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Urban Agriculture and Ecosystem Services: A Typology and Toolkit for Planners

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URBAN AGRICULTURE AND ECOSYSTEM SERVICES:

A TYPOLOGY AND TOOLKIT FOR PLANNERS

A Thesis Presented

by

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ABSTRACT

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This thesis makes the connection between urban agriculture and a specific suite of ecosystem services and lays out a typology and toolkit for planners to take advantage of these ecosystem services. The services investigated here are: food production, water management, soil health, biodiversity, climate mitigation, and community development benefits. Research from a variety of fields was aggregated and synthesized to prove that urban agriculture can be beneficial for human as well as environmental health.

A set of urban agriculture typologies was generated to illustrate best practices to maximize a particular set of ecosystem services. The typologies are: production farm, stormwater garden, soil-building garden, habitat garden, climate mitigation farm, cultural/educational garden, and ecosystem garden. Each typology was paired with a precedent study to demonstrate how that typology might be realized in the real world.

Finally, a toolkit for planners was assembled to demonstrate some tools and techniques that planners might use to implement urban agriculture as a strategy for providing ecosystem services. Planners can utilize the toolkit to insert themselves into the urban ecosystem at multiple scales in a creative way to apply best practices and urban

agriculture typologies in order to take advantage of the multiple benefits of urban agriculture.

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CHAPTER 1

INTRODUCTION

1.1 Overview

It is well-established that humans depend on goods and services from the natural environment in order to survive and thrive; even in cities, manmade systems that often seem devoid of nature, ecosystems both natural and artificial play an essential role in climate regulation, purification of air and water, cycling of water and nutrients, and other local and global processes necessary for human survival (Millennium Ecosystem Assessment, 2005). These processes, known as ecosystem services, are often grouped into four categories: provisioning services (e.g., food and fiber), regulating services (e.g., climate regulation, erosion control), supporting services (e.g., soil formation, oxygen production), and cultural services (e.g., recreational and health benefits) (Millennium Ecosystem Assessment, 2005). The high cost of providing these services artificially has proven a strong argument in favor of keeping ecosystems intact.

It is important to acknowledge the role that manmade ecosystems can play in providing ecosystem services. Although not ‘natural’ in the strictest sense, landscapes such as constructed wetlands and green roofs can restore certain ecosystem services previously provided by natural systems, especially in urban areas. Agricultural landscapes currently account for about a third of global land cover and are often viewed as destructive consumers of ecosystem services that contribute food and fiber at the expense of local wildlife habitat, water supply and quality, and soil health (Bringezu, et al., 2014). However, with conscientious design and sustainable management practices, agricultural systems can provide more ecosystem services than they consume and contribute to the health of the regional ecosystem. Repositioning agriculture, especially urban agriculture, as an element of a larger green infrastructure system may result in a network of agricultural systems that improve the health of the local ecosystem by providing ecosystem services and avoiding negative externalities. The first step will be to acknowledge the restorative and regenerative role that agricultural systems can play in landscapes where natural ecosystems have been severely disturbed by human activity, such as cities, and to implement best practices in the design of these systems to provide a diverse array of ecosystem services.

1.2 Project description and goals

The goal of this thesis is twofold: first, to make the connection between urban agriculture and ecosystem services through an analysis and synthesis of literature from various fields, and second, to provide planners and community groups with a typology and toolkit for implementing urban agriculture at the municipal level. The broader objective is to identify urban agriculture as an element of green infrastructure and facilitate its implementation as part of a wider strategy to improve the provision of ecosystem services in cities. With their regional perspective and long-term planning tools, planners are uniquely equipped to take advantage of urban agriculture’s many benefits and participate in building a more sustainable food system.

1.3 Limitations and delimitations

I approach this subject through the lens of planning, which necessarily takes a broad, long-term view of issues such as ecosystem health and urban development. As such, my investigation into the link between urban agriculture and ecosystem services does not delve too deeply into any one type of agriculture or any one ecosystem service. This thesis represents a broad, qualitative look at the link between agriculture and ecosystem services and the role planners and community groups can play in building a sustainable food system while maximizing ecosystem health.

I have chosen to focus on six specific ecosystem services: food production, stormwater management, soil building, biodiversity and habitat, climate mitigation, and cultural and educational benefits. As shown in , these six were gleaned from the literature as the services with the most robust connection to urban agriculture and are representative of the four categories of ecosystem services identified by the Millennium Ecosystem Service Assessment (MEA); these categories are provisioning services, regulating services, supporting services, and cultural services (2005). Other services that may potentially have a link to urban agriculture, including air quality, mitigation of the urban heat island effect, water purification and recycling, and mental and physical health benefits, are not discussed here.

Table 1: Ecosystem services selected for investigation

Category (from MEA)	Ecosystem Service
Provisioning	•Food production
Regulating	•Stormwater management •Climate mitigation •Biodiversity
Supporting	•Soil building
Cultural	•Cultural and educational benefits

Finally, I have limited myself to precedent studies and examples located in the United States; many precedents are located in the Northeast. Similarly, the typology and toolkit are geared towards planners and other professionals practicing in the social context and legal framework of the U.S.

1.4 Research questions and claims

Outlined below are the research questions I set out to answer, as well as the claims I make throughout the thesis, which are backed up by my research.

Questions: What ecosystem services can be provided by agricultural systems? What factors affect the ability of any agricultural system to provide these services?

> ***Claim:*** Agricultural systems can provide multiple benefits in addition to food production. These include water infiltration, soil regeneration, wildlife habitat, climate mitigation, and community revitalization and education.
>
> ***Claim:*** The ability of any agricultural system to provide these benefits will depend on various factors, including scale, climate, management strategies, species composition and diversity, watering and fertilizer regimens, and social context.

Questions: How can a new model of food systems planning incorporate all the various functions of agricultural systems, as well as the factors that affect those functions? How can different types of agricultural systems be categorized to assist policymakers with strategic food systems planning?

> ***Claim:*** Different types of agricultural systems, in different contexts, can provide different types of ecosystem services.

Question: What precedent studies can illustrate these typologies and effectively demonstrate a more modern model of food systems planning?

Claim: Food systems planning is an important issue for every city and town, but it will not take the same shape in every context.

Claim: Cities and towns can increase local food production and provide other ecosystem services as well by strategically selecting a variety of agricultural typologies to apply.

Question: What tools and techniques can planners and community groups use to effectively utilize urban agriculture to provide ecosystem services?

Claim: Traditional planning tools, such as land use regulation, financial and non-financial incentives, and zoning, can be used creatively to encourage the development of new urban agriculture initiatives and support existing urban farms and gardens.

1.5 Outline of chapters

Chapter Two is a review of the literature. This chapter delves into the history of urban agriculture as well as organic growing practices and identifies trends in food systems planning in the past, present, and future. A definition of ecosystem services is given, and a broad overview of the relationship between urban agriculture and ecosystem services is presented.

In Chapter Three I identify my methodology, which consists of an analysis and synthesis of findings from fields as diverse as ecology, agricultural science, urban planning, landscape architecture, construction technology, and climate science. Journal articles and grey literature sources from these fields provide evidence to back up my claim that urban agriculture can provide ecosystem services and support my recommendations for the toolkit and typology for planners and community groups.

Chapter Four is an exploration of the relationship between urban agriculture and six selected ecosystem services: food production, water management, soil health, biodiversity, climate mitigation, and community benefits. For each of these six categories, I identify the benefits of urban agriculture as well as potential limitations and risks and lay out best practices for maximizing ecosystem services and minimizing negative impacts of urban agriculture.

In Chapter Five, I synthesize the best practices laid out in Chapter Four into a set of urban agriculture typologies that can be utilized to optimize the provision of ecosystem services. Finally, Chapter Six presents a toolkit of techniques and strategies that planners and community groups can use to apply these urban agriculture typologies in the real world and take advantage of the many benefits of urban agriculture. Chapter Seven concludes with some highlights of my research and overarching recommendations for planners and community groups, as well as directions for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In order to understand the link between urban agriculture and ecosystem services, as well as the tools planners can use to operationalize this connection, it is important to review the history of agriculture in cities, the context and framework of food systems planning, and some background and definitions of ecosystem services. This review of the literature is therefore divided into three sections: the first explores the past, present, and future of urban agriculture and organic farming, the second broadly describes the relationship between ecosystem services and urban agriculture, and the third discusses the history of food systems planning as well as the present state of the field. Themes that emerge from the literature include a historical trend of renewed focus on urban agriculture and organic growing practices during times of crisis; the mobilization of urban farms and gardens throughout history as a strategy for not only producing food, but also for social and individual benefits; a strong connection between agriculture and ecosystem services, especially for small-scale organic agriculture systems such as those often found in cities; and a need for greater integration of urban agriculture systems and ecosystem service monitoring and research.

2.2 Urban agriculture and organic farming: Past and future trends

2.2.1 Historic context of urban agriculture and organic farming

The concept of growing food in cities is not a new one; in fact, ancient civilizations including the pre-Columbian Maya (1000 B.C.E.—1500 C.E.) and Byzantine Constantinople (500 B.C.E.—1500 C.E.) subsisted on a combination of food grown within city limits and food acquired through trade with neighboring cities (Barthel & Isendahl, 2013). In both cases, responsible stewardship of the land by city residents, a diversity of food production options within the city, and the prevalence of 'memory carriers' to pass agricultural knowledge from one generation to the next contributed to the resilience of these long-lasting centers of power in times of war and crisis (Barthel & Isendahl, 2013).

In the United States, urban garden programs became prevalent as early as the 1890s, partly as a response to the Industrial Revolution and an economic depression in 1893. As the poor flooded into the city from the countryside and failed to find factory jobs, vacant-lot cultivation associations began forming as an alternative to charitable giving. The prevailing attitude at the time was that the poor should be put to work, not only to help them feed themselves but also as a way to build moral character; this may be viewed as an early acknowledgement of the ability of urban gardens to provide social services as well as food production (Lawson, 2005).

During this period, the development of urban gardens also gained momentum due to the City Beautiful movement; gardens were seen as a way to counteract the sanitation issues, aesthetic ugliness, and social ills arising from the rapid urbanization that occurred during the Industrial Revolution (Lawson, 2005). Here again, urban agriculture was identified as a strategy for providing ecosystem services like cultural enrichment and mental health benefits. School gardens also became popular at this time; the federal Bureau of Education even established an Office of School and Home Gardens to provide healthy after-school activities and instill a love of nature in the nation's schoolchildren (Lawson, 2005).

The emergence of organic farming techniques represents an acknowledgement of the relationship between agricultural systems and the natural environment and can be viewed as a step towards the incorporation of ecosystem services into the field of agriculture. The organic farming movement traces its roots back to the mid-19th century, when some scientists began objecting to findings by their peers that artificial 'manures' or fertilizers could augment or replace organic manures. As early as the 1840s, German chemist Justus von Liebig published a monograph arguing this case, and a factory producing artificial fertilizer opened in London, prompting the beginning of a debate over the relative merits of artificial and organic growing techniques that persists even today (Conford, 2001).

Early experiments in organic agriculture demonstrated the link between disease resistance in cattle and a diet of grass, grain, and silage grown from organic soil (Howard & Wad, 1931), as well as the connection between the robust health of a remote tribe in India and their healthy diet and organic agricultural practices (McCarrison, 1961). Modern experiments have substantiated these findings, and have gone on to find that organic agriculture has benefits for a wide spectrum of ecosystem services, including soil health, erosion control, pollination, and watershed health (Sandhu, Wratten, & Cullen, 2010).

Urban gardening in the United States experienced another boost during the early 20th century, although the connection had not yet been made between organic cultivation practices and urban farms and gardens. The ‘war garden’ campaign of World War I saw widespread conversion of ‘slacker land’ in cities to food gardens to help combat food shortages in Europe (Lawson, 2005). During the Great Depression following the First World War, relief gardens also briefly came back into vogue, both as a way to put the unemployed to work and to provide subsistence for needy families (Mok, et al., 2014).

Perhaps the best-known and most successful movement to promote urban gardening in the United States was the victory garden campaign during World War II. At their peak, there were more than 20 million victory gardens across the country that were responsible for over 40 percent of vegetable production nationwide; all told, over one million tons of vegetables were produced during the war (The National WWII Museum, 2015). School gardens played an important part in this program (Lawson, 2005). However, interest in gardening waned in the years after the war, and it was also during this period that the widespread use of refrigerated train cars and trucks to ship food allowed the food system to become increasingly global and industrialized.

In spite of declining interest in small-scale food production, the environmental movement of the 1960s brought a renewed interest in the merits of organic farming practices and an expansion of the debate to include not just the origin of the amendments farmers added to the soil, but also the broader applications of ecological science to farming (Beeman & Pritchard, 2001). As one author put it,

> "In the 1930s and 1940s, the crisis of the soil appeared to threaten American civilization. In the 1960s and 1970s, a wider and deeper ecological crisis of the land appeared to threaten the very survival of humanity. At both times, critics cited misguided technology as a major obstacle to building a new, ecologically oriented husbandry, and they looked to ecology as a scientific and ethical guide for piecing together the new farming" (Beeman & Pritchard, 2001, p. 101).

Hints of this emphasis on the connection between agriculture and ecology can be seen in modern agricultural movements and a renewed interest in urban agriculture that has cropped up in the last several decades.

2.2.2 Urban agriculture: Present and future

Food production in cities reached its historical zenith in the United States during the 1940s, but in more recent years urban gardening has been bolstered by the environmental movement that began in the 1960s. Spurred by the oil crisis and rising food prices of the 1970s and by concern over global climate change trends in the 1990s and 2000s, urban gardens have become the sites of community development and grassroots activism, where the goal is often not just food production, but also education and community building (Lawson, 2005).

Today's urban gardens take many forms. In the United States, community gardens are spaces managed by government or non-profit agencies where neighborhood residents may either work an individual plot of land or collaborate to care for the entire garden (Taylor & Lovell, 2014). This is perhaps the most frequently studied type of garden in the United States; nevertheless, private gardens and farms, including large commercial farms and smaller home gardens, also form an important part of the urban green mosaic (Taylor & Lovell, 2014).

As the urban agriculture movement continues to evolve, several visions of its future have been predicted. Perhaps the most high-tech prediction envisions skyscrapers made of glass in which food is grown hydroponically. This technocratic approach, commonly called ‘vertical farming,’ would eliminate the need for food transport and enable year-round production (Torreggiani, Dall'Ara, & Tassinari, 2012; Despommier, 2010), but very little peer-reviewed research exists to support its feasibility (Mok, et al., 2014). On the other end of the spectrum, permaculture advocates envision a low-tech future for urban agriculture in which food is grown on every available surface in the city, but the only inputs are human and animal energy, organic soil amendments, and sunlight (Mollison & Holmgren, 1978). It is unclear whether either of these solutions, or perhaps some hybrid of the two, will prevail, but with the world’s population becoming increasingly urban, some form of urban agriculture will likely manifest in every city around the world in the future. Widespread acknowledgement of the scientific connection between urban agriculture systems and ecosystem services will foster urban farms and gardens that supply ecological benefits in addition to food production.

2.3 Ecosystem services and urban agriculture: An overview

2.3.1 What are ecosystem services?

Ecosystem services are the benefits obtained by people from ecosystems (Millennium Ecosystem Assessment, 2005, p. 27). These benefits are commonly categorized into four groups: provisioning services, regulating services, cultural services, and supporting services.

> “Provisioning services are the products people obtain from ecosystems, such as food, fuel, fiber, fresh water, and genetic resources. Regulating services are the benefits people obtain from the regulation of ecosystem processes, including air quality maintenance, climate regulation, erosion control, regulation of human diseases, and water purification. Cultural services are the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences. Supporting services are those that are necessary for the production of all other ecosystem services, such as primary production, production of oxygen, and soil formation” (Millennium Ecosystem Assessment, 2005, p. 29).

Until recently, agriculture was generally considered to be a threat to the provision of ecosystem services; conversion of natural ecosystems to farmland often results in a reduction of biodiversity and the release of greenhouse gases including CO_2 and nitrous oxide (Millennium Ecosystem Assessment, 2005). However, researchers and practitioners have recently begun to recognize that agricultural ecosystems can be managed to maintain or even improve the provision of ecosystem services (Power, 2010).

> "In maximizing the value of provisioning services, agricultural activities are likely to modify or diminish the ecological services provided by unmanaged terrestrial ecosystems, but appropriate management of key processes may improve the ability of agroecosystems to provide a broad range of ecosystem services" (Power, 2010, p. 2960).

Although this report will focus on the ecosystem services provided by agricultural systems, it is important to bear in mind that farms and gardens are also consumers of ecosystem services, and may in fact be the cause of certain dis-services (such as nutrient loading of local waterways, loss of biodiversity, etc.) (Zhang, Ricketts, Kremen, Carney, & Swinton, 2007; Power, 2010). The complex relationship between urban agriculture and ecosystem services is discussed in greater depth below.

2.3.2 What ecosystem services can agriculture provide?

Naturally, the provision of food and fiber is the primary function of most agricultural systems and is an extremely important ecosystem service. However, agriculture can provide many other types of ecosystem services as well, especially when urban agriculture systems and systems that use non-conventional growing techniques are considered (Clark & Nicholas, 2013; Sandhu, Wratten, & Cullen, 2010). Wildlife habitat is perhaps the most well-known and well-researched of these; studies have shown that, while all urban green spaces serve an important function for urban wildlife, urban gardens are especially rich in biodiversity (Andersson, Barthel, & Ahrné, 2007; Gardiner, Prajzner, Burkman, Albro, & Grewal, 2014; Matteson & Langellotto, 2010). Urban agriculture has also been shown to provide water management and soil regeneration benefits; one study even found that some soil qualities adversely affected by conventional agriculture are maintained in urban community gardens (Edmondson, Davies, Gaston, & Leake, 2014).

The provision of these and other services is heavily dependent on garden-specific factors such as climate, management techniques, plant species composition, and local context. Many researchers have found that, while conventional, industrialized agricultural systems characterized by monoculture fields and mechanized growing and harvesting practices have few functions apart from food production and may in fact produce ecosystem disservices (EFTEC, 2005), agricultural systems that use unconventional techniques, including permaculture and other sustainable growing systems, contribute a wide array of ecosystem services (Sandhu, Porter, & Wratten, 2013; Deutsch, Dyball, & Steffen, 2013). Urban farms and gardens often utilize these unconventional growing techniques due to their uniquely small scale and urban context. Although these systems may produce less food than a conventional farm, the other ecosystem services they provide make them a worthwhile cause for planners and other food system professionals to fight for.

2.3.3 What ecosystem services does agriculture require?

The concept of ecosystem services is most often discussed in the context of natural environments, such as forests or wetlands, rather than artificial ones, such as farm fields or urban vacant lots, and indeed, all agricultural systems depend on ecosystem services provided by these natural environments in order to function. For example, nutrient cycling is a natural process that maintains soil fertility with the help of microorganisms and natural geochemical processes (Zhang, Ricketts, Kremen, Carney, & Swinton, 2007). Other examples of supporting services required by agricultural systems include water provision and maintenance of genetic biodiversity for breeding crops and livestock (Power, 2010).

Agricultural systems also depend on regulating services from the surrounding natural landscape. These services include pollination and pest control provided by insects and other animals in the surrounding ecosystem (Power, 2010), the purification of water as it travels through the watershed on its way to the farm field, and atmospheric regulation and larger climate patterns (Zhang, Ricketts, Kremen, Carney, & Swinton, 2007).

2.3.4 What ecosystem dis-services can agriculture cause?

In addition to providing beneficial services, agriculture can also cause certain ecosystem dis-services. The negative impacts of these dis-services depend heavily on the types of crops or livestock being raised as well as the management techniques of the particular farm in question; for example, excessive use of synthetic fertilizers results in nutrient loading in streams and contribution of nitrous oxide, a powerful greenhouse gas, to the atmosphere, but farms that use non-synthetic fertilizers and efficient fertilizer application techniques can avoid these negative impacts (Millennium Ecosystem Assessment, 2005).

Pollution and waste of water resources is another negative effect of agriculture systems; irrigation systems worldwide use about 20 to 30 percent of the world's available water resources, but only 40 to 50 percent of that water is actually used in crop growth due to inefficiencies of distribution and application (Millennium Ecosystem Assessment, 2005). Again, factors such as the scale and management techniques of the individual agricultural system are extremely important in determining the potential for ecosystem dis-services; a small urban garden that uses no-till techniques and organic fertilizers will have a much smaller ecological footprint than a large rural farm that relies on mechanized equipment and synthetic fertilizers. Planners and policymakers can insert themselves into the food system in order to discourage agriculture systems that produce excessive ecosystem dis-services and promote those that provide benefits for the health of humans and the environment.

2.4 Food systems planning: Past and future trends

2.4.1 Historic context of food system planning

Although "food system planning" is a term that has only appeared in the past two decades, food has always been a crucial consideration in the location and development of cities and towns. In the United States, colonial settlements were necessarily organized around agricultural fields, and overseas trade of agricultural products contributed to the development of cities more than any other factor (Vitiello & Brinkley, 2014). A century later, architects and planners grappled with the issues caused by the Industrial Revolution, including the loss of agricultural land to urban expansion and the lack of space for home gardening in newly-teeming cities (Vitiello & Brinkley, 2014). Today, planners' renewed interest in food system issues can be attributed in part to the close connection between food and sustainability.

The field of food system planning began coalescing during the 1990s, but it was, and still is, a somewhat haphazard undertaking. In their seminal 1999 article, Kameshwari Pothukuchi and Jerome Kaufman describe the piecemeal approach to food systems taken by city planners, business owners, and non-profit organizations to date:

> "Knowledge about the city's food system is like the proverbial elephant and the six blind men – each describes the whole by the part they know best. Hunger prevention organizations may see hunger as the key issue. The city's public health department may see raising public consciousness about nutrition and diet as most important. Groups involved in promoting an alternative food system may see the conventional food system as the chief stumbling block to a more sustainable food system. And the food store and restaurant owners may wonder why there is concern about the present food system since most of them probably believe that the conventional food sector provides sufficiently affordable, accessible, and adequately nutritious food" (Pothukuchi & Kaufman, 1999, p. 218).

Although the field has progressed in the past fifteen years, contemporary literature on food systems planning still seems to reflect this pattern of fragmentary research. Planners with a social justice bent may focus on food access and affordability, while community development planners may view urban gardens as an opportunity for education and job training without regard for the sustainability of growing practices. Food is an issue that touches on many aspects of planning, including environmental sustainability, social equity, community development, land-use planning, and many others, but planners often struggle to address all these issues at once.

2.4.2 The role of the planner in building the modern food system

The place of food on the planners' agenda has been more formally recognized in the past few years. In 2007, the American Planning Association (APA) released a report called "Policy Guide on Community and Regional Food Planning." Drawing heavily on Pothukuchi's 1999 and 2000 articles about food systems planning, the APA describes the dearth of food systems research in the planning field and proceeds to outline general policies for community and regional food planning. Although broad in its recommendations, the report is a milestone in food systems planning; the APA explicitly advocates for the inclusion of food systems analysis in comprehensive plans, the creation of local food policy, and the linking of food systems with more traditional planning sectors like transportation and economic development (American Planning Association, 2007).

Some commonly used tools to assess the sustainability and equity of the food system include foodshed assessment, food miles and ecological footprint, and food access analysis. Foodshed assessment maps the area of land that would be needed to feed the entire population of the study area, usually a city or region (British Columbia Ministry of Agriculture and Lands, 2006; Peters, Wilkins, Fick, Bills, & Lembo, 2009). The concept of food miles, closely related to the concept of ecological footprint, is the distance food travels from farm to table and often serves as a proxy for the amount of fossil fuels consumed by the food distribution system (Paxton, 1994). Food access analysis focuses on the environmental justice implications of food systems planning, measuring factors that affect the ability of city residents to access healthy food (Gordon, et al., 2011). Each of these methods has its strengths and weaknesses, but none focus specifically on strategies for implementing urban agriculture or the connection between agriculture and ecosystem services. A more comprehensive framework of food systems planning that acknowledges the multiple benefits that can be provided by urban agriculture is needed.

2.5 Conclusion

Throughout American history, food has been an extremely important consideration in the development of cities. Although food system planning has only recently been formalized as a sub-discipline within planning, urban agriculture has a long history as a strategy for providing benefits such as food production, social cohesion, and mental health benefits. Urban agriculture has recently been shown to have significant potential to provide ecosystem services, and organic growing practices are proven to provide ecological benefits as well. Modern food system planning methods can benefit from an ecosystem services framework that acknowledges the importance of urban agriculture and the multiple benefits it can provide.

CHAPTER 3

METHODOLOGY

In order to accomplish my research goals, I used a multi-disciplinary mixed-methods approach, combining a thorough review and synthesis of scholarly articles and grey literature with the application of relevant examples and precedent studies. First, I identified six distinct categories of ecosystem services on which to focus: these are food production, stormwater management, soil health, biodiversity, climate mitigation and adaptation, and cultural and educational benefits. These categories emerged from an initial review of the literature as the services most pertinent to urban agriculture.

In order to establish the scientific connection between these services and urban farms and gardens, I mined scholarly articles from journals for the fields of urban planning, landscape architecture, ecology, construction technology, climate science, environmental justice, agricultural science, soil science, and many others. I also used several sources of grey literature, including publications by the United Nations Environmental Program, the Freshwater Society, the Center for Neighborhood Technology, and other non-profit and governmental agencies, as well as books published by researchers in the fields of ecology and agricultural science. I synthesized findings from all of these sources to reveal a robust connection between urban agriculture and ecosystem services. I also identified a set of best practices that were consistent across multiple sources for maximizing the provision of ecosystem services.

Next, I synthesized these best practices into a set of urban agriculture typologies. Each typology exemplifies a set of best practices for maximizing a particular ecosystem services, such as climate mitigation or biodiversity. I found precedent studies to illustrate a real-world example of each typology. The precedent studies I selected are all located in the United States, and most are in New England and New York. My research for these precedent studies was conducted partly through direct observation and informal conversations with the farmers involved with each project, partly through scholarly articles and newspaper and magazine articles, and partly through news articles posted on the organization's own website.

Finally, I assembled a toolkit for planners and other food system actors interested in implementing these urban agriculture typologies for the ecosystem services they can provide. The tools and techniques I identified came from a variety of sources, including grey literature publications from the American Planning Association and other organizations as well as scholarly articles from law reviews and planning journals. I also identified examples of cities and regions that have implemented some of these tools, using municipal comprehensive plans, regional food security plans, city zoning ordinances, and other official documents to demonstrate the real-world utility of these techniques. The toolkit represents a synthesis of all my research and should be an avenue for planners to implement urban agriculture as a tool for providing ecosystem services in the city.

CHAPTER 4

ECOSYSTEM SERVICES OF URBAN AGRICULTURE

4.1 Introduction

The relationship between urban agriculture and ecosystem services is one of give and take. Much research has shown that agricultural systems, including those in cities, depend upon services provided by natural ecosystems; these include supporting services such as nutrient cycling and genetic biodiversity as well as regulating services like water purification and habitat for beneficial insects (Zhang, Ricketts, Kremen, Carney, & Swinton, 2007). Poorly managed agricultural systems tend to degrade these services. Some examples of the ecosystem 'dis-services' caused by agriculture include habitat degradation, nutrient loading and pollution of local waterways, and greenhouse gas emissions from on-farm activities (Power, 2010). However, with conscientious design and planning, agricultural systems can also be providers of ecosystem services that positively impact both human health and environmental integrity. Six services are identified here as potential benefits of urban agriculture: food production, water management, soil health, biodiversity, climate mitigation, and community development benefits. Table 2 identifies the benefits urban agriculture can provide for each of these services, as well as potential limitations and dis-services that may be caused by urban agriculture. Although limitations exist on the ability of urban agriculture to provide these services, a selection of best practices can be employed to maximize the benefits of urban agriculture for human and environmental health.

Table 2: Summary of the ecosystem services and potential limitations and risks of urban agriculture

Ecosystem service	Benefits of urban agriculture	Limitations and potential dis-services of urban agriculture
Food production	•Intensive management practices can improve productivity of urban farms and gardens •Urban agriculture can improve food security for low-income families	•Municipal food self-sufficiency using urban agriculture is unlikely and in many cases impossible •Some gardeners may spend more growing food than they would buying it at the store
Water management	•Urban agriculture practices reduce stormwater runoff, resulting in reduced peak flows and higher base flows in streams •The presence of pervious surfaces reduces the likelihood of CSOs in combined sewer systems •Groundwater recharge is facilitated by urban agriculture systems	•Like rural farms, urban agriculture is a potential source of non-point source pollution •There is a small chance of erosion of topsoil from urban farms and gardens
Soil	•Urban agriculture is associated with increased soil nutrient content (SOC, C:N, TN) •Urban agriculture decompacts soil, or reduces soil bulk density •The soil food web in urban farms and gardens supports beneficial biocontrol interactions	•Conversion of vacant lots to urban gardens may initially disturb existing soil food webs •The potential exists for toxins in soil to contaminate food grown in urban gardens
Biodiversity	•Farms and gardens provide habitat for insects, birds, microbes, and some mammals in the city •Urban agriculture contributes to improved connectivity of the larger matrix of green space •Beneficial species such as seed-dispersers, pollinators, decomposers, and species that prey on pests inhabit urban farms and gardens	•Conversion of forest or meadow land to agriculture may result in loss of biodiversity •Some species fare better in vacant lots than urban gardens •Generalist species usually fare better in urban gardens than specialists •Farms and gardens must form part of a larger green network

Table 2 continued

Ecosystem service	Benefits of urban agriculture	Limitations and potential dis-services of urban agriculture
Climate mitigation	•Small-scale organic farming techniques release less emissions than large-scale mechanized farming practices •Soil and woody vegetation sequester carbon •Producing food closer to where it is consumed may reduce GHGs from the transport sector •Potential exists for adaptation and 'co-development' benefits, including improved food security and reduced vulnerability to climate effects for city residents	•In some cases, emissions due to transport may be higher for 'locally-grown' food due to the economies of scale enjoyed by large-scale farming and distribution systems •Emissions from transportation are only a small percentage of total emissions from the food supply chain; all stages of the chain must be considered
Cultural/ educational benefits	•Urban gardeners experience health benefits from a more nutritious diet •Adults and children can gain skills and knowledge by working in the garden •Participating in urban agriculture empowers marginalized groups and facilitates the formation of social networks •Urban agriculture can serve as a planning tool to fill vacant spaces in the city	•Urban farms and gardens may be viewed as an 'eyesore' or a nuisance by neighbors •Care must be taken to avoid positioning urban agriculture as a conflicting land use

4.2 Food production

The implicit goal of most urban agriculture systems is food production; however, unlike large rural farms, which are generally geared exclusively to this purpose, urban agriculture programs often have secondary goals in addition to food production. For some programs, food production is itself secondary to other objectives, such as community development, youth education, or aesthetic expression. For this reason, and because of the small scale of many urban agriculture systems, a lively debate surrounds the question of urban agriculture’s role in food security, especially in the developing world. Some scholars have estimated that urban farms and gardens could have a significant impact on improving food security, especially for the urban poor (Zezza & Tasciotti, 2010; Algert, Baameur, & Renvall, 2014), while others have dismissed the potential contribution of urban agriculture as negligible (Badami & Ramankutty, 2015).

The debate over urban agriculture's capacity for large-scale food production is largely hypothetical; very few cities in the world have enough farms and gardens within city limits to even approach maximum production capacity. However, some important lessons may be gleaned from the literature, as well as best practices for maximizing the food production capacity of urban farms and gardens.

4.2.1 The food production benefits of urban agriculture

One method for estimating the potential food production capacity of urban agriculture systems involves envisioning a total transformation of all vacant land and open space in the city into agricultural land. Using this method, one study found that the city of Cleveland, Ohio could grow enough produce within city limits to meet 100 percent of its population's needs, and enough poultry and eggs to meet 94 percent of its needs (Grewal & Grewal, 2012); another, in the city of Burlington, Vermont, found that over 100 percent of the population's recommended intake of fruit could be met using urban food forestry techniques (Clark & Nicholas, 2013). However, both studies assumed widespread conversion of urban rooftops, vacant lots, and residential lawns into agricultural uses, and both called for intensive growing techniques to make these scenarios feasible. These extreme scenarios are unlikely to manifest in the near future, but they serve as a powerful argument for comprehensive planning for agriculture systems in the city over a more piecemeal approach.

In spite of the fact that large rural farms have an economy of scale when it comes to monoculture production, they are often less spatially efficient than smaller farms that are more intensively managed. As a result of certain biointensive practices, including intercropping and intensive management, urban gardens often produce higher yields per square foot than conventional agricultural systems; one study estimated that urban gardens produced 0.75 lbs./ft^2 of vegetables, compared to 0.60 lbs./ft^2 in a conventional farming system (Algert, Baameur, & Renvall, 2014). Food grown on urban plots is therefore more spatially efficient than food grown in conventional farm fields, both in terms of yield per unit area and in terms of the length of the supply chain from farm to table.

While it may be unlikely that an entire city will ever subsist entirely on produce grown within city limits, at the scale of the individual household or neighborhood, urban agriculture can have a significant impact on food security. Although a poor household's participation in urban gardening does not always contribute greatly to household income, urban agriculture has been shown to increase both dietary diversity and calorie consumption, two important measures of health and food security (Zezza & Tasciotti, 2010). Urban agriculture, though certainly not sufficient to feed an entire city on its own, may nevertheless be an important component of food security, especially for the urban poor.

4.2.2 Limitations of an urban agriculture model for food production

As mentioned previously, although food self-sufficiency is hypothetically possible for some cities, it would require such a radical change in land uses and attitudes towards food production as to be virtually impossible, or at least possible only on a very long time-scale (Grewal & Grewal, 2012). Further complicating the issue is the fact that not all cities are created equal; biophysical conditions will of course affect the feasibility of implementing urban agriculture to improve food security, but so too will socio-economic conditions. Although urban agriculture may have a significant impact on improving food security for the urban poor in more developed countries, that impact will be negligible in cities with larger populations of poor people; the nutritional needs of the urban poor in these cities are simply too great to be met by urban agriculture alone (Badami & Ramankutty, 2015). This is not to say that urban agriculture will not have a positive effect on nutrition and health for people living in cities, merely that it cannot solve a problem as complex as urban poverty on its own.

Another measure of the capacity of urban agriculture systems for food production is cost-efficiency. The question of whether urban farms and gardens are more cost-effective for the gardener than participating in the conventional food system is heavily context-dependent. One study found that community garden plot holders and backyard gardeners in San Jose, California saved over $400 per plot over the course of a growing season by growing their own produce (Algert, Baameur, & Renvall, 2014); another found that city gardeners in Guelph, Ontario actually spent more money growing their own vegetables than they would have spent had they purchased those same vegetables at the grocery store (CoDyre, Fraser, & Landman, 2015). Naturally, the cost-effectiveness of producing food in a backyard or community garden as opposed to purchasing the same food from the grocery store will depend on the crops produced, as well as the type of food being replaced by own-grown produce. Certain best practices, outlined below, contribute to both the yield and the cost-effectiveness of urban farms and gardens. The most important factor appears to be the skill of the gardener, indicating that widespread urban gardening training programs could increase the capacity of urban agriculture to contribute to food security and cost savings for city residents (CoDyre, Fraser, & Landman, 2015; Algert, Baameur, & Renvall, 2014).

4.2.3 Best practices for maximizing food production in the city

While urban agriculture is already comparatively spatially efficient in terms of yield per unit area (Algert, Baameur, & Renvall, 2014), the use of certain intensive management techniques, including intercropping, vertical stacking, and soil building, can increase the spatial efficiency of urban gardens (Algert, Baameur, & Renvall, 2014). The very fact that urban gardens differ so much from conventional farm fields in terms of crop diversity, spatial arrangement, and scale means they are more likely to benefit from the farmer's local ecological knowledge and values. Hence, gardener skill is an extremely important factor in the success of urban farms and gardens (CoDyre, Fraser, & Landman, 2015).

An extreme example of this concept may be seen in permaculture systems, including urban food forestry systems. In contrast to conventional monoculture fields, these systems use techniques such as companion planting and intercropping, which both increase the biodiversity of the system as well as increase the overall yield and improve the resilience of the system to disturbance (Mollison & Holmgren, 1978; Clark & Nicholas, 2013). As defined by founders Bill Mollison and David Holmgren, permaculture systems embrace the multiple benefits of managing the land in this way, and as such are not geared exclusively towards food production (1978). Nevertheless, these systems are much more spatially efficient at producing food (and providing other ecosystem services besides) than conventional agricultural systems; the limiting factor is labor, as these systems are much more time- and labor-intensive to design and maintain (Clark & Nicholas, 2013; Zainuddin & Mercer, 2014).

4.3 Water management

Stormwater management is a major challenge for all major cities; the large amount of impervious area, including roofs, roads, and sidewalks, prevents rainwater from infiltrating into the ground, which leads to problems ranging from depletion of groundwater and higher peak stream flows to pollution of the local watershed by combined sewer overflows (CSOs) (Novotny, Ahern, & Brown, 2010). However, designers and policymakers are increasingly shifting their perspective to 'see the problem as a solution,' in the spirit of permaculture founders Bill Mollison and David Holmgren (1978); as one author put it,

> "The problem is not that urban areas produce excessive quantities of stormwater. On the contrary stormwater is a resource. The problem redefined is that urban areas have a deficit of beneficial uses for the runoff they shed" (Liebman, Jonasson, & Wiese, 2011, p. 240).

These beneficial uses might include irrigation of decorative or edible landscapes, or even reuse of stormwater as drinking water (after treatment) (San Francisco Public Utilities

Commission and Water Resources Engineering, Inc., 2011). Urban agriculture may be one strategy for putting excess stormwater in cities to good use.

4.3.1 The benefits of urban agriculture for stormwater management

In addition to the large amount of impervious surface in cities, soil and other supposedly pervious materials are often compacted and disturbed in urban areas, which can impair their ability to infiltrate water. Urban agriculture can be a solution to this problem on multiple fronts; adding soil and vegetation to formerly impervious surfaces such as rooftops and parking lots can slow down stormwater and reduce runoff (Center for Neighborhood Technology, 2010), while installing gardens on vacant lots, especially those with disturbed soils, can improve infiltration of rainwater into the ground (The Freshwater Society, 2013). Adding compost and tilling the soil can greatly improve the ability of soil to slow down and infiltrate stormwater, which improves the health of the watershed by decreasing peak storm flows, increasing base stream flows, and recharging groundwater (Olson & Gulliver, 2011; Glanville, Richard, & Persyn, 2003; Harrison, Grey, Henry, & Xue, 1997).

In addition to facilitating the passive infiltration of stormwater into the ground, urban agriculture systems may also serve a more active role in stormwater management schemes by using rainwater captured from surrounding roofs for irrigation purposes. Liebman et al. (2011) found that a neighborhood-scale rainwater catchment system could be constructed in conjunction with edible gardens and permaculture systems to reduce runoff while improving the sustainability of the local food system. The concept of ‘virtual water’ expresses the idea that food and other goods require water as part of the production process, and that this ‘embodied’ water is often not accounted for when calculating the daily water usage of an individual or community (Hoekstra & Chapagain, 2011; Liebman, Jonasson, & Wiese, 2011). Using locally captured stormwater to grow food can improve the sustainability of a community’s food system by reducing both food miles and virtual water usage (Liebman, Jonasson, & Wiese, 2011).

Although stormwater has great potential to be used for irrigation of edible crops in the city, the use of ‘first flush’ systems, which divert the first inch or so of water to avoid a ‘flush’ of pollutants from roofs and other surfaces, as well as frequent water quality testing are important practices to avoid contamination of food plants with toxins from the urban environment (The Freshwater Society, 2013). In spite of the potential initial costs of implementing catchment systems, the synergies between rainwater catchment and urban agriculture make for an extremely cost-efficient system; rainwater that would otherwise have to be treated is used as irrigation that would otherwise have to be paid for.

In addition to the potential for urban agriculture to utilize unwanted excess stormwater runoff, there are also potential synergies between urban agriculture and wastewater recycling systems. Treated greywater, and even treated effluent, may be used as a nutrient-rich source of irrigation for urban agriculture, provided certain safety measures are followed (Moglia, 2014). These measures include frequent water testing and drip irrigation lines that ensure the water does not come in contact with humans, animals, or leaves or other above-ground parts of the plants (San Francisco Public Utilities Commission and Water Resources Engineering, Inc., 2011). Implementation of decentralized agriculture systems that use treated wastewater from the local neighborhood for irrigation would serve multiple functions and improve the resilience of the system as a whole (Nhapi, 2004).

4.3.2 Potential negative impacts of urban agriculture on water systems

There exist some potential hydrological drawbacks of urban agriculture; for instance, some researchers have expressed concern that urban agriculture systems, like conventional rural farms, may become a source of non-point source pollution as water runs off the soil, picking up toxic fertilizers and pesticides on the way (Cohen, 2013); however, this risk may be mitigated by using organic soil amendments and covering soil with mulch or vegetation to reduce runoff. There is also a small risk of soil erosion from urban agriculture plots, which, although minuscule compared to the amount of erosion from rural farms, may be more noticeable to city-dwellers as soil washes onto the sidewalk or road (The Freshwater Society, 2013).

However, on the whole, researchers have found that urban agriculture systems generally experience fewer issues with runoff and soil erosion than other urban plots; many practices commonly used in urban agriculture systems, such as adding compost and tilling the soil, have been found to reduce soil compaction (Balousek, 2003), decrease stormwater runoff (Glanville, Richard, & Persyn, 2003), and increase time to stream peak flow while increasing base flow (Harrison, Grey, Henry, & Xue, 1997), even in highly disturbed sites like construction sites and roadway embankments. Even residential lawns and parks have been found to benefit from these practices (Kolsti, Burges, & Jensen, 1995; Olson & Gulliver, 2011), indicating that widespread application of urban agriculture practices throughout the city can improve the health of the watershed overall.

4.3.3 Best practices for maximizing synergies between urban agriculture and water systems

The simplest way to increase urban agriculture's provision of ecosystem services related to water is to increase the ability of the farm or garden to infiltrate water into the ground. As discussed previously, the benefits of infiltration of stormwater include groundwater recharge, reduced runoff, reduced stream peak flow, increased stream base flow, and decreased likelihood of combined sewer overflows (Novotny, Ahern, & Brown, 2010). Best practices for increasing the ability of an urban farm or garden to infiltrate water into the ground include the addition of compost, maximizing garden area, and the use of deep tilling (although this may have negative impacts on the soil, as discussed in the next section) (Olson & Gulliver, 2011; Harrison, Grey, Henry, & Xue, 1997). Impervious surfaces in the garden, such as stone pathways or concrete patios, should be minimized as well (Perry & Nawaz, 2008; Verbeeck, Van Orshoven, & Hermy, 2011).

To maximize the benefits of urban agriculture for the larger watershed, farms and gardens should be paired whenever possible with a decentralized, non-potable water source, such as a rainwater catchment system or wastewater recycling system (Liebman, Jonasson, & Wiese, 2011; Metson, Aggarwal, & Childers, 2012). Frequent water testing is important to maintain the safety of these systems, and in the case of rainwater harvesting, first flush systems will also help ensure water quality (San Francisco Public Utilities Commission and Water Resources Engineering, Inc., 2011; The Freshwater Society, 2013).

4.4 Soil

Soil is an extremely important input to any agricultural system, including those in urban areas. Factors affecting the ability of soil to support plant life include the physical composition of the soil, including parent material, particle size, and physical structure; the availability of nutrients, especially nitrogen, phosphorous, and potassium; bulk density, a measure of soil compaction; and the health of the arthropods, worms, and microbes in the soil, sometimes known as the soil food web (Natural Resources Conservation Service, 2001). Soil is a complex system, and as such, a holistic approach to soil health is the most effective strategy to improve the services provided by soil (Kibblewhite, Ritz, & Swift, 2008).

Agriculture, including urban farming, both affects and is affected by soil. Conventional rural agriculture often degrades the soil by cultivating it too intensely, forcing farmers to attempt to replace the nutrients, moisture, and microbial activity lost with chemicals and mechanized equipment (Edmondson, Davies, Gaston, & Leake, 2014). A more sustainable approach to soil management is to use growing techniques that cultivate the health of the soil, so that the soil in turn will contribute to the health of the crops. Not all urban agriculture systems take this approach, but many do. When managed properly, urban agriculture can provide enormous benefits to urban soils, especially in areas where the soil is disturbed due to human activity.

4.4.1 The benefits of urban agriculture for soil

A major difference between rural agricultural systems, which are often large-scale mechanized systems that rely on chemical inputs and farm machinery to grow large monoculture crops, and urban agriculture systems, which are often too small to warrant the use of traditional farm equipment, is the treatment of the soil in each system. The negative externalities generated by conventional agriculture, such as erosion and compaction of the soil, often do not occur in urban agriculture systems (Kibblewhite, Ritz, & Swift, 2008; Edmondson, Davies, Gaston, & Leake, 2014).

Urban gardens have been found to have healthier soil than other urban sites, whose soil is often disturbed and compacted due to human activity (Edmondson, Davies, Gaston, & Leake, 2014). Even more significantly, urban gardens often have healthier soil than rural pastures or arable fields, based on four major indicators of soil quality (soil organic carbon, carbon to nitrogen ratio, total nitrogen, and bulk density or compaction). These positive effects are related to the growing techniques used by urban gardeners, including the application of compost produced on-site, the presence of woody vegetation, and the application of organic materials including manure (Edmondson, Davies, Gaston, & Leake, 2014).

These practices to build healthy soil also provide habitat for beneficial species; specifically, insects and microbes that prey on pests depend on healthy soil to thrive (Yadav, Duckworth, & Grewal, 2012). Therefore, building healthy soil supports the health of plants in the garden and also reduces pest activity.

4.4.2 Risks and limitations of urban agriculture for improving soil health

In urban areas, soil is often disturbed by human activity, which can cause issues such as compaction and contamination. As a result, the addition of nutrients and moisture resulting from urban agriculture activities often changes the composition of the soil in a healthy way. However, in the case of vacant lots, there may already be a thriving and diverse soil food web in place, which may be disrupted by the conversion of the lot to an urban garden (Grewal, et al., 2011; Yadav, Duckworth, & Grewal, 2012). The diversity of microbes such as nematodes is generally higher in vacant lots than in newly established gardens, and certain other indices for soil structure and maturity are also often higher (Grewal, et al., 2011). However, in soils that have been farmed for several years, most indices of soil health are equal to those in vacant lots, indicating that it is not the act of farming that harms the soil, but rather the disruption of the soil food web caused by the initial establishment of the garden (Grewal, et al., 2011; Yadav, Duckworth, & Grewal, 2012). This may be mitigated by establishing the farm or garden in phases, or by the use of no-till or low-till methods (Grewal, et al., 2011).

A major risk of establishing a farm or garden in the city is soil contamination. Some bioremediation techniques exist to remove heavy metals and other chemical contaminants, ranging from compost application and compost tea treatments to the use of plant and fungi species that uptake or bind up toxins to make them inert (Kellogg & Pettigrew, 2008, pp. 181-182). Although these techniques have proven effective, especially when applied over a long time period, care should be taken to ensure that edible plants do not come into contact with contaminated soil before the bioremediation process is complete (Kellogg & Pettigrew, 2008). Planting edible crops in contaminated soil increases the risk that the plants will uptake the toxins, which are then consumed by humans and could cause health problems (Cruz, et al., 2014). If soil tests reveal levels of contaminants that are higher than the acceptable levels, edible plants should be grown in containers filled with ‘clean’ soil while the bioremediation process takes place. (Wieland, Leith, Rosen, & Hart, 2010).

4.4.3 Best practices for improving soil health with urban agriculture

The first consideration when establishing a new urban agriculture site should be the potential for soil contamination. Soil testing for heavy metals and other potentially toxic elements should be completed before garden construction begins; if contamination is found, clean soil may have to be added or raised beds used to prevent uptake of those contaminants by edible plants (Cruz, et al., 2014; Wieland, Leith, Rosen, & Hart, 2010).

Practices for designing urban agriculture systems to improve the health of the soil will depend on the specific characteristics of the site. For example, a site established in an area that was formerly paved may have serious compaction issues, while a site established on a vacant lot may already enjoy a relatively healthy soil food web, leaving it up to the farmer to avoid disturbing the healthy soil. Some urban agriculture systems, such as hydroponic systems and many rooftop gardens, do not even use soil. Additionally, different types of plants have different needs, so some soil conservation practices may not be appropriate for all agriculture systems.

Nevertheless, certain practices have proven to improve soil health across the board. The presence of woody vegetation provides multiple benefits; the deep roots contribute to decompaction of the soil, and the plants themselves as well as the leaf litter they produce provide habitat for birds, insects, and microbes while also contributing organic matter and nutrients to the soil as they decompose (Edmondson, Davies, Gaston, & Leake, 2014). The addition of organic materials, including the use of organic fertilizers rather than synthetics, is extremely important to maintaining the fertility of the soil (Sandhu, Wratten, Cullen, & Case, 2008; Edmondson, Davies, Gaston, & Leake, 2014). The presence of compost heaps and the use of compost produced on-site has been found to be particularly beneficial, as it both provides habitat for insects and microbes and adds nutrients to the soil (Edmondson, Davies, Gaston, & Leake, 2014). In order to minimize the risk of nutrient loading of local waterways, application of fertilizer should be matched as closely as possible with the rate of nutrient uptake by the specific plants growing in the garden (Cameira, Tedesco, & Leitão, 2014).

The question of whether tilling the soil is best for the health of the soil and of the plants growing in the soil is also context-dependent. It has been shown that deep plowing is best for decreasing the bulk density of the soil and improving infiltration of water into the ground (Balousek, 2003; Harrison, Grey, Henry, & Xue, 1997); however, in healthy soil, tilling may harm soil health by disrupting the soil food web (Grewal, et al., 2011). A potential compromise is chisel plowing, which aerates the soil without turning it, thus preserving the vertical structure of the soil and minimizing disturbance of soil microorganisms (Balousek, 2003); however, many urban gardens and farms are too small to use this type of plow. For smaller farms, hand tilling methods such as double-digging may be the best solution. Constructing new gardens in phases may also reduce the impact of construction on the existing soil food web.

4.5 Biodiversity

Biodiversity is another ecosystem service that may be provided by urban farms and gardens, although its presence is easily overlooked and its importance often undervalued in urban environments. Dearborn and Kark (2010) offer the following seven motivations for conserving biodiversity in urban areas:

1. Preserving local biodiversity currently threatened by urbanization
2. Creating stepping stones to nonurban habitat, thereby improving the overall connectivity of the regional network of habitat
3. Understanding and facilitating species' responses to environmental change (i.e., studying bird populations in urban habitats to understand ways to better preserve those species in other rapidly urbanizing areas)
4. Conducting environmental education
5. Providing ecosystem services such as pollination by bees, seed-dispersal by birds, air quality improvements by trees, etc.
6. Fulfilling ethical responsibilities to be good stewards of the land
7. Improving human well-being, both physical and psychological

From a financial perspective, the most rational motivation for conserving biodiversity in urban areas is the preservation of the ecosystem services it provides; plants, wildlife, and microbes provide important services for human beings that would otherwise have to be paid for (Dearborn & Kark, 2010). Urban agriculture can facilitate the provision of these services by providing habitat for urban wildlife, insects, and microbes, serving as a corridor or stepping stone for species dispersal, and forming part of a larger mosaic of green space throughout the city (Goddard, Dougill, & Benton, 2010).

4.5.1 The benefits of urban agriculture for biodiversity

Most existing research on the biodiversity of urban gardens focuses on birds, insects, and microbes, in part because these species provide important ecosystem services both to the garden and to the ecosystem of the city at large. Birds are seed-dispersers and may prey on harmful pests; insects are pollinators as well as predators; and microbes serve to improve soil health (Andersson, Barthel, & Ahrné, 2007; Yadav, Duckworth, &

Grewal, 2012). Urban farms and gardens both benefit from these services and serve to facilitate their provision.

The movement of many species is limited by urban land-use patterns, both for individuals moving from place to place and for populations dispersing over time (Forman & Godron, 1986). One study found that bumblebee gene flow is significantly limited by impervious cover associated with commercial, industrial, and transportation related land uses (Jha & Kremen, 2013); another found that the abundance and richness of arthropod species in urban gardens were significantly affected by the surrounding land-uses, especially whether the garden was located adjacent to a green corridor within the city (Vergnes, Viol, & Clergeau, 2012). Urban agriculture systems can contribute to biodiversity by simply adding some green space to the urban mosaic and improving connectivity between green spaces (Forman & Godron, 1986).

In addition to forming part of a larger green network, urban farms and gardens can improve biodiversity in more specific ways. One study of community gardens in New York City found that 54 different species of bees inhabited the gardens (Matteson, Ascher, & Langellotto, 2008); another found that vacant lots and community gardens are both home to an abundance of arthropod species (Gardiner, Prajzner, Burkman, Albro, & Grewal, 2014). These sites are home to complex food webs and chains of predation, including naturally-occurring predation of harmful pests. These naturally-occurring 'biocontrol' interactions, wherein predatory insects and microbes prey on harmful pests, are an indicator of a healthy soil food web and may obviate the need for chemical pest control measures in properly managed urban gardens (Yadav, Duckworth, & Grewal, 2012).

Urban gardens may even harbor more biodiversity than other urban green spaces, such as parks or cemeteries (Andersson, Barthel, & Ahrné, 2007). This may be related to structural features in the garden such as plant species composition, amount of impervious area, and the presence of trees (Uno, Cotton, & Philpott, 2010), but managerial norms also play a large role. Urban gardeners have been found to experience a greater sense of place, possess more local ecological knowledge, and practice more protective norms (i.e., not disturbing beehives and birds' nests) than managers of other types of green space in the city, leading them to be more proactive about preserving biodiversity (Andersson, Barthel, & Ahrné, 2007).

4.5.2 Limitations on urban agriculture's ability to provide habitat

Although urban agriculture does provide habitat for a wide variety of species, it is not the same type of habitat provided by forests, meadows, or even vacant lots. In the case of rural farms, the result of establishing a farm is often a net loss of biodiversity as a previously 'natural' area is transformed for human use (Zhang, Ricketts, Kremen, Carney, & Swinton, 2007). Forests are especially important in cities for the services they provide and should not be supplanted by urban agriculture. Even vacant lots in the city can provide habitat for certain species, especially arthropods and certain beneficial microbes (Gardiner, Prajzner, Burkman, Albro, & Grewal, 2014; Grewal, et al., 2011). When selecting a site for establishing a new urban garden or farm, care should be taken to avoid disturbing existing habitat networks.

The composition of species in an urban garden will naturally differ from that of an urban forest or other type of green space; generalist species will fare better than specialists, which may mean that exotic species will have an edge over natives (Uno, Cotton, & Philpott, 2010; Matteson, Ascher, & Langellotto, 2008). Nonetheless, these species still provide important services and are not necessarily edging out specialist species, which would likely not survive in an urban environment regardless of garden management practices.

Of course, one garden alone is not enough to support an entire population of birds, insects, or mammals; in order to maximize the biodiversity conservation potential of gardens or other urban green spaces, managers must take a multi-scalar approach. This may be done through top-down strategies, such as tax incentives or grants for wildlife-friendly management practices on private land, or through bottom-up approaches, such as coordinating with local homeowners' associations or horticultural societies (Goddard, Dougill, & Benton, 2010).

Additionally, although many gardeners may possess some knowledge of the species of birds, insects, and mammals that inhabit their gardens, there is a gap between possessing that knowledge and taking action to preserve urban biodiversity. Researchers have found that the knowledge, values, and attitudes of gardeners regarding urban biodiversity can be positively impacted by a friendly dialogue between gardeners and ecological 'experts' (as opposed to an impersonal, top-down transmission of knowledge) (van Heezik, Dickinson, & Freeman, 2012).

4.5.3 Best practices for maximizing biodiversity in an urban farm or garden

When establishing a new urban agriculture site, preference should be given to locations where biodiversity can be improved the most. These might be impervious areas such as parking lots or rooftops, or pervious areas that are underutilized or severely disturbed by human activity. Urban agriculture can be an effective tool for remediating these sites, and by avoiding the destruction of urban forests and other greenfield sites, the presence of the garden will serve to improve biodiversity across the city.

Regional context is another important factor when locating an urban agriculture site. Farms and gardens that are nearby or adjacent to other urban green spaces generally have higher levels of biodiversity than farms that are isolated from other green spaces (Vergnes, Viol, & Clergeau, 2012). These spaces are also better for dispersion of a population across the larger matrix of habitat (Forman & Godron, 1986). Planning for urban agriculture should be included as part of the city's larger plan for open space in order to maximize biodiversity across the city.

Urban farmers can take action to improve biodiversity in the garden. An open, sunny garden with plenty of flowers will improve bee and butterfly species richness (Matteson & Langellotto, 2010), and the presence of wild, unmanaged areas (especially those with trees) will improve the abundance of many species of birds, bees, and arthropods (Matteson & Langellotto, 2010; Uno, Cotton, & Philpott, 2010). Woody vegetation is especially important for creating microhabitats within the garden; the mixture of sun and shade, the presence of branches to support nests and hives, and the decomposing leaf litter all increase the variety of habitat types within the garden.

Perhaps the most important factor affecting the ability of an urban garden or farm to contribute to biodiversity is the level of knowledge and skill on the part of the gardener. Gardeners with a high level of local ecological knowledge will select plants to attract certain species, practice conservation in the garden, and educate visitors about the importance of certain species (Andersson, Barthel, & Ahrné, 2007; van Heezik, Dickinson, & Freeman, 2012). The knowledge and values of urban farmers and gardeners regarding biodiversity should not be undervalued, and should be cultivated through workshops and friendly dialogue (van Heezik, Dickinson, & Freeman, 2012).

4.6 Climate mitigation

A recent network analysis of the flow of food products between cities in the United States illustrates the national food system as an enormously complex web, with connections between far-flung places and import-export relationships between every one of the fifty states (Lin, Dang, & Konar, 2014, p. 5442). In this globalized food system, the supply chain for food in the U.S. is 6,760 kilometers (about 4,200 miles) long on average (Weber & Matthews, 2008). There are a number of externalities associated with the modern industrial food system, including air and water pollution, carbon emissions, and associated human health effects (Pretty, Ball, Lang, & Morison, 2005).

As cities search for ways to mitigate their impact on global climate change, reducing the carbon emissions associated with the food chain has come to the forefront as a priority in many areas; however, the exact mechanisms for realizing this goal are the subject of debate. A life-cycle analysis of the U.S. food system revealed a number of unsustainable trends threatening the nation's food system, not least of which is a heavy reliance on fossil fuels (Heller & Keoleian, 2003).

Advocates for organic farming claim that organic growing techniques are less fossil-fuel intensive than conventional techniques; however, a recent life-cycle analysis of organic farming revealed that large-scale mechanized organic farms are nearly as energy-inefficient as conventional farms (Schramski, Jacobsen, Smith, Williams, & Thompson, 2013). Similarly, local food advocates claim that shortening the distance food travels from where it is grown to where it is consumed will reduce carbon emissions from the transport sector; however, transportation accounts for such a small percentage of the emissions generated by the food chain (eleven percent, by one calculation) that these reductions may be negligible (Weber & Matthews, 2008).

The role of urban agriculture in this debate is complex and heavily context-dependent. It would be naïve to argue that urban agriculture techniques universally produce less carbon emissions than conventional agriculture. However, certain practices can improve the climate benefits of urban agriculture and make it worthwhile for cities attempting to mitigate their climate change impacts.

4.6.1 The benefits of urban agriculture for climate mitigation and adaptation

Implementation of agriculture and forestry systems in all sectors of the city (the city center as well as more peripheral areas) can result in benefits relating to climate change mitigation and adaptation, as well as 'co-development' benefits such as increased food security. For example, the climate mitigation benefits of productive rooftop gardens include some carbon sequestration as well as reduced heating and cooling needs for the building, resulting in reduced GHG emissions; adaptation benefits of a backyard garden include reduced vulnerability to food prices and other shocks to the food system as well as increased urban biodiversity (Dubbeling, 2014). These benefits are especially significant in cities in the developing world, where urban and peri-urban agriculture may contribute significantly to daily calorie consumption (Lwasa, et al., 2014), but the potential to realize these benefits in U.S. cities should not be overlooked.

The most direct climate benefits provided by urban agriculture are mitigation benefits due to the shortening of the food supply chain, the replacement of impervious cover with vegetation, and sequestration of CO_2 in woody vegetation and soil. A life cycle analysis of the food system in one UK city found that the establishment of urban agriculture within the city and in peri-urban areas could reduce GHG emissions in that city by up to 34 tons/ha/a (Kulak, Graves, & Chatterton, 2013); a similar study in Boston found that converting 50 acres of city land to urban agriculture would result in 114 tons of CO_2 sequestered in the soil per year, among other benefits (The Conservation Law Foundation and CLF Ventures Inc., 2012).

One challenge of calculating the true costs and benefits of different agricultural systems with regards to climate is that many of the negative impacts of agriculture, such as air and water pollution and carbon emissions, are externalized, so that their costs are not accounted for. One study suggested that if these externalities from agricultural production were accounted for, the price of food would be almost twelve percent higher to account for these additional costs. The authors suggested that these costs could be significantly reduced if the more farms adhered to organic practices and more consumers purchased locally-grown food (Pretty, Ball, Lang, & Morison, 2005). A more extreme scenario, involving not only a transition to local, organic production methods but also a commitment to reducing fossil fuel inputs throughout the production process, would reduce carbon emissions even more significantly, but would also require a more drastic change in current farming practices and would almost certainly reduce food production potential.

4.6.2 The limitations of “locally-grown” food for climate change mitigation

Although many studies have examined the potential for food self-sufficiency within city limits (e.g., Peters, Wilkins, & Fick, 2007; Thompson, Harper, & Kraus, 2008), it is becoming clear that large cities will likely never completely extricate themselves from the global food system. Even Ebenezer Howard, a seminal thinker in the planning field whose Garden City model included agricultural belts circling the city and provisions to recycle the food waste of the citizens back into the soil, recognized that a municipality cannot meet all of its food needs within city limits:

> “The ‘30,000 townspeople to be fed’ could ‘of course ... get their food stuffs from any part of the world,’ Howard wrote, noting the garden city’s farmers ‘are hardly likely to supply them with tea, with coffee, with spices, with tropical fruits or with sugar’” (Vitiello & Brinkley, 2014, p. 99 [citing Howard, 1902, p. 33]).

Municipal food self-sufficiency is not a realistic goal for modern cities, nor would it necessarily provide significant benefits in terms of reducing greenhouse gas emissions.

Transporting food long distances in refrigerated trucks or train cars will necessarily generate a large amount of greenhouse gases; however, recent research has begun to question the impact that reducing emissions from this sector would actually have. A 2008 study found that, although 'eating local' is touted by many food activists as an effective strategy for reducing the 'carbon footprint' of each individual consumer and the food system as a whole, in fact the average American household could achieve only a 4-5 percent reduction in greenhouse gas emissions buy 'buying local' (Weber & Matthews). Some researchers have even found that the amount of carbon emissions generated by the storage, packaging, and transportation of vegetables by a large-scale distributor often works out to be less (per vegetable) than the emissions generated by the transportation of 'local' vegetables from the farm or market to the consumer's doorstep, due to the 'economies of scale' enjoyed by large-scale food distributors; in many cases, the regional or national food system is more efficient than a 'local' food system when it comes to carbon emissions (Coley, Howard, & Winter, 2009; Roggeveen, 2014). In spite of this, it is important to keep in mind that locally-produced food can have other sustainability benefits, including benefits for the local economy such as job creation (Bregendahl & Enderton, 2014).

Researchers are increasingly finding that promoting ‘locally-grown’ food is not enough to reduce the carbon footprint of the food system. In fact, only a small percentage of the carbon emissions attributable to the food system are generated by transporting the food; the vast majority of emissions are generated during the production phase, indicating that changes in production practices or even the types of food produced would have a larger impact on reducing carbon emissions than promoting a more localized food system (Weber & Matthews, 2008). In terms of urban agriculture, this implies that, while it is important to increase food production in cities in order to shorten the food supply chain, a shift towards more sustainable production methods is also necessary to reduce the climate impact of agriculture systems.

4.6.3 Best practices for mitigating climate change with urban agriculture

Production methods that reduce municipal greenhouse gas emissions and increase carbon sequestration include the use of organic management techniques and the inclusion of woody vegetation, which both sequesters carbon and provides some adaptation benefits such as providing a cool, shady microclimate (Sandhu, Wratten, Cullen, & Case, 2008; Lwasa, et al., 2014). Any efforts to reduce on-farm fossil fuel usage will result in reduced emissions; these might include minimizing the application of synthetic fertilizers, substituting the use of tractors or other farm equipment for human- or animal-powered equipment, and use of water-efficient irrigation systems (Schramski, Jacobsen, Smith, Williams, & Thompson, 2013). Crop selection will also have an impact on climate change mitigation; maximum climate benefits can be achieved by growing high-yield crops that thrive in the local climate, and especially those that would ordinarily be grown or shipped using fossil fuel-intensive methods, such as in heated greenhouses or using air freight shipping (Kulak, Graves, & Chatterton, 2013). These techniques will vary from site to site, but every effort should be made to reduce greenhouse gas emissions during every stage of production.

In the interest of mitigating climate effects from every stage of the food supply chain, promoting consumption of ‘locally-grown’ food should not be dismissed; rather, the concept of reducing emissions from the transport sector should be expanded to include the mode of transport from the community garden, farm stand, or market to the consumer’s home. Herein lies the great strength of urban agriculture: in a well-planned, city-wide network of urban farms and gardens, the potential exists for city residents to walk, bike, or take public transit to their farm or garden plot, thus substantially reducing greenhouse gas emissions from this final leg of the supply chain. A diverse network of urban farms and gardens, from small backyard gardens to larger peri-urban farms, will increase the diversity of locally-grown produce available within the city and reduce the carbon footprint of each individual consumer within that network as well as providing local economic benefits.

4.7 Community benefits

One of the least tangible, but most often cited, benefits of urban agriculture is its contribution to community well-being and development. In a general sense, urban agriculture can serve to reconnect the rift between humans and nature, and especially between urban residents and the food they eat (McClintock, 2010). The benefits of urban green space for human health, both physical and psychological, is well-documented; these benefits include relaxation, stress relief, longevity, and better self-reported health (Tzoulas, et al., 2007; de Vries, Verheij, Groenewegen, & Spreeuwenberg, 2003). Urban agriculture can play a role in providing these individual benefits as well as providing benefits for the community at large.

4.7.1 The community benefits of urban agriculture

The most tangible benefits of urban agriculture for the individuals participating relate to physical health. Gardeners experience significant health benefits related to a more nutritious diet (Kortright & Wakefield, 2011), especially in low-income areas (Armstrong, 2000). Another individual benefit is education; both children and adults can gain skills and knowledge by working in the garden (Blair, 2009; Fulford & Thompson, 2013; Levkoe, 2006).

In addition to these benefits to the individual, there are also benefits to the wider community associated with urban agriculture. Participating in urban agriculture has been proven as a successful strategy for empowering marginalized groups; these groups include minorities (Saldivar-Tanaka & Krasny, 2004), women (Slater, 2001), or groups lacking a political voice (Levkoe, 2006). Urban agriculture can facilitate cultural cohesion as well, especially among immigrant communities (Saldivar-Tanaka & Krasny, 2004). Gardens may serve as a meeting and gathering place for immigrants in the city, and growing traditional foods may help further bind the community to its roots (Mangan, 2015).

Often, the mechanism by which urban agriculture serves to empower these groups is the formation of social networks and the building of human and social capital. Although urban agriculture systems are often not high-value enterprises like rural farms, "people who cultivate urban land to supplement their income, feed neighbours or build job skills create economic value that purely commercial farming does not"; this added economic value comes in the form of human and social capital, which are the precursors to community revitalization (Vitiello & Wolf-Powers, 2014, p. 520). Youth also benefit from the formation of these networks; some urban agriculture programs focus on fostering social networks and cultivating self-esteem among young people as a strategy for counteracting gang activity (Fulford & Thompson, 2013).

On a larger scale, urban agriculture can benefit the city as a whole when used as a planning tool to fill in vacant spaces in the urban core. Especially in 'shrinking cities,' those post-industrial cities experiencing a rapid population decline, urban agriculture can revitalize neglected land both in the city center and on the urban fringe. This technique is being tested in Cleveland, Ohio (LaCroix, 2010) and Detroit, Michigan (Bonfiglio, 2009), and has met with success so far.

4.7.2 Limitations on the community benefits of urban agriculture

In spite of its many community benefits, urban agriculture can also cause tension in the community. Farms and gardens located in residential areas might be viewed as eyesores by residents or as conflicting land uses by town officials. Private gardens may be ‘too messy’ for neighbors with manicured lawns; larger farms and community gardens may be seen as a nuisance due to the traffic, noise, smells, and other negative impacts they may produce (Haeg, 2008). This is not to say that farms and gardens are always incompatible with residential land uses; on the contrary, food production should be decentralized and spread across every area of the city to maximize residents’ access to healthy food. However, certain strategies may be used to better integrate farms and gardens with surrounding land uses. A 1995 study examined the landscape preferences of suburban residents and found that residents were more likely to respond positively to ‘unconventional’ front yard landscapes when certain ‘cues to care’ were present; these included fences, identifiable landscape patterns, and trimmed shrubs and trees (Nassauer, 1995). The key take-away is that even ‘messy’ landscapes like urban gardens may be accepted by neighbors if it is clear that the land is not simply being neglected, but rather is being enhanced and managed for a specific set of goals.

4.7.3 Best practices for improving the value of urban agriculture in the community

The potential community benefits of urban agriculture are so varied that each individual garden or farm site should be viewed as one component in a larger strategy for community development. The best strategy for maximizing these benefits is to plan for a variety of types of urban agriculture for a variety of audiences. These might include school gardens, community gardens, backyard gardens, and commercial farms. Farms and gardens should be located in every area of the city to maximize access, with special attention paid to existing ‘food deserts’ or neighborhoods lacking access to fresh food. Some tools for improving the availability of agricultural land in the city might include tax incentives for landowners who donate or lease land for agricultural purposes, or subsidized community garden plots for low-income residents (Peters K. , 2010). Education and training programs should be emphasized to encourage the participation of beginning gardeners and expand the agricultural skill base across the city (Peters K. , 2010).

Design is an important factor in improving public perception of urban agriculture systems. Including certain ‘cues to care,’ such as fences or signage, in the design of what otherwise might be viewed as a ‘messy’ garden can increase community acceptance and reduce the chances of conflicts with neighbors (Nassauer, 1995). Urban farmers can incorporate bold, recognizable patterns into their planting design, include bird feeders or other identifiable habitat features along with native plants to improve biodiversity, and include flowers and trees to bolster community acceptance of the garden ecosystem (Nassauer, 1995).

As discussed previously, urban agriculture should be planned for in a comprehensive way, rather than implemented haphazardly. Although it is important that city-led initiatives be balanced with grassroots projects, the city should be strategic in its zoning and approval for agricultural projects in order to meet the diverse needs of the specific neighborhoods in question. A large commercial farm is not always the most beneficial option for neighborhood residents, even if there is enough land available, just as community gardens are not always wanted or needed even in densely populated areas. The city should be careful in its decision-making regarding urban agriculture and should give preference to projects that will have the greatest benefit for the community.

4.8 Conclusion

Urban agriculture can be a powerful tool for delivering ecosystem services, provided that certain best practices are employed, but there are some risks and limitations associated with these techniques. A holistic approach that focuses on providing a wide array of ecosystem services, rather than on maximizing just one service, may be the best strategy for avoiding externalities and ecosystem dis-services. Table 3 summarizes the best practices for urban agriculture discussed in this chapter. Best practices for maximizing each of these ecosystem services and minimizing dis-services can be extended into urban agriculture typologies, which is the subject of the next chapter.

Table 3: Summary of best practices for each ecosystem services with selected references

Ecosystem service	Best practices	Selected References
Food production	•Use intensive management techniques (intercropping, vertical stacking, soil building) to improve yield •Use permaculture techniques to increase spatial efficiency •Improve gardener knowledge to improve yield and cost-efficiency	•Algert, Baameur, & Renvall, 2014 •CoDyre, Fraser, & Landman, 2015 •Clark & Nicholas, 2013 •Mollison & Holmgren, 1978 •Grewal & Grewal, 2012
Water management	•Apply compost •Limit use of synthetic fertilizers •Till soil to reduce compaction •Minimize impervious surface in the garden •Use first flush systems and water testing for water catchment systems	•Liebman, Jonasson, & Wiese, 2011 •The Freshwater Society, 2013 •Balousek, 2003 •Olson & Gulliver, 2011 •Perry & Nawaz, 2008
Soil	•Test for soil contaminants; if necessary, add soil or use raised beds •Apply organic materials and own-grown compost to improve soil fertility •Include trees and woody vegetation •Apply fertilizer at a rate appropriate for plant uptake •Use low-till or no-till practices where soil already exists to avoid disturbing soil food web •Use chisel plowing where appropriate to till soil without turning it	•Grewal, et al., 2011 •Cruz, et al., 2014 •Cameira, Tedesco, & Leitao, 2014 •Edmondson, Davies, Gaston, & Leake, 2014 •Yadav, Duckworth, & Grewal, 2012
Biodiversity	•Reclaim land that was previous vacant or impervious rather than establishing gardens on greenfield sites •Provide multiple micro-habitats: leave some areas unmanaged, provide both sun and shade, and include native flower species •Include trees and shrubs •Encourage conservation practices: leave nests and hives undisturbed •Link garden with nearby green spaces to form a regional network	•Andersson, Barthel, & Ahrne, 2007 •Matteson & Langellotto, 2010 •Forman, 1986 •Uno, Cotton, & Philpott, 2010 •Gardiner, Prajzner, Burkman, Albro, & Grewal, 2014

Table 3 continued

Ecosystem service	Best practices	Selected References
Climate mitigation	•Avoid or limit use of synthetic fertilizers •Limit fossil fuel use in every stage of production •Include woody vegetation and incorporate soil building techniques to maximize sequestration •Select crops that thrive in the local environment, especially those that would otherwise be grown or shipped using fossil fuel-intensive methods •Promote locally-grown food and reduce 'food miles' from every stage of transport, including the final stage from market to consumer	•Weber & Matthews, 2008 •Coley, Howard, & Winter, 2009 •Pretty, Ball, Lang, & Morison, 2005 •Dubbeling, 2014 •Kulak, Graves, & Catterton, 2013
Cultural/ educational benefits	•Plan comprehensively for urban agriculture in every sector of the city, with special attention to low-income areas •Improve access by providing tax incentives to landowners for agricultural use and subsidizing community garden plots for low-income residents •Use urban agriculture strategically to fulfill diverse neighborhood needs •Include fencing, signage, and other 'cues to care' to improve public perception of urban agriculture	•Vitiello & Wolf-Powers, 2014 •Tzoulas, et al., 2007 •Armstrong, 2000 •Saldivar-Tanaka & Krasny, 2004 •LaCroix, 2010 Nassauer, 1995

CHAPTER 5

URBAN AGRICULTURE TYPOLOGIES

5.1 Introduction

In order for city planners and food system actors to effectively implement urban agriculture as a technique for providing ecosystem services, a strategic method for linking ecosystem ‘problems’ with urban agriculture ‘solutions’ must be developed and implemented. The following two chapters of this report move towards the development of this strategic method by identifying and describing various typologies of urban agriculture and tools that food system planners can use to implement these typologies. Table 4 illustrates the seven typologies identified in this chapter, some synergies and co-benefits between the typologies, and a relevant precedent study for each.

A note on the typologies: although food production is named as a primary goal of almost every urban agriculture system, the production farm is called out as its own typology in order to distinguish farms that provide few ecosystem services apart from food production from farms that provide a more diverse range of ecosystem services. It is assumed that farms and gardens of each typology will produce some amount of food; however, some typologies are better than others for providing other ecosystem services in addition to food production. These typologies are designed for planners and farmers working in temperate climates with a moderate amount of rainfall, but could be adapted for other climates.

Table 4: Examples of each urban agriculture typology and co-benefits between typologies, with precedent studies

Typology	Examples	Synergies/ Co-benefits	Precedents
Production farm	Peri-urban commercial farm, hydroponic greenhouse, backyard garden	Cultural/educational	Corner Stalk, Boston
Stormwater garden	Rooftop farm, vacant lot cultivation	Soil, climate, cultural/ educational	Brooklyn Grange, New York
Soil-building garden	Bioremediation garden, biointensive farm	Stormwater, habitat, climate, cultural/ educational	Berkshire Permaculture Garden, Amherst, MA
Habitat garden	Allotment garden, forest garden	Soil, cultural/ educational	Food forest at Boston Nature Center, Boston
Climate mitigation farm	Rooftop farm, forest garden	Stormwater, soil, cultural/ educational	Montview Neighborhood Farm, Northampton, MA
Cultural/ educational garden	Institutional garden, community garden	Food, stormwater, soil, habitat, climate	New Lands Farm, West Springfield, MA
Ecosystem garden	Permaculture garden, forest garden	All of the above	Holyoke Edible Forest Garden, Holyoke, MA

5.2 Production farm

Farms and gardens that produce a large amount of food, to the exclusion of other ecosystem services, fall into the *production farm* typology. Farms in this typology are characterized by a focus on intensive production and thus often use conventional farming techniques, including mechanized equipment, tilling of the soil, and monoculture cultivation of annual crops. Hydroponic systems also fall into this category. The scale of these systems is often large, but smaller gardens that focus exclusively on food production, such as backyard container gardens, also fall into this typology. Food producing farms can be located anywhere, from a window box to a rooftop to the peri-urban fringe, and can be managed as commercial farms, private subsistence gardens, or even as community gardens. Their main distinguishing feature is that the crops planted and the techniques used to grow those crops do not contribute significantly to the provision of regulating, supporting, or cultural ecosystem services. This typology does have some synergies with the cultural/educational garden typology; many gardens that are nominally focused on food production also have significant benefits for community development, cultural heritage preservation, and environmental education.

Corner Stalk Farm in Boston is an excellent example of the production farm typology. The farm produces greens and herbs in modified shipping containers supplied by a company called Freight

Box 1: Hydroponics

Broadly defined as the cultivation of crops without soil, hydroponics can take many forms. Often plants are grown in trays filled with an artificial growing medium, and water loaded with a specially calibrated nutrient mix is pumped through the trays. Some systems use no growing medium at all; plant roots are allowed to dangle directly into the water stream. Both water and nutrients are recycled, making for an extremely resource-efficient system. Hydroponic systems are often housed in heated greenhouses to enable year-round production.

Farms (Freight Farms, 2015). The containers utilize LED lighting and hydroponic growing techniques to grow plants with no soil and minimal inputs of water and fertilizer (Cooney & Cooney, 2015). With five containers total in East Boston and New Market Square, Corner Stalk Farm produces a harvest equivalent to what would be produced on five acres of traditional farmland (Corner Stalk and Freight Farms, 2014). The containers come equipped with computerized systems to control irrigation, temperature, humidity, pH, nutrient levels, and ventilation, which the farmer can control remotely on a smartphone or tablet (Freight Farms, 2015). Using this technology, Corner Stalk broke even after only four years and now sells their produce wholesale to restaurants (Hobson, 2015). The growing techniques used by Corner Stalk are extremely efficient when it comes to water, energy, and fertilizer use, but do not provide other ecosystem services such as soil remediation or stormwater management benefits.

5.3 Stormwater garden

A *stormwater garden* is one that produces food while simultaneously managing a significant amount of stormwater on-site. Although this is not the explicit goal of most urban farmers, certain commonly-used agricultural techniques provide unintended water co-benefits. For example, gardens planted on formerly impervious surfaces, such as rooftops or parking lots, will naturally absorb more stormwater than was infiltrated previously. Farms and gardens falling into this category are characterized by soil management practices that improve the permeability of the soil; these include tilling the soil to decompact it, adding compost, and using trees with wide canopies and deep-rooted perennials to slow and infiltrate rainwater. These systems may be large or small, and may be located anywhere; however, stormwater gardens sited on previously impervious areas, such as rooftops, paved areas, or areas of compacted soil, will yield the most stormwater benefits. Due to the focus on building and decompacting soil and the use of woody vegetation and perennial plants, this typology can easily be merged with the soil-building garden typology and the climate mitigation farm typology for greater ecosystem co-benefits.

A successful example of the stormwater garden typology can be found at Brooklyn Grange in New York City. A commercial operation launched in 2010, the farm grows annual vegetables, herbs, and flowers for wholesale markets, farmers markets, and CSA (community supported agriculture) shares. Production occurs on two rooftop sites: the Flagship Farm, which occupies over 40,000 square feet of roof space on an industrial building in Queens, and the Navy Yard Farm, which is located on 65,000 square feet of space on top of a building at the historic Brooklyn Navy Yard (Brooklyn Grange Rooftop Farm, 2015). Each of these has significant stormwater benefits; in fact, the construction of the Navy Yard Farm was funded by a grant from the Department of Environmental Protection’s Green Infrastructure Stormwater Management Initiative (Brooklyn Grange Rooftop Farm, 2015). According to the organization’s website, over one million gallons of stormwater are managed annually at this site alone. The Flagship Farm site was the subject of a research project by two Master’s students at the Pratt Institute, who studied the potential for urban agriculture to manage stormwater through detention (temporary storage) and retention (permanent storage) (Facteau & Caruso, 2011; Urban Omnibus, 2012). In the case of Brooklyn Grange, it was the addition of 10-12 inches of green roof soil media to a formerly impervious rooftop that provided the most stormwater benefits;

however, the student researchers working with the Flagship Farm posited that the use of water-intensive crops in a rooftop urban agriculture system might have additional stormwater retention benefits compared to a typical extensive green roof planted with native grasses (Facteau & Caruso, 2011).

5.4 Soil-building garden

Although soil is the foundation of any agricultural system, certain farming techniques are better than others for building the health of the soil over the long-term. Farms and gardens that remediate disturbed or contaminated soil fall into the *soil-building garden* typology. These systems may be large or small and may be located anywhere, but will provide the most significant co-benefits if sited in areas where the soil is disturbed or contaminated by urban land uses. Commonly used techniques in soil-building gardens include bioremediation techniques, which employ plants to uptake and dispose of chemical contaminants, and biointensive techniques, which build soil by

Box 2: Bioremediation

Bioremediation is the use of biological processes to break down or otherwise 'clean up' soil or water contaminated with toxins or heavy metals. There are three major categories of bioremediation:

- *Microbial remediation: Beneficial microbes break down contaminants, or bind them into a more inert state.*
- *Phytoremediation: Plants break down contaminants, or extract and accumulate them in their leaves, stems, and roots.*
- *Mycoremediation: Fungi break down contaminants with digestive enzymes, or extract and accumulate them.*

The most effective bioremediation strategy will depend on the particularities of the site; common techniques include application of compost tea or biochar to facilitate microbial remediation, selecting plants that are 'hyperaccumulators' or that can effectively degrade organic toxins, or application of myceliated straw (straw with mushroom spawn) to the contaminated area. (Darwish, 2013) adding compost. Farmers often opt for no-till or hand-till methods in order to avoid disrupting the physical structure and biological interactions of the soil. Woody vegetation contributes leaf litter, which provides habitat for soil organisms and adds nutrients to the soil as it decomposes. Nitrogen-fixing plants, such as legumes, are also often employed to improve the nutrient content in the soil without the use of fertilizer. This typology has some amount of synergy with the stormwater garden typology and the climate mitigation typology; again, all three utilize woody vegetation, polyculture growing techniques, and soil-building practices to maximize ecosystem services.

The Berkshire Permaculture Garden in Amherst, Massachusetts is an excellent example of the soil-building garden typology. Designed in the fall of 2011 and planted the following spring and summer, the Berkshire Permaculture Garden was the second major project of the UMass Permaculture Initiative. The garden is located outside one of the university's four dining halls, and produce grown in the garden is used by chefs in the dining hall to feed the student body. This precedent study is highlighted here as an example of the soil-building garden typology, but it could just as easily exemplify a cultural/educational garden, or even an ecosystem garden. As with all gardens designed and installed by UMPI to date, the Berkshire Permaculture Garden was designed with explicit consideration of a diversity of ecosystem services, chief among them being education.

The Berkshire Permaculture Garden is an excellent example of the soil-building garden typology. Located in the Southwest residential area, the most urban area of campus, the site was formerly used as a parking area and staging ground for construction vehicles during the installation of a nearby rain garden. This caused the soil to become extremely compacted, and as a result of the slope of the site, each rainstorm resulted in deep gullies that visibly scarred the site as rainwater washed the topsoil away. The site was specifically chosen for its poor soil; the goal was to demonstrate the regenerative power of permaculture techniques for urban areas.

After soil testing revealed no dangerously high levels of contaminants, terraces were installed to prevent further erosion of soil down the slope. There followed an intensive effort to reduce the bulk density of the soil without the use of tilling or mechanical equipment of any kind; student volunteers were recruited to loosen the soil by hand with forks and pickaxes. Next the entire site was sheet mulched; newspaper formed the bottom layer of the mulch, followed by compost and then woodchips. The newspaper acted as a weed barrier, while the compost added nutrients to the soil and the woodchips prevented erosion. Finally, woody shrubs and trees as well as perennial vegetables were interspersed with annual crops to further decompact the soil with their roots; these included elderberry, raspberry, gooseberry, and Chinese chestnut.

5.5 Habitat garden

A *habitat garden* is one that provides habitat for mammals, birds, arthropods, and microbes in the city. Techniques for attracting these species depend heavily on the climatic and geographic context of the garden as well as the needs and preferences of the particular species, but generally habitat gardens are identifiable by a diversity of plants, an emphasis on native plant species, and the presence of some wild, unmanaged areas. Also important is the location of the garden in relation to a larger network of green space; a successful habitat garden will facilitate the movement of species in the city by forming a stepping stone or link to larger habitat patches. Larger gardens offer more habitat benefits than small ones, but as long as a link exists between the garden and surrounding patches, a habitat garden may be any size. Examples might include a large allotment garden replete with woody vegetation and flowers, or a medium-sized forest garden. Due to the diversity of plants and the importance of maintaining some wild, unmanaged areas in a habitat garden, this typology has some synergy with the soil-building garden typology, and some co-benefits may be gained by combining elements of each.

Box 3: Forest gardening

In their seminal volume, Edible Forest Gardens, *Dave Jacke and Eric Toensmeier give this description of forest gardening: "Forest gardeners use the forest as a design metaphor, a model of structure and function, while adapting the design to focus on meeting human needs in a small space" (2005, p. 2). Forest gardens mimic the structure of a natural forest, but utilize plant and animal species that are edible or otherwise useful to humans. The goals of forest gardening are:*

- *Grow an abundant diversity of tasty, nutritious food and other useful products*
- *Create a stable, resilient garden ecosystem, driven by solar energy, that largely maintains and renews itself*
- *Protect and restore ecosystem health*
- *Improve economic sustainability*
- *Cultivate a new paradigm for human participation in the ecology of cultural and natural landscapes* (Jacke & Toensmeier, 2005, p. 46)

The Boston Food Forest Coalition's flagship farm at the Boston Nature Center is an excellent example of a garden designed to accomplish a dual goal of food production and habitat conservation. The Boston Nature Center is a Mass Audubon wildlife sanctuary, with 67 acres of forest, meadows, and wetlands home to over 150 species of birds, 40 species of butterflies, and 350 species of plants (Mass Audubon, 2015). The newly established forest garden, launched in 2014, integrates areas of intensive food production with plantings of native herbs and shrubs and some wild, unmanaged areas.

Some beds are reserved for native plants, with special attention paid to the needs of native bees and other pollinators (Boston Food Forest Coalition, 2015). The structure and management of the food forest is compatible with the needs of many species; trees and shrubs provide shelter for birds and mammals, and the leaf litter they drop is beneficial for insects, arthropods, and soil microbes. The farmers use organic growing practices and natural soil-building techniques, including a technique of burying tree trunks to boost soil nutrient content and water retention known as hugelkultur, which prevents wildlife in the garden from experiencing negative impacts from the application of fertilizers and pesticides (Boston Food Forest Coalition, 2015). Finally, the proximity of the forest garden to other green spaces, including not only the Nature Center but also Clark-Cooper Community Garden and Franklin Park, increases its utility as a stepping stone for species movement across patches in the urban mosaic.

5.6 Climate mitigation farm

A *climate mitigation farm* is designed to provide climate change benefits, including reduced greenhouse gas emissions from food production and transport and sequestration of carbon in woody plants and soil. The focus of gardens in this typology is on sustainable, low-emissions production practices; hand-tilling or no-till methods are often practiced, and organic fertilizers are preferred over synthetic ones. Local food consumption is also emphasized. Additional climate mitigation benefits can be gained from siting a farm of this typology on a rooftop, as the soil and vegetation will insulate the building and reduce greenhouse gas emissions from heating and cooling the building. Some climate adaptation benefits can also be provided by these gardens, most notably mitigation of the urban heat island effect. Climate mitigation farms can be located anywhere, but will have the most notable effect as rooftop farms or as large green oases in an otherwise urbanized area. Again, this typology has some synergy with both the stormwater garden typology and the soil-building garden typology.

Montview Neighborhood Farm in Northampton, Massachusetts is a farm of this typology that exemplifies a commitment to urban agriculture as a tool for climate mitigation. Launched in a residential neighborhood near downtown Northampton, MA in 2005, Montview operated as an organic CSA farm until 2011 (Walsh & Welch, 2012). The farm was unique in both its situation on city-owned land and in its philosophy of holistic design. The farmers obtained a three-year lease from the Northampton Conservation Commission in exchange for maintaining the land as an organic farm (Walsh & Welch, 2012). The 3.2 acre parcel was managed as a human-powered permaculture farm, with a particular emphasis on zero-carbon agricultural practices and experimental forest garden beds (Theophilos, 2012). In addition to using organic practices, farmers at Montview were committed to using human-powered, no-till practices; beds were prepared using sheet mulching and other no-till methods, and all farm operations were carried out without the use of machinery. Grass was mowed using hand scythes or allowed to grow wild, and beds were irrigated with water carried in pails from a nearby water source. In an agreement between the farmers and their neighbors, the farmers even promised to arrive at the site by foot or bicycle whenever possible to mitigate traffic impacts of the farm (Walsh & Welch, 2012). Throughout its six year tenure, Montview Neighborhood Farm combined zero-carbon growing techniques with educational workshops and neighborhood development initiatives.

5.7 Cultural/educational garden

Farms and gardens whose major purpose is to provide cultural and educational benefits to the community fall into the *cultural/educational garden* typology. Decisions about which crops to grow and which management techniques to use are subordinate to the overall mission of cultural enrichment and community development. For example, a farm or garden whose main mission is cultural cohesion among particular immigrant groups will be characterized by the cultivation of ethnic crops, while a school garden whose goal is education might have demonstration beds containing crops that are easy to grow and fun for children to harvest. Another example might be an institutional farm attached to a shelter or prison, whose goal of producing food for the facility is secondary to its mission of job training and community building. Community gardens also often fall into this typology. Hence, gardens in this typology are extremely diverse in scale, location, and context. Although some gardens of this typology are managed exclusively for their educational or cultural benefits, many have secondary goals relating to food production, soil-building, habitat, or other ecosystem services, meaning that this typology has some synergy with every other typology listed here.

New Lands Farm, a network of farms and community gardens in western Massachusetts operated by Ascentria Care Alliance, is an excellent example of the cultural/educational garden typology. The mission of New Lands is to provide farmland and training for refugees and immigrants arriving in Massachusetts through the United Nations Refugee Resettlement Program (Lucio, 2014). Over 100 families from Bhutan, Burundi, Vietnam, Burma, Iraq, and many other countries have participated in the program to date; over a dozen languages are spoken on the farm (New Lands Farm, 2014). The program gives participants the opportunity to adjust to their new environment and gain job skills while staying connected to their country of origin through traditional agricultural practices. Ethnic crops, including African eggplant, amaranth greens, bitter melon, bottle gourd, and long beans, are sold at local markets and as part of the farm's CSA share, along with traditional recipes for people who may be unfamiliar with these crops, facilitating a cultural exchange between refugees and native residents (New Lands Farm, 2014). With farm sites in West Springfield and Sutton and community gardens in Westfield, Springfield, West Springfield, and Worcester, this program provides cultural and educational benefits to people across western Massachusetts.

5.8 Ecosystem garden

This final typology describes gardens that encompass a wide diversity of ecosystem services. *Ecosystem gardens* are characterized by a holistic approach to garden design and management, a diversity of annual and perennial plants, and explicit consideration of the long-term provision of ecosystem services. An emphasis on perennials and woody plants provides benefits for stormwater, soil, and biodiversity, while an intensive management approach maximizes spatial efficiency for food production. The use of mechanized equipment is often eschewed in favor of neighborhood work days or other community-building techniques. Farms and gardens of this typology often utilize permaculture design techniques or forest gardening techniques to maximize ecosystem services across the board. By definition, this typology provides some of the benefits of all the other typologies and therefore may have certain elements from each of the others merged into one diverse ecosystem.

The Holyoke Edible Forest Garden in Holyoke, MA, perfectly exemplifies the ecosystem garden typology. Established in 2004, the garden contains over one hundred plant species, most of them edible and perennial, on only one-tenth of an acre. The design was guided by permaculture principles and utilizes forest gardening techniques, with polyculture guilds of edible trees, shrubs, vegetables, berries, and herbs (Toensmeier & Bates, 2013). Year-round food production was an explicit goal of the garden from the outset, but so were soil remediation, habitat improvement, and climate mitigation (Toensmeier & Bates, 2013). Education has also been an emergent goal, as has cultural heritage preservation to a lesser extent; students and permaculture practitioners come from all over the country for tours and workshops, and Puerto Rican neighbors come to borrow banana leaves and other produce from the tropical garden in the front yard.

These goals have mostly been fulfilled. A 2011 soil test revealed that lead levels had been reduced to a safe level, and that soil organic matter had increased by almost 500 percent from the time the garden was established (Toensmeier & Bates, 2013, p. 192). An assessment of local wildlife habitat in 2013 found that the addition of flowers, trees, and a pond to the formerly barren lot has greatly improved habitat availability; anecdotally, the farmers have

Box 4: Permaculture

Permaculture is a design system that meets human needs while improving the health of the ecosystem. In the context of food production, permaculture systems are often characterized by a diversity of plants growing together (polyculture guilds), strategic location of design elements to take advantage of site-specific microclimates, and functional interconnection of all design elements. Selected design principles include:

- *Work with nature, not against*
- *Least change for the greatest effect*
- *Each design element should support multiple functions*
- *Use and value diversity*
- *Cycle energy* (Mollison, 1997)

witnessed species such as salamanders, frogs, bees and wasps, and even some rare bird species in the garden, where before there was little wildlife activity (Toensmeier & Bates, 2013, p. 192). The addition of compost and the planting of deep-rooted perennials along with trees and shrubs has decompacted the soil (formerly compacted fill), contributing to the infiltration of stormwater into the ground, while a commitment to no-till methods and minimal use of mechanical equipment have contributed to climate mitigation. The farmers also source much of their food from their own backyard, further reducing their climate footprint (Toensmeier & Bates, 2015). Through holistic design, the Holyoke Edible Forest Garden provides a spectrum of ecosystem services and perfectly characterizes the ecosystem garden typology.

5.9 Conclusion

These seven typologies represent a range of urban agriculture systems designed to maximize a range of ecosystem services. The most holistic of them, the ecosystem garden typology, combines best practices from each of the other six to produce an extremely spatially efficient system that delivers a diversity of services to improve human and environmental health. Table 5 illustrates these typologies and their identifying characteristics. At the scale of an individual site, the planner’s challenge is to select a typology that best suits the needs of the particular site; at a regional scale, the planner must strategically plan to include these typologies as appropriate to form a city-wide network of productive green space that maximizes a diverse portfolio of ecosystem services.

Table 5: Urban agriculture typologies with identifying characteristics

Typology	Location and scale	Soil	Woody vegetation	Crops	Mgmt techniques
Production farm	Usually large; often located on urban periphery	Deep soil, containers, or no soil (hydroponic); soil often tilled	No	Annual food crops; often monoculture fields	Intensive management; synthetic fertilizers; mechanized equipment
Stormwater garden	May be large or small; located on rooftops, parking lots, or areas of compacted soil	Deep soil; tilling; compost	Often	Polycultures of mixed perennials and annuals	Organic fertilizers applied to match plant uptake rates
Soil-building garden	May be large or small; located in areas of disturbed soil	Deep soil; no-till; compost	Yes	Polycultures of mixed perennials and annuals; inclusion of nitrogen-fixers	Organic fertilizers applied to match plant uptake rates; biointensive or bioremediative techniques
Habitat garden	May be large or small; sited as part of a larger network of green space and habitat	Deep soil; no-till	Yes	Polycultures of mixed perennials and annuals, with lots of native flowers	Organic fertilizers; some areas left unmanaged
Climate mitigation farm	Usually large; located on rooftops or in urbanized areas	Deep soil; no-till	Often	Polycultures of mixed perennials and annuals	No mechanized equipment; organic fertilizers
Cultural/ educational garden	Often small; located in neighborhoods or as part of an institution	Deep soil or containers	Sometimes	Polycultures of annual food crops, often with some specialty ethnic crops	Non-intensive management
Ecosystem garden	May be large or small; may be located anywhere	Deep soil; no-till	Yes	Polycultures with mostly perennials	Intensive management; organic fertilizers; little mechanized equipment

CHAPTER 6

AN URBAN AGRICULTURE TOOLKIT FOR PLANNERS

6.1 Introduction

With the connection between urban agriculture and ecosystem services well established, the question remains: what is the best way for planners and other food system actors to implement urban agriculture at a municipal and regional scale? To date, agriculture initiatives in the city have often been implemented rather haphazardly, with community groups often acting opportunistically without the benefit of a city-wide vision or regulatory framework (Angotti, 2015). Just as natural ecosystems often operate as a complex, interconnected system across a region, urban agriculture systems should not be viewed in isolation but rather as one element of a comprehensively planned network of green infrastructure. In order to obtain the maximum benefit from implementing urban agriculture, policymakers must plan for these systems in a comprehensive, holistic way. Table 6 identifies various strategies for planning for urban agriculture, along with associated tools and techniques and relevant examples. The tools presented here have proven successful for planners and community groups in the United States as strategies for envisioning, and subsequently implementing, urban agriculture networks at the municipal scale.

Table 6: Tools and techniques for fostering urban agriculture with relevant examples

Urban ag planning strategy	**Tools/techniques**	**Relevant Examples**	**Resources**
Incorporate urban ag into the planning process	•Set goals for urban ag in comprehensive plan •Prepare a municipal or regional food security plan that includes the role of urban agriculture in food security •Identify priority parcels for different types of urban agriculture •Consult with farmers and other food system actors •Form a food policy council or other advisory group to advise on urban ag policy issues	•Madison, WI Comprehensive Plan (adpoted in 2006) •San Francisco, CA General Plan •Portland Multnomah Food Policy Council	•Voigt, 2011
Create urban agriculture initiatives on city land	•Establish a farm or garden on city land •Manage the land using dedicated city staff, or form an arrangement with a non-profit or community group to manage the land	•Montview Neighborhood Farm, Northampton, MA	•Walsh & Welch, 2012
Support new urban ag initiatives by providing resources	•Link urban farmers with grant and loan programs •Provide a directory of vacant land and facilitate its conversion to urban ag •Provide discounted water utilities for urban farms, or subsidize a compost pick-up service	•Cleveland-Cuyahoga Food Policy Coalition Vacant Land Inventory for Urban Agriculture •Grounded in Philly	•Grounded in Philly, 2015
Modify zoning and land use policies to be more friendly to urban ag	•Create an urban ag land use category •Address all facets of urban ag in zoning codes, including livestock, accessory structures, rooftop farming, fencing, aesthetics, etc. •Create an urban ag district to protect existing urban farms from future development	•Boston, MA Article 89 •Cleveland, OH Chapters 336 and 347	•Mukherji & Morales, 2010
Incentivize inclusion of urban ag in new development and redevelopment projects	•Provide financial benefits, such as grants, loans, and fee rebates, for development projects that include urban ag •Provide non-financial benefits, such as density bonuses and expedited permitting, for development projects that include urban ag	•Austin, TX	•Shepard, 2010
Encourage monitoring and celebrate success	•Utilize adaptive monitoring strategies •Create indicators to measure progress over time •Celebrate successful urban agriculture projects	•Bloomington, IN •Farming Concrete	•Bagstad, Semmens, Waage, & Winthrop, 2013 •Chapman, 2012

6.2 Incorporate urban agriculture into the municipal and regional planning process

Urban agriculture is a multi-faceted issue that touches on many aspects of municipal planning, including land use, transportation, economic development, open space, and human health and well-being. As such, it should be considered in comprehensive plans at the municipal and regional levels. Many cities across the country have begun to incorporate urban agriculture into their comprehensive plans in different capacities; for example, the city of Madison, Wisconsin, addresses urban agriculture in the Natural and Agricultural Resources section of their comprehensive plan, while San Francisco reserves it for the Recreation and Open Space element of their general plan (City of Madison, 2006; San Francisco Planning Department, 2015). A regional planning agency in Washington State analyzed Seattle’s comprehensive plan and found that food policy could be related to and incorporated into nearly every element of the plan, from land use and housing to economic and human development (Puget Sound Regional Council, 2012). Given the cross-cutting nature of food system issues, it may also make sense for the city to develop a separate food system plan, similar to a municipal open space plan, that outlines a vision for the city's food system and mechanisms for incorporating urban agriculture as part of that vision.

It is important for cities to set specific goals and policy objectives when incorporating urban agriculture and food planning into the comprehensive planning process. These might include reforming zoning and land use codes to be friendlier to urban agriculture, hiring dedicated city staff to promote urban agriculture and implement other food policies, or even setting a particular goal for how much land should be converted to urban agriculture or how much food should be produced locally. For example, the city of Madison set a goal of one community garden site for every 2,000 households in the city, while the city of Seattle set a goal of one community garden site for every 2,500 households in a neighborhood (City of Madison, 2006; Puget Sound Regional Council, 2012). Priority sites for urban agriculture should be identified, along with the type of agriculture the city would like to see on each site and the ecosystem services it should provide. Model comprehensive plan language for urban agriculture is included in Box 5.

In addition to comprehensive municipal planning, regional food system planning is an essential avenue for the promotion of urban agriculture. For certain ecosystem services, including climate mitigation and habitat provision, a regional view is necessary to understand how urban agriculture can best be deployed to maximize these services. Although many regional planning agencies and non-governmental groups have prepared regional food plans, very few highlight urban agriculture as a primary focus. The Pioneer Valley Food Security Plan, prepared in 2014 by the Pioneer Valley Planning Commission, analyzes hunger, food access, and food production for three counties in western Massachusetts, but stops short of identifying the best locations and strategies for implementing urban agriculture in the region (Pioneer Valley Planning Commission, 2014). A robust food security plan should include recommendations for urban agriculture and an acknowledgement of the benefits it can provide beyond improved food security.

Finally, planners should consult with farmers and other food system actors when making decisions that might affect the food system. Food policy councils (FPCs) can be an effective tool for addressing food system issues at the municipal level; comprised of farmers, hunger prevention activists, nutrition educators, retail food vendors, urban agriculture advocates, and other stakeholders, these councils "try to monitor their city's food system and work to get various rips and tears in that system mended" (Pothukuchi & Kaufman, 1999, p. 219). FPCs are non-governmental

Box 5: Model Comprehensive Plan Language to Protect and Expand Urban Agriculture
From Voigt, 2011, p. 562

Background: Because the City of Compostville recognizes urban agriculture as a desirable activity that creates a more livable community, we state the following goals and objectives:

Goal: Encourage the use of urban agriculture in Compostville as a means of increasing access to healthy, local, and affordable foods, encouraging the productive use of vacant land, and opening up more agriculture-based business opportunities.

- Objective: Encourage appropriate agricultural uses of urban land.
- Policies/Actions:
  - Adopt zoning regulations that clearly define urban agriculture to include the cultivation of fruits, vegetables, flowers, nuts, and like products, as well as raising farm animals.
  - Adopt zoning regulations that discourage health and nuisance hazards sometimes associated with agricultural activities, which may include setback requirements, yard size requirements, complaint procedures, or permitting procedures.
  - Appoint a government employee in an appropriate agency who can serve as the point person on urban agricultural questions for residents.
- Objective: Promote more widespread use of urban agriculture.
- Policies/Actions:
  - Identify additional zoning districts that would be appropriate in which to allow urban agriculture.
  - Expand community gardening opportunities.
- Objective: Encourage residents to use urban agriculture as a tool for economic development.
  - Policies/Actions:
  - Adopt zoning regulations that allow urban agriculture as a home occupation in appropriate districts.
  - Allow the on-site and off-site sale of products from urban agriculture where appropriate.

bodies that typically serve an advisory role for municipal food issues. The Portland Multnomah Food Policy Council in Oregon is a particularly robust example, with working groups assigned to food justice, sustainable food metrics, urban food zoning codes, and many other issues in Multnomah County's food system (Portland Multnomah Food Policy Council, 2011). In 2006 the council refined an inventory of public land available for urban agriculture completed by a group of students from Portland State University (Balmer, et al., 2005), identifying three priority sites for pilot projects along with potential partners and resources for each site (Moran, et al., 2006). With the support of the city council, the FPC was able to push for urban agriculture in a more specific and directed way than the city might be able to do on its own.

More than the other strategies in this toolkit, incorporating urban agriculture into the municipal and regional planning process enables planners to take a comprehensive and holistic approach to food system planning. This tactic also enables the strategic implementation of urban agriculture to maximize the provision of ecosystem services across a regional network of green space. However, updating a master plan or creating a new advisory council can be a time- and labor-intensive process, and as such it may not be an appropriate first step for cities seeking to take action on urban agriculture in the near-term. Nevertheless, constructing a coherent policy framework regarding food system planning is an extremely important strategy for sustaining urban agriculture and providing ecosystem services in the long-term.

6.3 Create urban agriculture initiatives on city land

Underutilized public land presents an ideal opportunity for the implementation of urban agriculture. Cities may establish a farm on public land and manage it using dedicated city staff; however, the time, money, and resources required to do so are often prohibitive. More often, cities will partner with non-governmental bodies, such as a municipal food policy council or a local non-profit group, to establish and manage a farm or garden on municipal land. This relieves the city of the burden of paying to maintain the land while still affording some control over the agricultural practices used and thus the ecosystem services provided.

Montview Neighborhood Farm, highlighted earlier as an example of a climate mitigating garden, was also unique for its location on public land. The 3.2 acre parcel of land on which the farm was located was donated to the Northampton Conservation Commission in 2000 and was managed as a recreational field until 2005, when a new lease was signed (Walsh & Welch, 2012). The city signed a three-year lease with the Montview farmers to establish an organic farm on the land in exchange for "the equivalent of one hundred dollars per acre per year in sweat equity, which will consist of stewarding the land, mowing as necessary and maintaining paths for farm and public use" (Walsh & Welch, 2012, p. 16). Through this innovative agreement, the farmers gained access to free land, and the city was relieved of the responsibility of maintaining the land for conservation. As dictated by the terms of the lease, when the city decided not to renew at the end of six years, the land was returned to native grasses; perennials and woody shrubs and saplings were uprooted and sold or swapped to other local gardeners.

Leasing city-owned land for urban agriculture projects can be an effective tool for cities to facilitate the success of these projects; however, the terms of the lease must be clear about what will and will not be allowed. For example, because Montview's lease specifically stated the requirement that the land be returned to native grasses if the lease should run out or be terminated, the farmers were never able to construct permanent structures. The farmers at Montview were conscientious about interacting with the neighbors in this largely residential area, going so far as to sign an agreement assuaging some residents' fears about the potential impacts of farming activity in the area before planting even began (Walsh & Welch, 2012); this type of agreement should be a requirement of the lease in order to facilitate the smooth integration of land-uses that have sometimes been viewed as incompatible. The lease also stipulated that the land remain open to the public, which for Montview provided an opportunity to further integrate the farm with the neighborhood by leaving some areas open for use as a soccer field and by hosting educational events and workshops.

Creating urban agriculture initiatives on city-owned land affords the city more control over the type of agriculture that is practiced and thus the kinds of ecosystem services that are emphasized. This strategy may be the best for planners interested in implementing a specific type of urban agriculture typology on a particular lot; for example, the city may send out a request for proposal (RFP) for farmers to install a habitat garden on a vacant city-owned lot, or solicit bids for farmers to build and maintain a stormwater garden on the roof of a city building. The major drawback of installing urban agriculture systems on city land is that they may become a drain on city resources.

For some cities, it may be easier to support existing urban agriculture projects and encourage new initiatives by providing resources other than land.

6.4 Support new urban agriculture initiatives by providing resources

Short of providing public land for urban agriculture initiatives, cities and community groups can facilitate the growth of urban agriculture by linking farmers with other resources. These might include discounted water utilities, reduced stormwater utility fees, subsidized compost pick-up, or even pathways for accessing privately-owned vacant land (Mukherji & Morales, 2010). Community groups could also provide grants and loans for new urban agriculture initiatives or provide resources on its website for third-party grants and loans. Another option is to provide property tax exemptions for landowners who lease their land to urban farmers (Peters K. , 2010). Naturally, the city will have less control over the design and management, and hence the ecosystem services, of urban farms established on private land than those on public land; however, through proactive zoning and permitting, the city may be able to negotiate with farmers to ensure sustainable management practices and maximization of ecosystem services on private land.

Connecting farmers with privately-owned vacant land is an especially innovative tool for ‘shrinking cities’ such as Detroit and Cleveland; these cities have seen their populations drop due to industrial decline and as a result contain a patchwork of vacant land throughout the city. Urban agriculture can be an excellent tool for revitalizing areas that have been blighted by high vacancy rates; in fact, community gardens often pop up without any action from the city as a neighborhood response to long-term vacancy. A city inventory of vacant land that could be used for urban agriculture can be a valuable starting point for farmers in search of land.

In 2010, the Cleveland-Cuyahoga County Food Policy Coalition created an inventory of vacant land in Cuyahoga County that could be used for urban agriculture (Taggart, Chaney, & Meaney, 2010). Criteria included size (only parcels over 1/4 acre were included), presence of prime farmland soils, zoning (land zoned industrial was excluded), contamination and brownfield status, and current land use (forested land was excluded). The inventory found a total of 1,108 parcels that met all of these criteria, comprising 1,754 acres of land that could be used for urban agriculture within Cuyahoga County. However, the inventory stopped short of suggesting ways for farmers to gain access to these vacant lots.

A vacant land inventory in Philadelphia contains this missing piece. A non-profit in Philadelphia called Grounded in Philly created an online tool to link the owners of vacant property with citizens interested in returning the property to productive use through the installation of green spaces, gardens, and community spaces (Grounded in Philly, 2014). The website includes a database of over 40,000 vacant parcels around the city with the landowner's name and the current status of the parcel, along with various 'pathways' for citizens to gain access to vacant land. Pathways include reaching out to private landowners to make an agreement, leasing or purchasing land from the city, petitioning for conservatorship of a blighted lot, reaching an agreement with the Redevelopment Authority or the Philadelphia Housing Development Corporation to manage land owned by those agencies, partnering with non-profits dedicated to converting vacant land to gardens, and even acquiring land through adverse possession (Gregory, 2010; Grounded in Philly, 2014).

Linking urban farmers with land and other resources involves not only identifying those resources, through a vacant land inventory or other means, but also providing pathways for farmers to access those resources. Boston's Grassroots program, administered through the Department of Neighborhood Development, funnels federal funding from the Community Development Block Grant program to local groups to install or improve community gardens on vacant land; over $2.3 million was channeled through the program from 2008 to 2014 (City of Boston Parks and Recreation Department, 2014). This program also provides technical assistance for these groups and, in some cases, conveys vacant city property to these groups for conversion to community garden space (City of Boston Department of Neighborhood Development, 2015). Programs such as this one that support urban farmers by providing resources are less costly than providing city land for these initiatives, but the drawback is that the city has less control over what types of farms are established and thus what ecosystem services may be provided.

6.5 Modify zoning and land use policies to be more friendly to urban agriculture

A fourth way for cities to foster the growth of urban agriculture initiatives is to reform city zoning ordinances to support urban agriculture. Many zoning codes inadvertently limit urban agriculture activities in one of two ways: by restricting agricultural activities in most zoning districts, and by restricting the scope of commercial activity in many districts (Voigt, 2011). These restrictions are in place to prevent conflicts between incompatible land use types, and indeed, a large commercial farm in a densely settled residential neighborhood may not be an appropriate form of urban agriculture. Nevertheless, by imposing blanket restrictions on all agricultural activities in certain zoning districts, cities limit opportunities for agricultural operations that could benefit the neighborhood as well as the city, such as community gardens, backyard homesteading operations, and rooftop farms.

Cities can address urban agriculture through two broad zoning mechanisms: urban agriculture districts and urban agriculture as a use category (Mukherji & Morales, 2010). Each of these has distinct advantages and applications. Creating a use category for urban agriculture allows cities to regulate what type of urban agriculture is allowed in each district; for example, urban gardens under a certain square footage may be allowed in high-density residential zones, while larger farms may be allowed in areas zoned commercial or industrial. This also allows the city more control over other aspects of urban agriculture, such as the animal husbandry and aesthetic cohesion with the neighborhood. The extent to which commercial activity, such as the sale of vegetables at a farm stand, is allowed on urban farms in each zone should be regulated as well; cities may consider including urban agriculture as a home occupation to enable private farmers in residential areas to sell their produce on-site (Voigt, 2011).

Complementary to the creation of an urban agriculture use category is the use of urban agriculture zoning districts. If used alone, urban agriculture zoning districts may be too restrictive; for example, farmers wishing to establish a new farm on a vacant parcel would have to petition for a variance or for the parcel to be rezoned as an urban agriculture district. In this scenario, an urban agriculture use category would be more permissive, especially if the city is proactive in specifying what types of urban agriculture uses are allowed in each zoning district. However, urban agriculture districts have an advantage when it comes to protecting existing urban gardens and farms from development. Identifying urban agriculture initiatives that are valued by the community and classifying them into an urban agriculture zoning district can help protect those parcels from future development because any developer that purchases the land will not be able to build on it unless it is rezoned (Voigt, 2011).

It is important that zoning address all aspects of urban agriculture to avoid confusion and provide clear guidelines for urban farmers; these include regulations for accessory structures, rooftop farming, fencing, livestock and bees, aesthetics, commercial activity, noise, and safety. City ordinances should be as permissive as possible, and part of the zoning reform process should include repealing old zoning laws that could be excessively restrictive or ambiguous. For example, the city of Los Angeles had a law on the books dating back to 1946 that allowed vegetables to be grown in residential areas and sold off-site at farmers markets or small farm stands, but without a clear definition of the term ‘vegetables,’ the law was interpreted to exclude fruit, flowers, eggs, and other farm products until it was reformed in 2009 (Spiers, 2009).

The zoning code of Boston, Massachusetts, contains a particularly comprehensive treatment of urban agriculture. After a process that involved collaboration between the Boston Redevelopment Authority, the Mayor's Office of Food Initiatives, and the Mayor's Urban Agriculture Working Group, consultation with farmers and agriculture experts, and a series of public and neighborhood meetings, Article 89 was adopted into Boston's zoning code to regulate agriculture in the city in 2014 (Boston Redevelopment

Authority, 2014). The article explicitly allows ground-level and rooftop farming in residential, commercial, industrial, and institutional zones, with more unconventional agriculture systems such as freight container farming and hydroponic greenhouses being allowed conditionally in these zones. The article is extremely comprehensive, with regulations to address accessory structures, signs, screening for compost piles and beehives, and keeping livestock. It even establishes a process of 'comprehensive farm review (CFR)' for farms that might have a larger impact on surrounding properties, such as those in dense residential neighborhoods or larger farms where livestock is kept. Small farm stands are allowed by right wherever urban agriculture is allowed (Boston Zoning Ordinances, Article 89).

Boston released a number of supplementary materials to make Article 89 easier to understand and implement; these include a report by the Boston Redevelopment Authority called “Article 89 Made Easy” (Boston Redevelopment Authority, 2014) and an online application called urb.ag. The application allows users to enter the address and specifications of a potential urban agriculture site (i.e., accessory structures, livestock, composting, hydroponics, etc.) and view all the restrictions governing that site. The website outlines the permitting process for different types of projects in different parts of the city, including historic districts, sites within 100 feet of Boston city parks, and sites that require comprehensive farm review.

Cleveland’s zoning code utilizes both an urban agriculture use category and an urban garden district. Passed in 2007, Cleveland’s Chapter 336 ordinance creates an 'urban garden district' and allows parcels to be rezoned for the purpose of urban agriculture. The district allows community gardens and market gardens, including the sale of produce, by right and contains supplemental regulations on buildings and accessory structures, fencing, and signs, parking (Cleveland Zoning Ordinances, Chapter 336).

The urban agriculture use category, defined in Chapter 347 of the city zoning code, has distinct regulations for small animals such as "chickens, ducks, rabbits, and similar animals" and for larger animals including "goats, pigs, sheep, and similar animals" (excluding horses and cows). These regulations include restrictions on number of animals (1 small animal per 800 square feet of parcel area, or 1 large animal per 2,400 square feet on lots larger than 24,000 square feet), location of structures (not allowed in side or front yards), and setbacks for structures (at least 5 feet from side yard line and 18 inches from rear yard line for small animal enclosures, or 40 feet from the street and 100 feet from other dwellings for large animal stables). Certain requirements for the construction of enclosures are also specified, such as fencing for chicken coops and a 'flyway barrier' for beehives less than 25 feet from the property line (to prevent bees from crossing the property line at a height of less than 6 feet) (Cleveland Zoning Ordinances, Chapter 347). Permits are required from both the Building and Housing Department and the Health Department for urban agriculture systems involving livestock.

A major advantage of modifying zoning and land use policies to be friendlier to urban agriculture is that planners can use zoning and permitting tools to protect urban farmers from development threats, nuisance suits, and other potential threats. These reforms may be implemented in a piecemeal fashion if necessary; for example, the city might pass legislation regulating livestock in the city center if this is a pressing issue, leaving other urban agriculture regulations for later. However, this strategy may leave gaps or loopholes in the zoning code or increase the complexity of the permitting process. As one author writes:

> "While municipal efforts to accommodate urban gardening have been useful, many are piecemeal provisions that fail to take a broader view towards addressing urban agriculture. Unfortunately, a piecemeal approach can serve to discourage urban farmers because it adds complexity and increases costs, thus deterring would-be farmers and entrepreneurs. To fully utilize urban agriculture as a tool for promoting the revitalization of a town or city, officials should consider a more comprehensive approach for incorporating urban agriculture into their zoning regulations. Such an approach would involve steps that clarify the city's support for urban farming, standardize the urban farming activities that are permitted, and facilitate the sale of goods produced from those permitted activities" (Voigt, 2011, pp. 559-560).

The best way to modify zoning is to enact reforms in a comprehensive way that lines up with the urban agriculture vision outlined in the comprehensive plan.

6.6 Incentivize the inclusion of urban agriculture in new development and redevelopment projects

Finally, cities may give developers incentives to include urban agriculture in new developments and redevelopment projects. Direct financial incentives might include grants, loans, and fee reductions or rebates for projects that include an urban agriculture component; indirect incentives include density bonuses and expedited permitting (Shepard, 2010). These incentives are already widely used to encourage the inclusion of public open space in development and redevelopment projects, and increasingly cities are also utilizing these tools to incentivize green roof construction on new buildings. Cities should incentivize new urban agriculture projects in the same way. In recognition of the ability of urban agriculture to provide ecosystem services, the city could also offer developers the option of implementing urban agriculture in order to fulfill other site planning requirements, such as stormwater management or carbon footprint reduction.

The advantage of this strategy for promoting urban agriculture is that construction costs are incurred by the developer, not by the city, and that maintenance of the new farm is also not likely to fall to the city. The question of who will be responsible for maintenance of the farm or garden will be decided on a case-by-case basis; in a new housing development, the space could be divided into individual garden plots for residents, or in the case of a new building, an agricultural space on the roof could be leased to a commercial farmer for intensive production. In some cases, the city may also require that urban farms be publicly accessible or provide additional incentives for those that are open to the public, thus providing additional benefits to the community.

The city of Austin, Texas, recently began utilizing some of these tools to incentivize the construction of green roofs on new buildings. This initiative was partly in response to issues of stormwater management in the downtown area and partly a way to increase the amount of public open space in the city. A 2011 proposal recommended a density bonus of two to three square feet of bonus floor area for each square foot of vegetated roof area, with an additional bonus of one to five square feet of bonus area per square foot of vegetated area for those roofs that are accessible to the public (Austin Green Roof Advisory Group, 2011). In this way, the city incentivized the development of green roofs in order to take advantage of the multiple benefits they provide without incurring additional costs.

6.7 Encourage monitoring and celebrate success

Finally, planners and community groups should encourage urban agriculture practitioners to monitor and report the amount of food produced, water managed, habitat created, carbon sequestered, and other indicators of ecosystem services provided by the farm or garden ecosystem. Monitoring of ecosystem services may be accomplished using a diversity of methods (Bagstad, Semmens, Waage, & Winthrop, 2013), but the best strategy is one that is adaptive and responds to current conditions and future trends (Chapman, 2012). Monitoring is an extremely important component of any sustainable development strategy and gives farmers and policymakers alike some insight into the specific benefits of urban agriculture and informs the creation of customized strategies for maximizing those benefits.

Complementary to monitoring the impacts of urban farms and gardens is celebrating projects that are successful at providing ecosystem services. Well-designed farms and gardens that are shown to have a positive impact on human and environmental health in the city should be highlighted as examples for practitioners in other cities to strive towards. Celebrating successful urban agriculture projects also serves to raise awareness and may provide opportunities for environmental education, which may in turn affect public perception about urban farms and gardens in a positive way. Defining what a ‘successful’ farm looks like will necessitate the creation of indicators that can be used to quantitatively or qualitatively measure the impacts of a particular urban agriculture project.

The City of Bloomington, Indiana has taken the first step towards monitoring ecosystem services by creating indicators for green infrastructure in the city (City of

Bloomington Environmental Commission, 2015). These include ecological indicators such as number of mature street trees as well as organizational indicators such as number of conservation easements held by private and non-profit groups. The indicators relating to urban agriculture, including number and area of community gardens as well as number of community garden plot holders, are broad and do not relate specifically to ecosystem services apart from food production; a more comprehensive set of indicators would include soil nutrient content, wildlife species witnessed in the garden, carbon sequestration capacity, and other metrics that relate more specifically to the ecosystem services of urban agriculture. The creation of these indicators is a good start towards monitoring the impacts of urban agriculture and other green infrastructure elements in the city, but so far the city has failed to follow up with continued monitoring and has not outlined any goals in its comprehensive plan for improving performance based on these indicators (City of Bloomington Planning Department, 2002).

Another group working to establish baseline indicators and a system of monitoring for urban agriculture systems is Farming Concrete in New York City (Farming Concrete, 2015). A project of the non-profit group Open Space Institute, Inc., Farming Concrete is a data aggregation interface for urban agriculture, where users can upload data about a particular urban farm or garden or download reports showing urban agriculture indicators for a particular city. Indicators include food production, compost production, landfill waste diversion, rainfall collection, market value of produce, and even some social indicators such as gardener skill and knowledge and attitudes towards food (Five Borough Farm, 2014). Although the focus was initially on New York City, data has already been uploaded by users on four continents (Farming Concrete, 2015).

This type of grassroots data collection and aggregation can be a powerful tool for monitoring the growth of urban agriculture and quantifying the benefits it can provide, but should be complemented with a policy framework that utilizes this data collected to make a positive impact on human and environmental health.

6.8 Conclusion

This toolkit represents a grab-bag of planning strategies that cities can use to foster urban agriculture. The particular circumstances of the city, as well as that city's urban agriculture goals and the timeframe of implementation, will determine which tools will be most effective for encouraging new urban agriculture initiatives and supporting existing ones. Table 7 identifies some strengths and weaknesses of each of the planning strategies discussed here. In order to maximize the ecosystem services that may be provided by urban agriculture systems, planning for these systems should be undertaken in a comprehensive, holistic way, using strategies that take into account the local and regional context as well as the city's particular goals for urban agriculture.

Table 7: Strengths and weaknesses of various urban agriculture planning strategies

Urban ag planning strategy	Strengths	Weaknesses
Incorporate urban ag into the planning process	•Provies a more holistic and comprehensive approach to food system planning •Enables strategic implementation of urban ag for maximization of ecosystem services	•More time-consuming than a more piecemeal approach
Create urban agriculture initiatives on city land	•May afford the city more control over what type of agriculture is practiced and what ecosystem services are emphasized	•City-managed urban ag initiatives require a large investment of time and money from the city
Support new urban ag initiatives by providing resources	•Less costly than a city-managed urban ag initiative	•City has less control over what types of farms are established and therefore what types of ecosystem services are provided
Modify zoning and land use policies to be more friendly to urban ag	•May be easier to implement in a piecemeal way •Protects urban farmers from nuisance suits, development threats, and other potential threats	•Zoning codes may have gaps or loopholes if not implemented comprehensively
Incentivize inclusion of urban ag in new development and redevelopment projects	•Construction costs are incurred by developer, not by city •Urban ag may be utilized by developers to fulfill other site planning requirements (i.e., stormwater management, carbon footprint reduction, etc) imposed by the city •City may require urban ag systems be publicly accessible, providing additional benefit for public	•City and developer must have a plan for who will maintain urban ag once project is complete (building owner, tenants, city, etc)
Encourage monitoring and celebrate success	•Allows for tracking of ecosystem services over time •Successful projects are examples for other practitioners to follow and may improve public perception of urban agriculture through environmental education	•Monitoring must be strategic and should involve pre- and post-installation measurements •Monitoring may be costly

CHAPTER 7

RECOMMENDATIONS AND DIRECTIONS FOR FUTURE RESEARCH

7.1 Highlights: Urban agriculture and ecosystem services

Agricultural systems, while not natural systems, can provide significant ecosystem services when planned and managed in a sustainable way. Urban farms and gardens differ from conventional rural farms in scale, purpose, and management techniques and, as a result, provide a unique suite of ecosystem services in the urban setting. These services include not only food production, but also stormwater management, soil building, habitat, climate mitigation, and cultural and educational benefits.

Farms and gardens that are carefully designed and sustainably managed using certain best practices can provide a diverse array of ecosystem services. Best practices include use of organic growing techniques; application of no-till techniques or tilling techniques that don't disrupt soil horizons, such as hand tilling or chisel plowing; utilization of a wide diversity of plant species, including plenty of native species; planting woody vegetation and perennial herbs; and forming connections with open space networks on a local and regional scale.

A multi-scalar approach is essential for obtaining the most benefits from an urban agriculture system. Agriculture in the city should be planned for in a holistic, comprehensive way in conjunction with other forms of green infrastructure. Education and monitoring of urban agriculture systems are essential to raise public awareness and celebrate successful projects.

7.2 Directions for future research

A more comprehensive assessment and quantification of the ecosystem services provided by urban agriculture is needed. Certain ecosystem services that were outside the scope of this project require further research; these include air quality, mitigation of the urban heat island effect, water purification and recycling, mental and physical health benefits, and economic benefits such as impacts on real estate values, among many others.

Certain areas of research have been extensively written about, including the potential contribution of urban agriculture to food security and the types of wildlife that may be found in urban gardens. Other areas demand further research; most glaring is the lack of quantitative data about the link between urban agriculture and climate mitigation. Also lacking is data about the effect of different urban agriculture techniques on water infiltration; most quantitative studies on this subject involve rural farms or vacant lots but do not directly address urban agriculture. As these gaps are filled in, funding opportunities relating to stormwater management and CSOs, green infrastructure, and climate change mitigation will become available to urban agriculture initiatives.

An important method for advancing research on this subject is on-farm experimentation. Most farmers do periodic tests of the soil to compare soil health before and after garden installation; similar tests should be done for water infiltration, biodiversity, carbon sequestration, and local air quality to compare conditions before and after the implementation of urban agriculture and to demonstrate the effects of different management techniques on the provision of these ecosystem services. An important question that remains unanswered is the relationship between ecosystem services and productivity; will farms that change their production methods to increase certain ecosystem services suffer in terms of productivity? If so, this may affect the types of incentives that planners and community groups choose to offer to farms and gardens that use sustainable production methods.

Finally, a natural complement to urban agriculture research is research about waste management systems, including both solid waste and wastewater. How can urban farms and gardens be linked with a larger system of reuse and recycling to make use of composted food waste, recycled greywater, and other 'waste' products? This question is closely linked to the concept of ecosystem services and is a necessary component of a sustainable city-wide network of urban agriculture.

7.3 Recommendations for urban agriculture planning

Planners at the municipal and regional scale can be key actors in the food system. Planners should acknowledge the important role of urban agriculture in providing ecosystem services and utilize planning tools and techniques to match farmers with land. A comprehensive, forward-thinking method of planning for urban agriculture should unfold in four stages:

1. Create a policy framework to acknowledge urban agriculture as a strategy for providing ecosystem services and support urban agriculture initiatives.
2. Identify priority sites for the implementation of urban agriculture as a technique to supply ecosystem services.
3. Facilitate the conversion of these sites to urban agriculture by providing resources and guidance on management practices to ensure maximum provision of ecosystem services.
4. Encourage long-term monitoring of these sites and celebrate successful urban agriculture projects.

The first step involves creating a policy framework to support urban agriculture. First, the city should update its comprehensive plan to acknowledge urban agriculture's role in the overall health of the urban ecosystem and set specific goals for the implementation of agriculture in the city. The city can also prepare a plan to address issues of urban food production more specifically, such as a food security plan or even an open space plan. After creating a broad framework in the plan, the city should modify its zoning and land use policies to be friendlier to urban agriculture.

Next, it will be important to identify priority sites for the implementation of urban agriculture as a strategy for providing ecosystem services. Performing an inventory of vacant land and rooftop space is a useful first step. Some criteria for identifying potential urban agriculture sites might include areas that are not already built on or forested, flat areas, south-facing aspect, prime farmland soil (or in the case of rooftop gardens, structural capacity to support the weight of soil), and areas that can be linked with nearby green spaces or corridors. Identifying the problems and opportunities of each lot in the inventory will help planners to understand the potential ecosystem services that could be provided by each site. A few sites should be selected as priority sites for the implementation of urban agriculture.

The third step is to facilitate the conversion of these sites to urban agriculture by providing resources or other incentives. Resources might include land or discounted utilities for urban farmers; incentives might include expedited permitting, grants and loans, or density bonuses for projects that include urban agriculture. Planners should examine the proposed management techniques of each new urban agriculture project and encourage urban agriculture typologies that maximize the provision of specific ecosystem services appropriate to the site and to the region.

Finally, it is important to monitor the success of urban agriculture projects over the long-term. Identifying a set of indicators to measure the provision of ecosystem services will help measure progress over time. Celebrating successful projects will highlight those particular farms and gardens as examples for practitioners to follow as well as presenting an opportunity for environmental education to raise awareness of the benefits of urban agriculture.

With conscientious design and an explicit focus on ecosystem services, urban agriculture systems can provide benefits to human and environmental health that extend far beyond food production. The health of the urban ecosystem, with human beings at its center, can be substantially improved with a multifunctional, multi-scalar network of urban agriculture when integrated with other forms of green infrastructure. Planners can insert themselves into this ecosystem at multiple scales and utilize traditional planning tools in a creative way to apply best practices and urban agriculture typologies in order to take advantage of the multiple benefits of urban agriculture.

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