and encourage dietary intake of nutritious foods and strong social networks (Kortright and Wakefield 2011). Urban agriculture designed by diverse social, economic, and ethnic groups would likely have greater multifunctional societal benefits and potentially greater economic benefits. Improved public education could decrease UA public health risks in food safety and facilitate improved soil fertility management.

The question remains: Is UA an activity that society should encourage, through government subsidies, planning, nonprofit activities, and education? Both research and promotion of UA suffer from the “local trap,” which assumes that there is something inherently good about local-scale agriculture: that UA will promote ecological sustainability, social justice, nutrition, food security, and food quality (Born and Purcell 2006). In reality, the context of the system determines its benefits or downsfalls, and importantly, who benefits and who does not (Born and Purcell 2006).

Conventional wisdom tells us that large-scale agriculture will benefit from efficiencies of scale, but our interdisciplinary perspective points to the need for an assessment of multifunctional efficiency. That is, a system that can function to provide benefits across a variety of economic, societal, health, and environmental benefits while using currently underutilized resources can play a role in furthering societal goals. Urban home gardens use resources (land, water, nutrients, and human energy) that would otherwise be either unused, underutilized, or (in the case of waste) become pollutants or that produce positive externalities (using human energy in the garden in place of carbon energy in conventional systems produces health benefits and happiness).
from being outdoors). But other resources, such as tools and infrastructure, might end up costing more in terms of both money and resources for home production systems. The benefits are clearer when water, carbon, and human resources that have traditionally been directed toward lawns are instead directed toward food production: In these cases, we are producing additional food while still lowering the environmental impact of these lands.

The benefits of home gardens, in terms of food security, health, and income, have been well documented in developing countries (Taylor and Lovell 2014), but the impact of home and urban gardens in developed countries is underexplored. Further research is needed to determine how to maximize the positive and minimize the negative impacts of UA. A lack of data on small home gardens is a particular challenge for researchers and policymakers. In light of current pressures on food systems and successful examples such as Victory Gardens, when civilian populations were encouraged to produce food at home, the potential for home gardens to improve human health and nutrition, conserve or improve biological diversity, and reduce or mitigate food waste and pollution merits further evaluation.

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Supplemental material
Supplementary data are available at BIOSCI online.

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