Urban Food Forestry

Low-hanging fruit for improving urban food security?

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For the degree of
Master of Science

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A thesis submitted in partial fulfillment of the requirements of Lund University International Master's Programme in Environmental Studies and Sustainability Science (LUMES), May 2011

Abstract

Global climate change and rapid worldwide urbanization are increasingly compromising urban food security. Urban forestry and urban agriculture are two widespread strategies for mitigating the effects of climate change and urbanization. This thesis proposes combining these two approaches into "urban food forestry" (UFF) as a multifunctional urban landscape planning strategy. Four research questions are addressed focusing on the prevalence of UFF, the potential production capacity and feasibility of UFF, and the specific species, resources and techniques available to assist local decision-makers in planning and implementing UFF landscape features. Various quantitative methods were utilized including text analysis of municipal urban forestry management plans (UFMPs), cataloging and categorizing initiatives that bridge urban forestry and food security, geographic information system (GIS) and horticultural yield calculations for Burlington, Vermont, and developing a Climate-Food-Species-Matrix (CFSM) to highlight recommended species. The concept of leveraging urban forestry for food security was found to be very sparse in academic literature, and only 4 out of 30 UFMPs analyzed made a connection between urban forestry and food security. Results from GIS and horticultural calculations indicate that UFF is a feasible and cost effective way to meet the caloric deficit of the urban food insecure population in the study area; the entire caloric deficit of the Burlington population could be supported on around 113 acres of low-density planted land out of 446 currently available, and around half this much land if planted high-density. A total of 69 species of perennial food-producing species were identified for use in temperate and continental climates and ranked according to drought and cold hardiness. Given these results, UFF appears promising as a widespread, adaptable and productive multifunctional landscape design strategy for improving urban food security as well as contributing to ecological, social, and economic capital of urban centers.

Key words: urban forestry, food security, resilience, urban agriculture, landscape ecology, multifunctional landscape, sustainability science

Word count: 14,830*

*Excludes abstract, references, figures, reference tables and appendices

Acknowledgements

As is often the case with thesis writing, my experience has been characterized by frequent ups and downs with regard to my inspiration, confidence and motivation. Throughout this period I have changed my topic numerous times and was fortunate to have Kim as my advisor, as she was able to deal well with my unpredictability and offer structure and sound advice to keep me on track. I am ever grateful for my family in the U.S. for their constant support and encouragement, as well as for fostering my creative interests which played a large part in inspiring my thesis topic. To my friends in LUMES, I will be ever thankful for the past two years that have provided me with so much inspiration, laughter, and joy, particularly to the seven close friends I lived with at the Yellow House – Tim, Nina, Mariana, Jess, Anja, Johanna, and Christoph. I equally thank all of my non-LUMES friends who have reminded me that there exists a world outside of our academic bubble. A special thanks to Aurora for her constant inspiration and encouragement. Finally, a big thanks to all of the faculty at LUCSUS who have facilitated many new thoughts and ideas during my time in Lund that will continue to inspire personal research and knowledge innovation for years to come.

Table of Contents

List of Figures

List of Tables

Abbreviations

UFF: Urban Food Forestry

VFI: Very Food Insecure

FAO: Food and Agriculture Association

WHO: World Health Organization

UFMP: Urban Forestry Management Plan

UPA: Urban-Periurban Agriculture

NTFP: Non-Timber Forest Products

USDA: United States Department of Agriculture

CSM: Climate-Species-Matrix

CFSM: Climate-Food-Species-Matrix

GIS: Geographic Information System

LE: Landscape Ecology

SS: Sustainability Science

1. INTRODUCTION

Among the greatest challenges faced by humankind during the 21st century is ensuring food security for the expected 10 or more billion people worldwide while simultaneously undergoing climate change (Easterling 2007). Considering that over half of the world's population now lives in urban areas and that this percentage is expected to grow (Dubbeling et al. 2009), coupled with the fact that urbanization disproportionately affects the poor (Ravallion 2007), maintaining and improving food security in urban areas presents a particularly difficult task. Fraser et al. (2005) have demonstrated that food systems supplying cities in the West are characterized by high levels of vulnerability as defined by Gunderson & Holling's (2002) Panarchy framework. Furthermore, each of the four primary dimensions of food security identified by the United Nation's Food and Agriculture Organization (access, availability, stability, and utilization) each face numerous threats including rising food prices, climate change, and various unpredictable disturbances and shocks (FAO 2002; Schidhuber & Tubiello 2007).

Urban and peri-urban agriculture (UPA) has emerged as a worldwide solution-oriented strategy to build urban food system resilience (De Zeeuw et al., 2011). A recent forum entitled "Urban and Periurban Agriculture for Resilient Cities" organized by the FAO, the International Development Research Center (IDRC), the Chinese Urban Agriculture Association and others concluded that it is critical to integrate urban agriculture into future urban plans, build urban agriculture capacity by integrating it into the curricula of schools, technical colleges and universities, and link municipal policies to central government policies in order to maximize the effectiveness of UPA (Dubbeling et al. 2009). Urban agriculture has also been advocated by the World Meteorological Organization, the World Bank, and the European Union as having high potential for improving the urban environment and contributing to climate change adaptation, echoing the FAO's position that local food production within cities is critical for future urban food security (De Zeeuw et al., 2011).

Fruit and vegetables have been specifically targeted by a number of high profile organizations and national governments as part of food security and public health initiatives. In 2004, the FAO and World Health Organization (WHO) held a series of conferences specifically aimed at developing strategies to increase the production, availability, access and utilization of fruits and vegetables worldwide (FAO/WHO 2004). By doing so, these organizations aim to reduce incidence of chronic diseases such as cancer, diabetes, obesity, and heart disease as well as micronutrient deficiencies (FAO/WHO 2004). A detailed framework was drawn up that includes goals such as increasing and diversifying global fruit and vegetable production, changing knowledge, attitudes and behaviors about fruit and vegetables, and increasing availability and affordability of fruits and vegetables; media education campaigns, school food programs, improving cultivar selection, and increasing land availability for urban agriculture are among the specific actions recommended to accomplish these goals (FAO/WHO 2004).

In this thesis, I investigate the concept of leveraging urban forests and other forms of urban green infrastructure as a new form of perennial-based urban agriculture, what I have termed *urban food forestry* (UFF). I begin by addressing the prevalence of this concept by conducting a literature review, textual analysis of urban forest management plans, and analysis of public artwork depicting perceived functions of the urban forest. Next, I describe existing initiatives which bridge urban forestry and food security and create a typology which divides them into three distinct categories: planting, mapping, and harvesting. Following this, I perform a GIS analysis to determine how much public land is available for UFF in the city of Burlington, Vermont and use horticultural data to calculate the potential yield of this land if it were planted with apple trees. Finally, I discuss practical considerations for municipalities considering implementing UFF; the most notable contribution being a Climate-Food-Species-Matrix (CFSM) which identifies suitable food-producing perennial plant species and ranks them based on their drought tolerance, cold hardiness, and edibility. The findings of my research are framed within the context of landscape ecology theory and sustainability science where I examine UFF as a potential solution-oriented multifunctional landscape design strategy for contributing to urban food security as well as building the resilience and adaptive capacity of urban social-ecological systems.

2. RESEARCH DESIGN AND METHODS

This thesis addresses four main research questions, each of which contains up to three subtopics. The overall research design is based on quantitative methods and is intended in part to address to the lack of quantitative analysis within urban agriculture research (Zezza & Tasciotti 2010; Dubbeling et al. 2009; De Zeeuw et al., 2011). Table 1 summarizes my research questions, subtopics, and methods used.

Research Question	Subtopics	Method(s)
1. How prevalent is the idea of leveraging urban forestry for food security?	1.1 Prevalence in academia	Literature review, text analysis
	1.2 Prevalance in policy & municipal planning	Urban forestry master plan text analysis
	1.3 Awareness among general public	Public artwork analysis
2. What types of initiatives bridge urban forestry and food security?	2.1 Urban food tree planting & community orchard initiatives	Internet research, cataloging
	2.2 Urban food tree harvesting & distribution initiatives	
	2.3 Urban food tree mapping initiatives	
3. What is the potential capacity of urban food forestry to meet food needs?	3.1 Available land within cities to plant food trees	GIS analysis
	3.2 Capacity for public land to meet needs of urban food insecure population	Horticultural calculations
4. What species should municipalities consider for urban food forestry?	4.1 Climate-ready food trees for urban food forestry	Literature review, cataloging
	4.2 Implementation cost	Internet research

Table 1: Research questions, subtopics, and methods used in thesis

2.1 Research Question #1: How prevalent is the idea of leveraging urban forestry for food security?

I identified, counted, and analyzed the relevance of documents mentioning both urban forestry and food security in three contexts: academia, municipal government, and the general public. Findings from one area were used to refine searches in another. For example, research addressing the prevalence of this subject among the general public yielded terms like *community orchards*, *food forests*, and *forest gardens*, which I was previously not well acquainted with. These terms were then added the list of search terms used in academic journal queries.

2.1.1 Prevalence in academia

I used Lund University's LibHub server and Google Scholar to conduct searches for peer-reviewed articles pertaining to my thesis topic. To concentrate my efforts and limit ambiguous results, I used the following guiding topic as a measure of relevance for searches: *utilizing urban forestry for public food production in order to improve food security and food system resilience in developed cities.*

Journal article searches were conducted in three phases, beginning with a wide scope and gradually narrowing in focus. In the first phase I used general search queries such as {"urban forestry" AND "food security"} and scanned titles and abstracts of returned articles to gauge their relevance. Adobe Acrobat was used to search documents for keywords. In the second phase, six relevant academic journals were selected for a more thorough examination. These journals were chosen based on the frequency of articles returned during the first phase. This gave me the opportunity to conduct more precise searches and examine results more thoroughly. I selected search terms for each journal based on applicability; e.g. "agroforestry" was considered an appropriate keyword for searches in the Journal of Urban Forestry & Urban Greening, but not appropriate for the Journal of Agroforestry Systems. The third phase of journal article searches involved thoroughly reading articles which were found to be relevant to the guiding topic.

2.1.2 Prevalence in municipal government

I analyzed the text of 30 urban forestry management plan (UFMP) documents to determine the prevalence of urban food forestry in a municipal government context. UFMPs were located using Google search queries such as: {urban forestry master plan} and {intitle:"urban forestry" AND plan}. All of the UFMPs are associated with North American cities; 20 in the United States, and 10 in Canada. I used Adobe Acrobat to locate instances of "fruit", "food", and "wildlife". "Wildlife" was included to illustrate the difference in frequency between these two functions of urban forestry in municipal planning (i.e. utilizing urban trees for wildlife food security vs. human food security). Each time an occurrence of either "food" or "fruit" was encountered, I read the accompanying section to determine if it was used in the context of human consumption and kept a tally. In addition to analyzing text, I visually scanned each document to ensure that no pictures or scanned pages were overlooked by the search algorithm. A total of 2099 pages were analyzed.

2.1.3 Awareness among the general public

I used two strategies to gauge the connection between urban forestry and food security among the general public. First, I analyzed a total of 573 public artwork banners submitted to the Urban Forestry Project (UFP 2011) depicting public interpretations of urban trees from three major metropolitan areas in the United States (New York City, San Francisco and Toledo). I examined each of these banners to determine how many make reference to food. Criteria for considering a banner as depicting urban trees as a food source were lenient: if the poster showed *any* hint of food, even a piece of fruit as a background feature, it was counted – the rationale being that fruit was still part of the artist's conceptualization of urban trees, even if a subtle one. Similar to the UFMP analysis, instances of wildlife were noted to illustrate the difference in frequency of wildlife versus food. This analysis gives a snapshot of the current prevalence of the notion of urban trees as a source of food amongst urban residents in these cities.

Following this analysis, I conducted internet searches to locate initiatives relevant to my guiding topic. These searches revealed a variety of news articles, videos and non-profit organizations websites. I decided that the number and diversity of initiatives merited an additional research question aimed at categorizing these initiatives, which ultimately led to the addition of Research Question 2.

2.2 Research Question #2: What types of initiatives bridge urban forestry and food security?

I used internet searches informed by knowledge gathered during my investigation into Research Question #1 to locate relevant initiatives. I recorded pertinent data in Excel including name of the initiative, location, year founded, type of initiative, number of volunteers active (if applicable), amount of fruit harvested (if applicable), etc. I documented a total of 31 initiatives and briefly researched each to understand its functions and history. This background allowed me to develop a typology of urban food forestry initiatives consisting of three types: harvesting, planting and mapping.

2.3 Research Question #3: What is the potential capacity of urban food forestry to meet food needs?

I used a combination of geographic information system (GIS) analysis and basic calculations based on United States Department of Agriculture (USDA) food security data and horticultural data derived from university horticultural extension services (e.g. VSE 2009) to address this research question.

2.3.1 Available land within cities to plant food trees

I used my hometown of Burlington, Vermont (USA) as a case study to calculate the amount of public land available for planting food trees. I used the ArcGIS software package to perform analysis for this subtopic. This process began by locating pertinent GIS data and determining which spatial information was needed. Table 2 contains a summary of the GIS data I used.

Filename	Source	Description
BountaryTown_TWNBNDS	VCGI 2011	Vermont town boundaries
CadastralParcels_VTPARCELS	VCGI 2011	Burlington parcels data
ImageryPhotos_VTORTHOS	VCGI 2011	Vermont digital orthophotography (aerial photography of Burlington)
CadastralPublands_CONSPUB	VCGI 2011	Public lands in Vermont
EmergencyE911_RDS	VCGI 2011	Road centerlines from 1:5000 orthophotos and GPS
WaterHydro_VHD	VCGI 2011	Vermont hydrography dataset (1:5000) - surface waters
Bike_Paths	CoB 2010	Burlington bike paths
Parks_and_Open_Space	CoB 2010	Burlington parks and public spaces

Table 2: GIS data used to calculate public park land available for planting public food trees in Burlington, VT

The following steps were taken to calculate available land for public food trees in ArcGIS:

1) Using 'Clip' function of ArcGIS's Toolbox, I clipped the following layers to the Burlington town boundary polygon: CadastralPublands_CONSPUB, EmergencyE911_RDS, WaterHydro_VHD
2) I analyzed metadata for CadastralPublands_CONSPUB to determine which parcels are publicly owned. Using the 'Select by Attribute' feature, I selected all parcels that had a 'Site Development' value between 7000 and 7999 in the (designating public park land). The selected parcels were then extracted and saved as a separate shapefile.
3) The resulting shapefile was crosschecked with spatial data in the CadastralPublands_CONSPUB and Parks_and_Open_Space layers.
4) Using the 'Statistics' function, I calculated the total area (in acres) of public land available in Burlington.

I chose not to include public land alongside streets and sidewalks due to the fact that these are the least suitable sites for public food trees and are often already planted. Bike paths were included in my analysis since they indicate high-traffic areas and provide easy access to trees. Hydrological and road data were included mainly for the purpose of creating intelligible maps.

2.3.2 Caloric requirements of the urban food insecure population

Burlington was again used as the study area to address this subtopic. Three values were used to calculate the caloric requirements of the food insecure population: population of Burlington (VIO 2010), percentage of population with very low food security (USDA 2007), and average daily caloric requirement per person (USDA 2005). These values were multiplied together to calculate the total caloric deficit of Burlington's VFI population.

According to the USDA's most recent study on nationwide food security, 10.2% of Vermont's population is categorized as having low or very low food security, 4.6% of which consists of those *very food insecure* (VFI) people; the nationwide average is 11%, 4% of which are VFI (USDA 2007). According to the USDA, the defining characteristic of *very low food security* is that at times during the year the food intake of household members was reduced and their normal eating patterns disrupted because the household lacked money and other resources for food (USDA 2007). Since individuals with very low food security are substantially more likely to skip meals and go entire days without eating, I chose to focus my calculations exclusively on this group. Figure 1 illustrates the major differences in food security between people categorized as having *low food security* versus *very low food security*.

Figure 1: Households reporting each indicator of food insecurity, by food security status in 2007 (3+ indicates that an event has occurred in 3 or more months out of the year). Source: USDA 2007

I made a number of assumptions in my calculation of Burlington's VFI caloric deficit. First, since food security data was not available for the city of Burlington, I extrapolated using the statewide USDA average value. Second, since the daily calorie deficit for someone categorized as VFI is not mentioned in USDA literature, I made an educated guess based on their definition; I assumed that 20% of the yearly caloric requirement of VFI individuals is not met. This figure was cross-checked with a staff member from the Chittenden County Emergency Food Shelter, who provided me with basic estimates suggesting that I was in the ballpark.

2.3.3 Production capacity of public lands

I reviewed horticultural literature to extract specific values needed to calculate the production capacity of public lands. I based my calculations on *Malus domestica* (the common apple) due to its versatility and pervasiveness throughout developed countries. Key values used include density of trees planted per acre and fruit yield per acre. Horticultural data was collected from various university extension websites (e.g. VSE 2009), as well as from the USDA. Data collected for this subtopic were used to compute values relevant to my research question, for example the total caloric yield derived from a one-acre planting of apple trees. The resultant calculations were then linked to the calculations discussed in Section 2.3.2 to derive results specific to Burlington (e.g. how many apple trees are needed to overcome the calorie deficit of the food insecure population).

2.4 Research Question #4: What species should municipalities consider for urban food forestry?

2.4.1 Climate-ready food trees for urban food security

I created a reference table of perennial food-producing plants in a three phase analysis plant species. During the first phase, I extracted food-producing species from the list of 250 commonly planted urban tree species documented by Roloff et al. (2009) using the Plants for a Future database (PFAF 2010), the USDA's National Plant Germplasm System Database (GRIN), and university horticultural extension publications, especially Purdue University's Center for New Crops & Plant Products (PUNCR 2011). During the second phase, I researched each of the species identified as food-producing to determine which have been cultivated commercially as a food crop, using the same three sources discussed above.

The third phase involved researching and cataloging additional food-producing species that were not part of the study conducted by Roloff et al. (2009). I drew primarily from the three sources mentioned above, as well as my own personal horticultural knowledge. I ranked each species in terms of edibility based on four criteria: 1) Has the species been commercially cultivated for food? 2) Is the species widely recognized and marketed? 3) Is the fruit or nut palatable when eaten raw? 4) Can the fruit or nut be eaten without special preparation (e.g. peeling or cooking). Each time a question was answered 'yes', a value of 1 was added to the edibility rating of that plant; the scale began at 1 (no criteria met) and had a maximum value of 5. The results of this research are summarized in my Climate-Food-Species-Matrix (CFSM).

2.5 Note on Units

Throughout my research, I drew from various sources that used both metric and standard measurement systems. Several sources of my horticultural data mixed the two systems (e.g. using acres and meters in the same report). While an effort was made to standardize these measurements to the metric system, it was often time prohibitive to convert data, and thus both measurement systems are used in my thesis.

3. RESULTS

3.1 Research Question #1: How prevalent is the idea of using urban forestry for food security?

3.1.1 Prevalence in academia

The first phase of my academic literature review, consisting of general searches on LibHub and Google Scholar, yielded very little material linking urban forestry and food security. Table 3 summarizes the results of these searches. In the two cells where a question mark appears there were too many results to reasonably scan, so only the titles and abstracts of the first 100 articles were analyzed.

Search criteria	Part of document searched	Returned results: LibHub	Returned results: Google Scholar	Articles bridging public food trees and urban food security
"urban forestry" AND "food security"	Title	0	0	0
	Abstract	0	n/a	0
	Entire document	0	300	0
"urban forest" AND "food security"	Title	0	0	0
	Abstract	0	n/a	0
	Entire document	0	234	0
"urban trees" AND "food security"	Title	0	0	0
	Abstract	0	n/a	0
	Entire document	0	87	0
"urban agriculture" AND "food security"	Title	6	91	0
	Abstract	16	n/a	0
	Entire document	32	4100	?
"urban agriculture" AND "food security" AND "fruit trees"	Entire document	2	495	?

Table 3: Results of first iteration of academic journal article searches

In the second phase, I focused on the six academic journals that returned the greatest number of papers dealing with urban forestry and urban planning. Appendix A contains a detailed summary of this analysis. Two relevant articles were found, but both made only weak connections between food security and urban forestry. The first article mentions that urban green areas in developing contexts sometimes provide non-timber forest products including fruit, mushrooms, and medicinal herbs, but that Western urban forestry has focused primarily on economic values (Konijnendijk et al. 2004:270). The second article discusses the food production as a potential benefit of urban fence plantings in a specific context in New Zealand (Cadieux 2008).

There are a number of academic journal articles which briefly discuss the historical role of urban forests with reference to their potential food-producing function. In general, the perspective among academics seems to be that medieval European city forests were once used for obtaining food, fodder and wood and as food 'banks' in times of war, but are today primarily valued for recreation and environmental qualities (Hunter 2003). This perspective is summarized in Table 4.

Table 1. General development of urban forests in Europe as synthesised by Konijnendijk (1999)

Urban development	Leading actors	Main urban forest functions	Urban forest development
• Medieval city (political, religious)	Nobility	Hunting, subsistence	• 1st generation
• Mercantilist and Renaissance city (trade)	Nobility and bourgeoisie	Recreation, prestige, production (for few)	• 2nd generation
• Industrial city	Local governments and industrials (private persons)	Recreation (for all)	• 3rd generation
• Modern city	National (and local) governments	Recreation, nature conservation, environment, landscape, production	• 4th generation

Table 4: General development of urban forests in Europe as synthesized by Konijnendijk (1999), from Hunter (2003)

Articles relating urban trees and food security within the fields of urban forestry, agroforestry, landscape and urban planning, urban ecosystems, and arboriculture were found to be extremely rare. Konijnendijk (2005) mentions the potential role of urban forestry as a source of food security and also points out that in Eastern and Northern Europe, the gathering of berries and mushrooms continues to be a popular activity in city forests, and that some restaurants in Copenhagen encourage the public to bring them culinary mushrooms (Konijnendijk 2008). Additionally, a number of concepts within the field of landscape ecology touch upon the idea of utilizing urban trees for food production including *continuous productive urban landscapes* (Viljoen 2005), *ecobelts* (Bentrup et al. 2001; Oberndorfer et al. 2007), and *multifunctional urban landscapes* (Ahern 2011; Lovell & Johnston 2009). I build upon the frameworks of Bentrup et al. (2001), Ahern (2011) and Lovell & Johnston (2009) in the Discussion section.

In addition to these findings, my searches yielded various non peer-reviewed documents connecting urban forestry and food security. The majority of this literature can be attributed to a handful of authors and organizations. The FAO has published a number of books on urban forestry and hosts an Urban Forestry Community website which was established with the aim of promoting urban and peri-urban forestry for poverty alleviation, food security, livelihood improvement and sustainable land and forest management in developing countries (FAOUF 2011). Numerous publications indicate that street trees play an important role in food security in various developing nations (Kuchelmeister & Braatz 1993; FAO 1995; Baumgartner & Belevi 2001; Smit 1996). However, the only article I found mentioning public trees specifically planted for food security in a *developed* context was written by Smit, Nasr & Ratta (2001) who describe Asheville's Bountiful City Project as the first edible public park system. The most explicit reference I found linking urban forestry and food security in a developed context is the book, *Public Produce: The New Urban Agriculture*, by Darrin Nordahl (2009). This book posits that municipalities can improve urban food security by engaging in what he calls *municipal agriculture* to grow food that is free and equally accessible to all members of society, referred to as *public produce*.

3.1.2 Prevalence among municipal governments

Urban forestry master plans (UFMPs) are common among municipal governments to document, analyze and manage urban trees and develop goals for urban forests based on public feedback. Although there is no standard template for UFMPs, Figure 2 shows a general flowchart for constructing one.

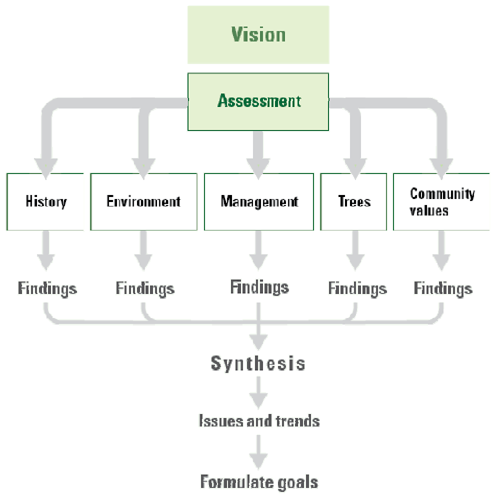

Figure 2: Framework for constructing an urban forestry management plan. Source: http://ufmptoolkit.com/

My analysis revealed that the connection between food security and urban forestry within municipal governments is quite rare. Of the 30 UFMPs analyzed (totaling 2099 pages), only four plans made a connection between urban forestry and food security; three in British Columbia (BC) and one in California (Table 5). With the exception of Grand Rapids, Austin and Walla-Walla, all UFMPs made some reference to the food security of wildlife.

#	City	Pages	Year of Publication	Instances of "fruit"*	Instances of "food"*	Instances of "wildlife"
1	Alexandria, VA	91	2007	0	0	1
2	Arlington, VA	38	2004	0	0	8
3	Austin, TX	63	2009	0	0	0
4	Banff, Alberta	121	2008	0	0	59
5	Boone, NC	80	2009	0	0	2
6	Brookings, SD	89	2010	0	0	11
7	Burlington, Ontario	60	2010	0	0	7
8	Burlington, VT	64	2002	0	0	21
9	Calgary, Alberta	61	2007	0	0	5
10	Charlottesville, VA (D)	77	2009	0	0	8
11	Chesapeake, VA	34	2010	0	0	9
12	Chicago, IL	39	2010	0	0	14
13	Dunn, WI	34	2008	0	0	1
14	Grand Rapids, MI	55	2009	0	0	0
15	Harbord Village, Toronto	82	2007	0	0	8
16	Lacey, WA	108	2005	0	0	16
17	Lousville, KY	86	2007	0	0	5
18	Nanaimo, CA (D)	116	2009	17	16	47
19	Norman, OK	34	2006	0	0	2
20	Saanich, British Columbia	105	2010	27	62	52
21	San Francisco, CA	32	2006	0	0	5
22	Seattle, WA	106	2007	0	0	17
23	Selchelt, British Columbia	56	2010	7	51	27
24	St. Catherines, Ontario	69	2011	0	0	12
25	Syracuse, NY	56	2001	0	0	4
26	Tigard, OR	35	2009	0	0	1
27	Vancouver, British Columbia	96	2007	0	0	16
28	Victoria, British Columbia (D)	63	2011	9	8	15
29	Walla-Walla, WA	53	2004	0	0	0
30	Wellington, Toronto	96	2009	0	0	5

(D) Draft document *In the context of human consumption

Table 5: Summary of UFMP analysis results

In the four relevant UFMPs, public feedback appeared to be a significant driver in bridging urban forestry and food security. For instance, Victoria BC's public feedback document contains an entire section devoted to public comments in support of urban food trees. Figure 3 summarizes this feedback and lists desired urban forest functions in order of popularity. Some attributes in this table, such as multi-functionality, quality of life and resilience to climate change overlap with food production.

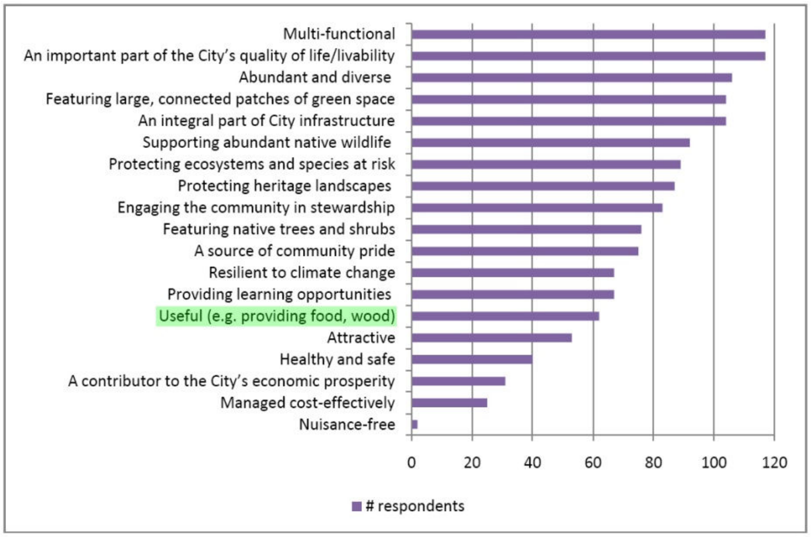

Figure 3: Summary of public comments from Victoria, BC urban forestry public consultations (highlighting added) Source: CVURPC (2009)

The nature of the public comments linking urban forestry and urban food security ranged from general support to very specific recommendations such as incorporating urban beekeeping, resilient landscaping, vertical forestry, and permaculture. Table 6 shows examples these public comments, which are similar to those found in the Saanich and Nanaimo management plans.

Public Comments from Victoria, BC's Report on Public Consultation
▪ Many natural areas provide food for insects and birds but not humans
▪ When replacing existing trees, we need to take food security issues into consideration
▪ Resilient landscaping to take into account global warming, e.g. Gingko trees which also produce edible nuts
▪ Integrate urban forestry into urban agriculture
▪ Sustainability – link to food tree project such as Life Cycles
▪ Beekeeping, pollinators such as Mason Bees
▪ ..more nut and fruit producing trees, e.g. edible chestnuts, walnuts, gingko, fig, cherry, etc.
▪ I would love to see more fruit and nut trees all over Victoria. We could easily supply the population…
▪ Plant more fruit trees and shrubs. Get public involved in maintenance, harvest and preservation of the food
▪ More edible trees and food forest (permaculture system)
▪ Vertical forestry, more community management, more food bearing, more pollinators…
▪ I would like to see more trees that supply food for our citizens…
▪ I would like to see more edible nut trees. What's wrong with real chestnuts?
▪ Demonstration/model edible forest gardens, designed on permaculture principles…

Table 6: Public comments in favor leveraging urban forestry for food security from Victoria, BC. Source: CVURPC (2009)

Table 7 shows a quote from each of the four relevant UFMPs explicitly connecting urban forestry and food security.

City	Quote from UFMP linking Urban Forestry and Food security
Victoria, BC	"The importance of locally grown food is increasing. Trees can produce a variety of fruit and nuts that can be harvested by individuals or donated to food banks." (VUFMP 2009:40)
Selchelt, BC	"…the District can protect the biodiversity of wild foods by educating about sustainable harvesting, diversifying Park planting regimens to include fruit and nut trees as street trees, addressing regulatory barriers to food production, and promoting shade grown foods to preserve tree cover." (SUFMP 2010:23)
Saanich, BC	"Incorporate food production opportunities in the District. As with other planting initiatives in this strategy, the planting of edible fruit and nut trees should occur deliberately and according to a District wide plan." (SUFP 2010:28)
Nanaimo, CA	"Fruit and nut bearing trees, as well as edible plants in Nanaimo's urban forest and parks, provide a great deal of nutrition to each other, animals and people. These species make up Nanaimo's edible landscape and are integral to Nanaimo's established and developing sustainable food systems." (NUFMS 2010:14)

Table 7: Quotes depicting municipal planning efforts that bridge urban forestry and food security

These four quotes exemplify an emerging realization on the part of municipal governments that urban forestry can successfully be leveraged for public food production. Each of these plans was written within the past two years, suggesting that this may be a relatively recent phenomenon. It is clear that the community values of the public played a significant role in shaping the management goals of municipal governments in these areas, although it is not clear to what degree the public *at large* in these cities view urban trees as a potential source of public produce. The following sections provide more insight into this overall awareness among urban residents in developed cities.

3.1.3 Awareness among general public

The Urban Forestry Project (UFP) offers unique insights into the public's perspective of urban forest functionality. Since 2006, nine major cities in around the United States have participated in this project, and over 1000 public interpretations of urban trees have been submitted, many of which were publicly displayed as banners on city streets (UFP 2011).

My analysis of public artwork interpreting the urban forest revealed that there is a very weak connection among the public between urban trees and their potential function as a food source. Even with very lenient criteria, only 2.2% of the 573 banners made any reference to food, compared to 9.0% for wildlife (Table 8). Only two banners made an unambiguous connection between trees and food production for human consumption; the remainder either used food in the context of wildlife consumption, or contained references that were unclear. In addition to analyzing the visual and textual content of banners, I reviewed artwork descriptions written by artists when it was uncertain whether a connection to food was intended. In all such instances it was found that visual references to food (i.e. fruits or nuts) was not intended to be in the context of human consumption.

City	Total Number of Banners	Banners depicting urban trees as source of food	Banners depicting wildlife
San Francisco, CA	243	2	25
New York, NY	186	8	18
Toledo, OH	144	3	9
Totals	**573**	**13**	**52**

Table 8: Results of urban forestry banner analysis

The results of this analysis are limited by several factors, including the small percentage of the urban population that submitted artwork and the unknown demographic makeup of artists (e.g. educational background, average age, income and ethnicity). Regardless of these limitations, this analysis offers an interesting snapshot of the functions commonly attributed to urban trees amongst the public in these three cities. The most common themes observed were air quality, climate change, biodiversity, aesthetics, deforestation, and consumerism. A large portion of the banners had no discernable message; they were simply abstract artistic interpretations of trees. Figure 4 depicts several examples of banners, as well as an example of how these posters were displayed in cities, in this case in New York City.

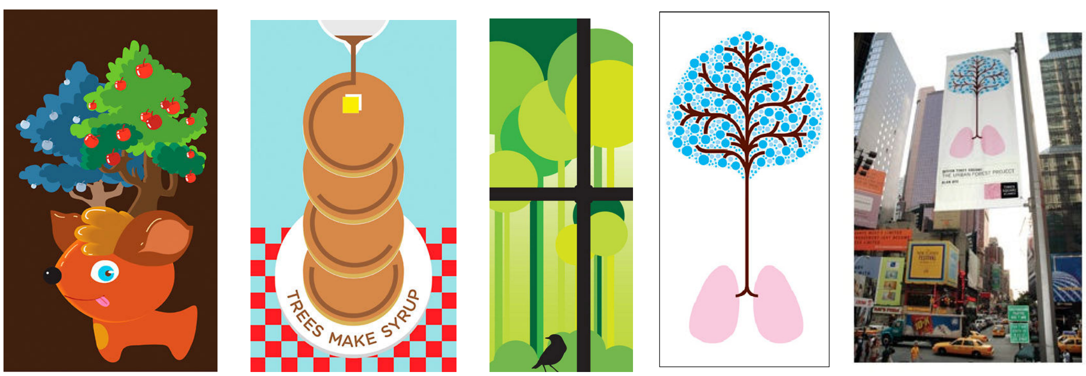

Figure 4: Examples of publicly-displayed artwork depicting various aspects of urban forestry. Artists from left to right: Deana Lee, San Francisco (depicting both wildlife and food); Brendan Callahan, San Fransisco (depicting only food); Andrea Colon, Toledo (depicting only wildlife); Alan Dye, New York City (depicting trees as air purifiers). Source: http://www.ufp-global.com/

3.2 Research Question 2: What types of initiatives bridge urban forestry and food security?

Over the course of my research, I encountered a variety of initiatives bridging urban forestry and food security. I reviewed each of these initiatives to determine their primary activities and then divided them into three categories (harvesting, planting and mapping), shown in Table 9. I found a relatively equal distribution between the three types of initiatives. Although the list is not exhaustive, it contains most of the high-profile urban food forestry projects in North America and the United Kingdom.

Name of Initiative or Organization	Location	Year founded	Urban food-tree harvesting	Urban food-tree planting	Urban food-tree mapping
Abundance Manchester	Manchester, UK	2008	x		
Backyard Harvest	CA, ID, WA	2006	x		
Ben Nobleman Community Orchard	Toronto, Canada	2009		x	x
Bloomington community orchard	Bloomington, IN	2010		x	
Boston Area Gleaners	Boston, MA	2004	x		
Bountiful Cities	Asheville, NC	1999		x	
Chicago Rarities	Chicago, IL	2009		x	
City Fruit	Seattle, WA	2008	x	x	x
Communities Take Root*	20+ cities around USA	2010		x	
Community Harvest of SW Seattle	Seattle, WA	2007	x		x
Earthworks	Boston, MA	1989		x	
Fallen Fruit	Los Angeles, CA	2004			x
Food Forward	Southern California	2009	x		
Forage Oakland	Oakland, CA	2008	x		
Fruit Tree Planting Foundation	115+ cities worldwide	2002		x	
GreenThumb NYC (orchard program)	New York, NY	1984		x	
Grow Sheffield	Sheffield, UK	2007	x		
Hackney Harvest	London, UK	2009			x
Husthwaite Community Orchard	Husthwaite, UK	2009		x	
Life Cycles (Fruit Tree Project)	Victoria, BC	2000	x		x
London Orchard Project	London, UK	2009		x	
Madison Fruits and Nuts	Madison, WI	2010		x	x
Neighborhood Fruits	USA, Canada	2009			x
Not far from the Tree	Toronto, Canada	2008	x		
Philadelphia Orchard Project	Philadelphia, PA	2007		x	x
Portland Fruit Tree Project	Portland, OR	2006	x		
San Francisco Urban Forest Map	San Francisco, CA	2007			x
The Guelph Fruit Tree Project	Ontario, Canada	?	x		x
Union Street Urban Orchard	London, UK	2010		x	
Urban Edibles	Portland, OR	?			x
Village Harvest	Southern California	2001	x		
		Totals	**13**	**14**	**12**

*A Fruit Tree Planting Foundation initiative

Table 9: Urban food forestry initiatives and their associated functions

The following sections offer a brief overview of each of these three types of UFF initiatives.

3.2.1 Urban food-tree planting initiatives

A variety of urban food-tree planting initiatives have taken root over the past two decades, the majority of which were started in the past five years. Most of these projects were initiated by members of the public who collaborated with municipal governments, public volunteers, and private donors. This finding is consistent with my analysis of UFMPs, which shows that the general public plays a major role in initiating urban food-tree planting projects.

The Ben Nobleman Park Community Orchard in Toronto is an example of municipal agriculture. This orchard was planted in 2009 as the result of efforts by local community members in collaboration with the City Councilor, Growing for Green (initiative non-profit), and Not Far From the Tree (an urban fruit harvesting initiative discussed in Section 3.2.2); the design for the orchard (Figure 5) was an iterative process, involving input from community members and landscape architects, and feedback from members of the municipality (BNP 2011).

Figure 5: First draft of Ben Nobleman Community Orchard by Jane Hutton, an example of a public urban orchard.
Red = cherry, purple = plum, green = apple, light green = pear, orange = hickory, dark blue = serviceberry, light blue = paw paw
Source: http://communityorchard.ca/about-us/designing-an-orchard-ben-noblemans-story/

Trees in the Ben Nobleman Orchard were planted by Toronto's department of Parks, Forestry and Recreation. At present three pears, three plums and three cherries have been planted, with more trees planned for coming years. The orchard is expected to yield its first fruits in 2012 and its first nuts in 2015 (BNP 2011).

Urban food-tree planting initiatives often utilize permaculture and agroforestry techniques to maximize the output and diversity of produce (both techniques are discussed in section 4.5.2). For instance, the Philadelphia orchard project (POP) creates vertical layers of perennial food crops based on permaculture forest gardening techniques; so far, they have established 23 urban orchards in locations like public schools, parks, and churches, consisting of 252 food trees, 424 food-producing shrubs and vines, and countless perennials (POP 2011). Another permaculture-inspired urban food forest is the Dr. George Washington Carver Edible Park (Figure 6), which is part of the Bountiful Cities Project in Asheville, North Carolina. This public orchard was planted on a former landfill site by volunteers who had recently completed a permaculture course and contains over 40 varieties of fruits and nuts (BCP 2011).

Figure 6: Fruit and nut trees in the Dr. George Washington Edible Park public orchard, located in a high density urban area in Asheville, North Carolina. Source: http://www.bountifulcitiesproject.org/gardens/bountiful-cities-gardens/

Other planting initiatives have taken advantage of underutilized or marginalized urban areas, including abandoned lots, median strips, and right of ways. An example of this is a public produce project in the Queen Anne neighborhood of Seattle shown in Figure 7, which was planted on a previously unutilized median strip covered with weeds and debris. The land was cleared by volunteers in collaboration with Seattle's Department of Transportation and planted with community garden plots and fruit trees (Nordahl 2010).

Figure 7: Gilman Gardens, an example of public produce in the Queen Anne neighborhood of King County, Seattle. Source: Nordahl 2010

3.2.2 Urban food tree harvesting initiatives

Urban food-tree harvesting initiatives utilize fruit and nuts grown on both public and private urban land to improve urban food security. The majority of these initiatives are non-profit organizations which donate the bulk of their harvest to charities and food banks, as well as keeping some for community-organized events to make preserves, fruit juices, ciders and wines, and other products.

Harvesting initiatives either forage or glean[1] fruit. Foraging is harvesting "wild" fruits and nuts that are growing on public land, or harvesting fruit overhanging fences on to public land (Figure 8). In many cities, fruit overhanging private fences onto sidewalks or other public land is legally public property (Severson 2009). Gleaning on the other hand involves harvesting fruits and nuts off of private trees with the permission of landowners. Gleaning initiatives are often highly organized and have websites where urban food-tree owners can register private trees that yield more fruit than they can use; volunteers are then sent out to harvest the fruit when it is ripe, and the bulk of the harvest is donated to food banks and charities.

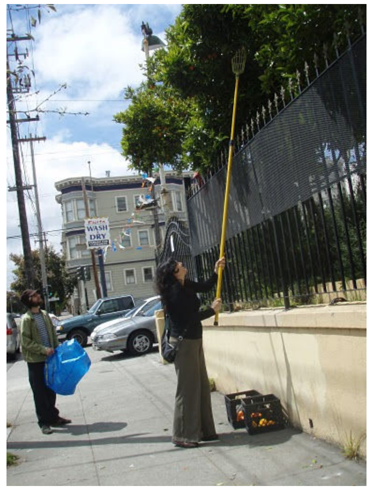

Figure 8: Gleaning public fruit in San Francisco.
Source: http://www.sfweekly.com/

One such organization is Toronto's *Not Far from the Tree* (NFFTT). Figure 9 summarizes the rapid growth of this organization, which has experienced a 570% increase in registered urban trees, 460% increase in volunteers, and a 670% increase in fruit picked during its first three years (NFFTT 2011). Since their start, NFFTT has won numerous high profile awards in Toronto, including the Urban Leadership Award for 'City Soul' from the Canadian Urban Institute in 2010 and the Environmental Award of Excellence in 2011. They have received funding from a variety of public and private sources, including the Ontario Ministry of the Environment and TD Bank's Friends of the Environment Foundation, and has received media attention from high profile outlets including the National Post, Toronto Star and Canadian Broadcasting Channel (NFFTT, 2011).

[1] The concept of gleaning originates in ancient Hebrew law, which states, "And when you reap the harvest of your land, you shall not make clean riddance of the corners of your field when you reap, neither shall you gather any gleaning of your harvest: you shall leave them to the poor, and to the stranger" (Leviticus 19:19).

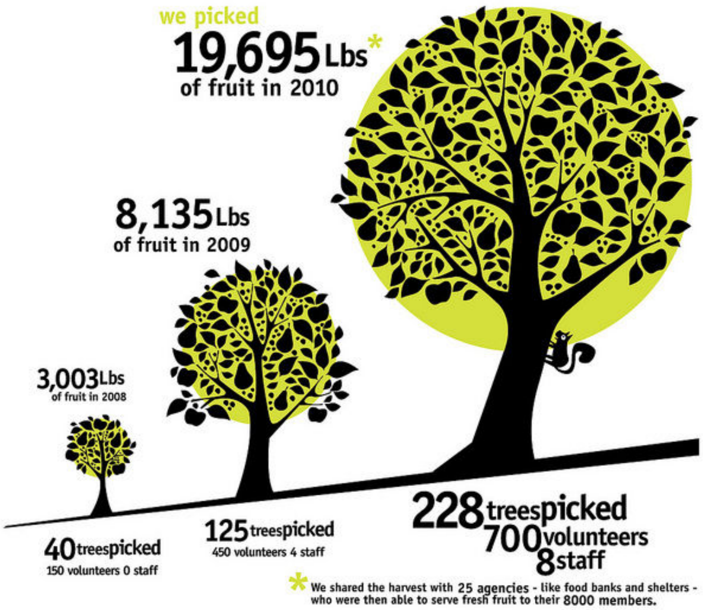

Figure 9: Fruit harvest, volunteer and staff growth of Not Far From the Tree initiative. Source: http://www.notfarfromthetree.org/about


Figure 10: Fruit yielded from urban fruit harvesting groups. Left: Gleaned fruit harvested by Not Far from the Tree Right: Fruit foraged from public plum trees by Grow Sheffield. Sources: NFFTT (2011), http://www.growsheffield.com/

Figure 10 shows an example of the amount of fruit that gleaning and foraging initiatives can harvest from urban food trees in just a few hours with volunteer labor.

3.2.3 Urban food tree mapping initiatives

Urban food-tree mapping has emerged as a strategy to increase public utilization of freely-available fruits and nuts. Mapping initiatives vary in terms of their ambition and geographic coverage, ranging in scale from neighborhood to nationwide. This section briefly covers three different types of fruit mapping that I discovered during my research.

The first generation of urban food tree maps was pioneered by organizations like Fallen Fruit (fallenfruit.org), an organization based in Southern California that makes copyright-free hand-drawn maps intended for public distribution. To date, Fallen Fruit has released public fruit maps for 26 locations in 8 countries; Figure 11 shows an example from Malmö, Sweden. These maps are regularly reproduced in newspapers and magazines and have been exhibited in museums and gallery exhibitions internationally (FF 2011).

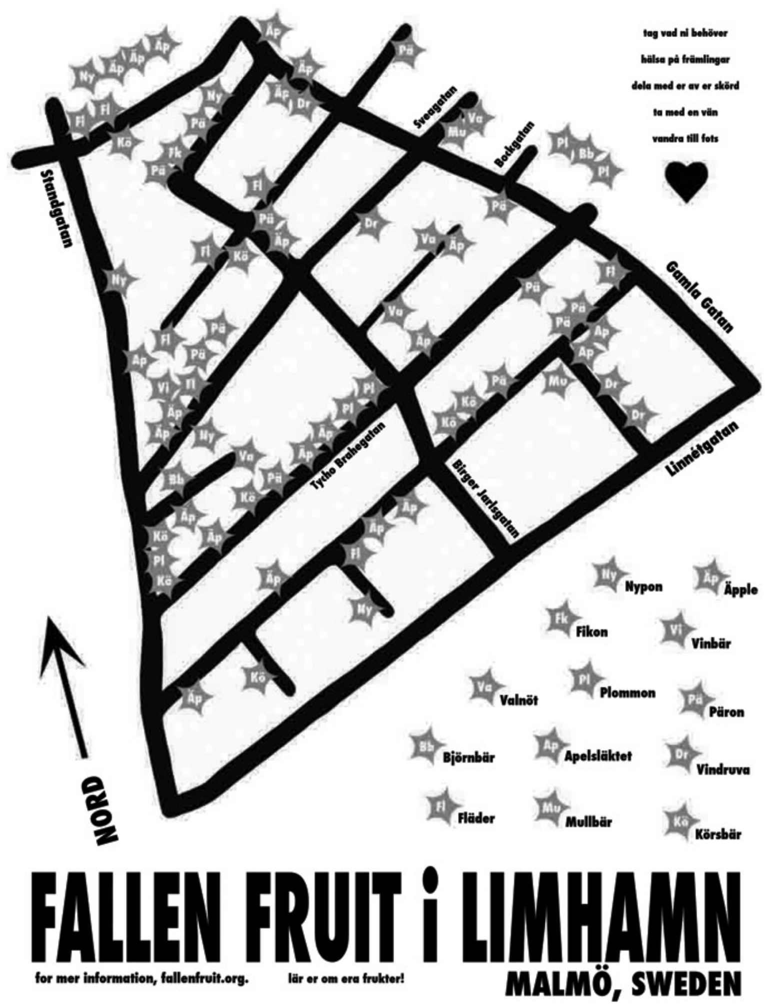

Figure 11: Public fruit tree map for Limhamn neighborhood of Malmö, Sweden by Fallen Fruit. Source: http://www.fallenfruit.org/index.php/media/maps/

The second generation of urban food tree maps are *geo-wikis*, a form of participatory mapping which typically interfaces with Google Earth to create interactive maps that the public can search, modify, and extract data from. One of the most well-established urban forest geo-wikis is the San Francisco Urban Forest Map (www.urbanforestmap.org), a collaboration between government, nonprofits, businesses and the public to build an inventory of San Francisco's urban forest. At present, there are tens of thousands of trees mapped on this site, which include attribute data such as species, diameter, planting date, flowering characteristics, and edibility. The map allows you to filter for specific trees and export data (e.g. as a shapefile for use in ArcGIS). Figure 12 shows a map I created by extracting all edible trees in San Francisco and overlaying this data on top of a poverty map of San Francisco using ArcGIS and Adobe Photoshop. This map demonstrates how municipal governments can combine census and GIS data with volunteer mapping projects to determine how many food trees are currently planted in low-income areas. This information could be used to target urban food tree plantings in low-income areas which may be located in food deserts (urban areas where fresh produce is difficult to access).

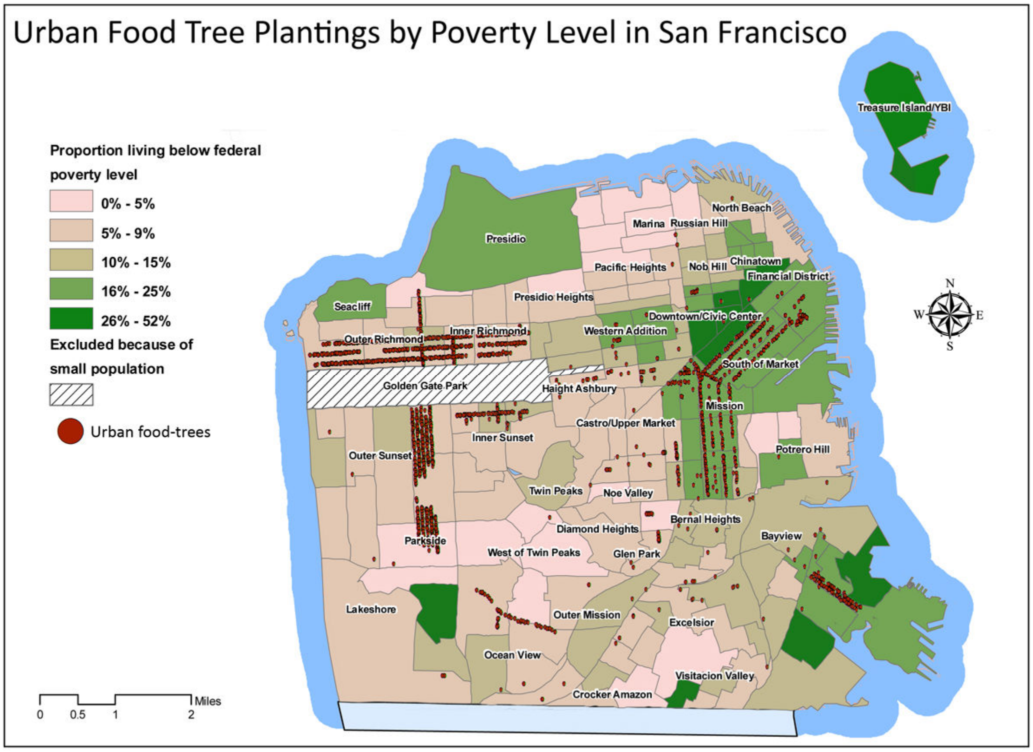

Figure 12: San Francisco edible trees overlaid on poverty map. Source: www.thehdmt.org

Smartphone applications, such as those for the iPhone, are the most recent development in urban food tree mapping. Neighborhood Fruits (neighborhoodfruit.com) recently released an iPhone app which gives users access to its geo-wiki style maps which cover the U.S. and currently list over 10,000 public fruit and nut trees. Figure 13 shows a screenshot from this app.

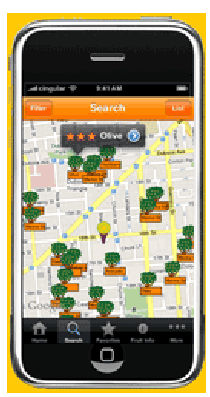

Figure 13: Screenshot from Neighborhood Fruit geo-wiki app for the iPhone. Source: http://neighborhoodfruit.com

3.3 What is the potential capacity of urban forestry to contribute to urban food security?

This section describes results from my GIS analysis of Burlington, Vermont as well as findings from horticultural yield calculations. This analysis is intended to serve as an illustration of how a municipality might conduct an inventory of public land and calculate the potential for urban food forestry to meet the caloric or nutrient deficit of a city.

3.3.1 Available land within cities to plant food trees

I overlaid several layers of spatial data to create a map showing land use in Burlington. Using this map, I calculated the total amount of public park land in Burlington to be 446 acres. It is important to note that significant resources of publicly-accessible land exist in addition to this, including land connected to public schools, universities, churches, private companies, cemeteries, sports fields, sidewalk strips, right of ways, etc.

Figure 14 is comprised of four separate maps which narrow in scale from the city level (upper left) to the neighborhood level (lower right). The upper left map depicts all 446 acres of public park land, highlighted in green; the upper right map shows public land surrounding the Burlington bike path (50 acres of public land are visible in this map); the lower left image shows Perkin's Pier, one of the numerous public parks located along the Burlington Bike path (2 acres of public land are visible in this map); and the lower right image shows a more detailed image of Perkin's Pier with highlighted areas to indicate spaces that could be utilized for urban food forestry landscape features.

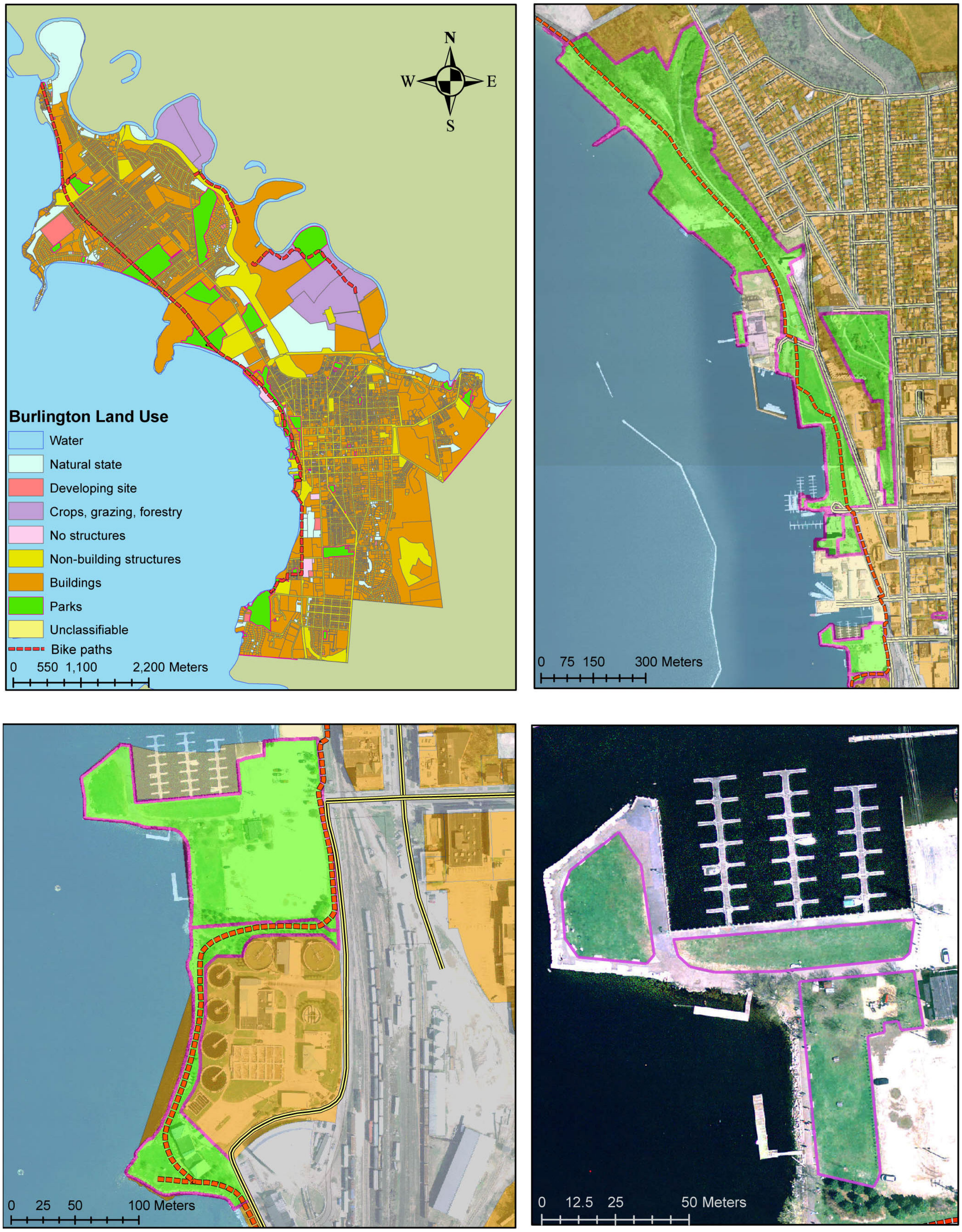

Figure 14: GIS analysis of public land in Burlington, Vermont. Upper Left: Land uses in Burlington; Upper Right: Burlington bike path and surrounding public land; Lower Left: Public and private land surrounding Perkin's Pier on the Burlington Bike path; Lower Right: Areas at Perkin's pier with potential for urban food forestry (highlighted in purple)

3.3.2 Capacity of public land to meet needs of urban food insecure population

By combining horticultural calculations with the results of my GIS analysis, I calculated the food production capacity of Burlington. I chose *Malus domestica*, the common apple, as my focus species due to its commonness and the availability of cultivation data. Table 10 summarizes the assumptions used in my calculations. The daily recommended intake of fruit is based a joint report by the FAO and WHO which recommends the intake of a minimum of 400g of fruit and vegetables per day (FAO/WHO 2004). Since they do not specify the percentage of vegetables and fruits that make up this 400g, I assumed that half of it should come from fruits, and the other half from vegetables.

Criteria	Value	Data Source
Latin name	Malus domestica	N/A
Common name	Apple	N/A
Rootstock	Dwarf	N/A
Years until fruit production	2 to 3	UVE (2009)
Productive Lifespan (years)	30-35	UVE (2009)
Standard density planting (trees per acre)	485	USDA (2003)
Low density planting (trees per acre)	240	N/A
Area required per tree (square feet)	182	N/A
Linear Feet required (for pathside planting)	8	UVE (2009)
Yield at maturity (bushels/tree/year)	1	UVE (2009)
Pounds per bushel	48	UME (2007)
Yield at maturity (kg/tree/year)	18	N/A
Grams per bushel (approximate)	21,772	N/A
Yield per low-density acre (bushels/year)	240	N/A
Yield per tree (grams/year)	21,772	N/A
Total yield per acre (kilograms of apples /year)	5,225	N/A
Total yield per acre (metric tons/year)	5.2	N/A
Retail price for bushel of apples	$30	UKE (2010)
Approximate retail value for output of 1 acre	$7,185	N/A
Kilocalories per gram of apples	0.55	USDA (2011)
Kilocalories produced per tree per year	11,975	N/A
Total yield per acre (kilocalories/year)	2,873,946	N/A
Daily recommended intake of fruit (grams)	200	FAO/WHO (2004)
People supported per year (at 200g/day for 1yr)	26,127	N/A

Table 10: Horticultural and dietary values, assumptions, and conversions used in calculations

Table 11 summarizes the results of my calculation of the total yearly caloric deficit of Burlington's VFI population. It is important to note that since specific food security data was not available for Burlington, I chose to use statewide food security data from the USDA (2007).

Estimated population of Burlington (2007), (VIO 2010)	38,897
Percentage of Vermont population with very low food security (average from 2005-2007) (USDA 2007)	4.6%
Population of Burlington residents with very low food security*	1,789
Average daily kilocalories required per adult per day (USDA 2007)	2,500
Daily kilocalorie deficit of very low food secure adult (percent of total daily kilocalories)**	20%
Daily kilocalorie deficit of very low food secure adult	500
Total yearly kilocalorie deficit of Burlington's VFI population	326,540,315
Approximate equivalent in fruit (kilograms)	593,710
Apples trees required to meet 100% of yearly caloric deficit of very low food security population	27,269
Acres required to plant apple trees (assuming 240 trees per acre)	113.6
Linear kilometers of bike path / walkway required (if planted on one side; based on 2.4m spacing)	66.5
Linear kilometers of bike path / walkway required (if planted on both sides; based on 2.4m spacing)	33.3

Table 11: Burlington, Vermont food insecure population calculations

*This does not include people categorized as having "low food security"
**Estimate

In addition to showing the caloric deficit, Table 11 gives the amount of apple trees required to produce the equivalent amount of fruit and the amount of land required to grow these trees if planted at low-density, as well as the linear kilometers of pedestrian walkway required if planted at a standard spacing (only one of these scenarios would be necessary to meet the caloric deficit, i.e. either planting 113 acres or 66.5 linear kilometers).

Using the population and caloric deficit data in Table 11, I calculated fruit yields for nine different scenarios. These scenarios are based on two dimensions: planting coverage area and planting density. Planting coverage area refers to the percentage of public park land in Burlington to be planted with food trees; I chose 5%, 20% and 50% as the three scenarios, given that some of the land is already occupied by forest, playgrounds, parking lots, or other landscape features. Planting density refers to the number of trees planted per acre. I chose to use 240, 360, and 485 trees per acre (low-, medium-, and high-density respectively), based on data from the USDA (2003). These three planting densities corresponded to yields of 5.2, 7.8 and 10.6 metric tons per acre, which is considerably lower than what is possible in high-density commercial orchards. A reasonable yield for a high-density apple orchard with 400-600 trees per acre is over 21 metric tons per acre, and some European orchards have planting densities as high as 9,000 trees per acre with even higher yields (NCCE 2008). I deliberately reduced the potential yield of publicly planted apple trees under the assumption that they will not be fertilized or sprayed with pesticides.

The results of these nine scenarios appear in Tables 12, 13 and 14 with accompanying Figures (15, 16 and 17). These tables and figures show the capacity of public produce to meet the yearly caloric deficit of the VFI population, as well as the capacity to supply fruit to the general population of Burlington based on the recommended daily intake specified by the FAO/WHO.

Planting Coverage Scenario (Low-Density):	Low	Medium	High
Acres of urban public park land available	446	446	446
Percentage of public park land planted with food trees	5%	20%	50%
Total number of acres planted with food trees	22	89	223
Number of trees to plant per acre	240	240	240
Total number of trees planted	5,352	21,408	53,520
Fruit yield potential (kilograms/year)	116,525	466,102	1,165,255
Fruit yield potential (metric tons/year/acre)	5.2	5.2	5.2
Fruit yield potential (kilocalories)	64,089,001	256,356,005	640,890,012
Number of people supported per year (by WHO/FAO standards)	1,596	6,385	15,962
Percentage of very food insecure (VFI) population's caloric deficit met	20%	79%	196%

Table 12: Potential yield of apple trees planted on public land at low-density under three coverage scenarios, the capacity of this yield to meet Burlington's VFI yearly caloric deficit, and the capacity of this yield to supply the public with fruit in quantities recommended by the FAO/WHO (2004)

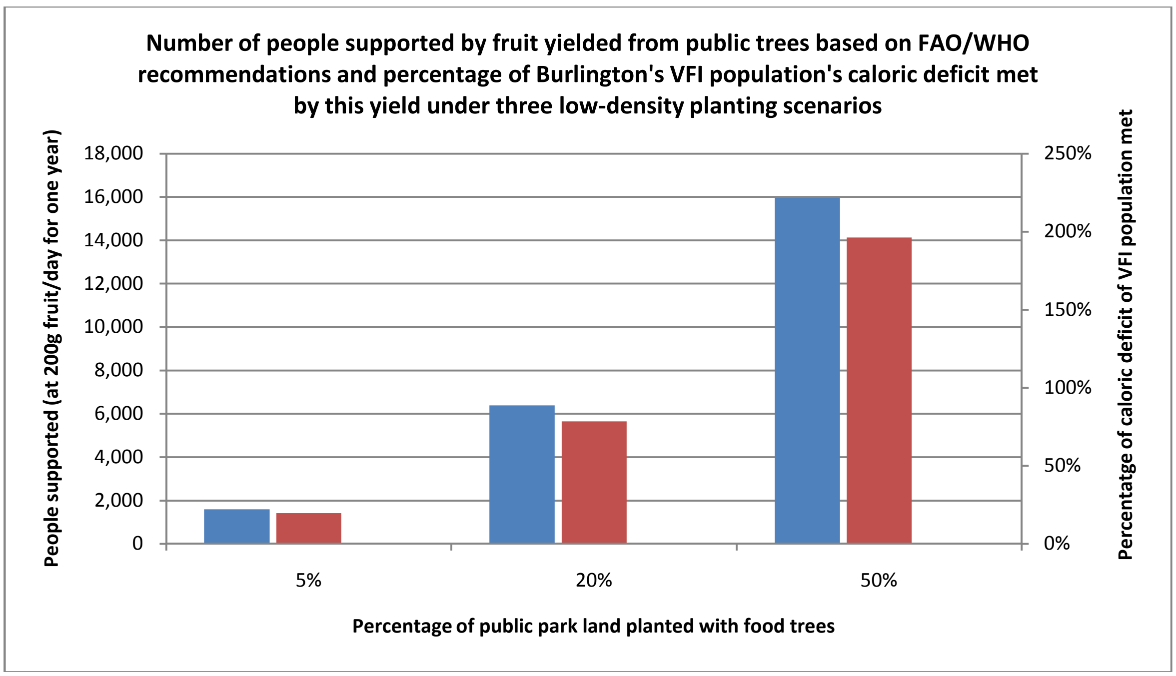

Figure 15: Number of people supported by public food trees based on the FAO/WHO (2004) recommendation of 200g of fruit per day (Blue), and percentage of VFI caloric deficit (Red) by under three planting coverage scenarios (5%, 20% and 50%) assuming low-density planting.

Planting Coverage Scenario (Medium-Density):	Low	Medium	High
Acres of urban public park land available	446	446	446
Percentage of public park land planted with food trees	5%	20%	50%
Total number of acres planted with food trees	22	89	223
Number of trees to plant per acre	360	360	360
Total number of trees planted	8,028	32,112	80,280
Fruit yield potential (kilograms/year)	174,788	699,153	1,747,882
Fruit yield potential (metric tons/year/acre)	7.8	7.8	7.8
Fruit yield potential (kilocalories)	96,133,502	384,534,007	961,335,017
Number of people supported per year (by WHO/FAO standards)	2,394	9,577	23,944
Percentage of very food insecure (VFI) population's caloric deficit met	29%	118%	294%

Table 13: Potential yield of apple trees planted on public land at medium-density under three coverage scenarios, the capacity of this yield to meet Burlington's VFI yearly caloric deficit, and the capacity of this yield to supply the public with fruit in quantities recommended by the FAO/WHO (2004)

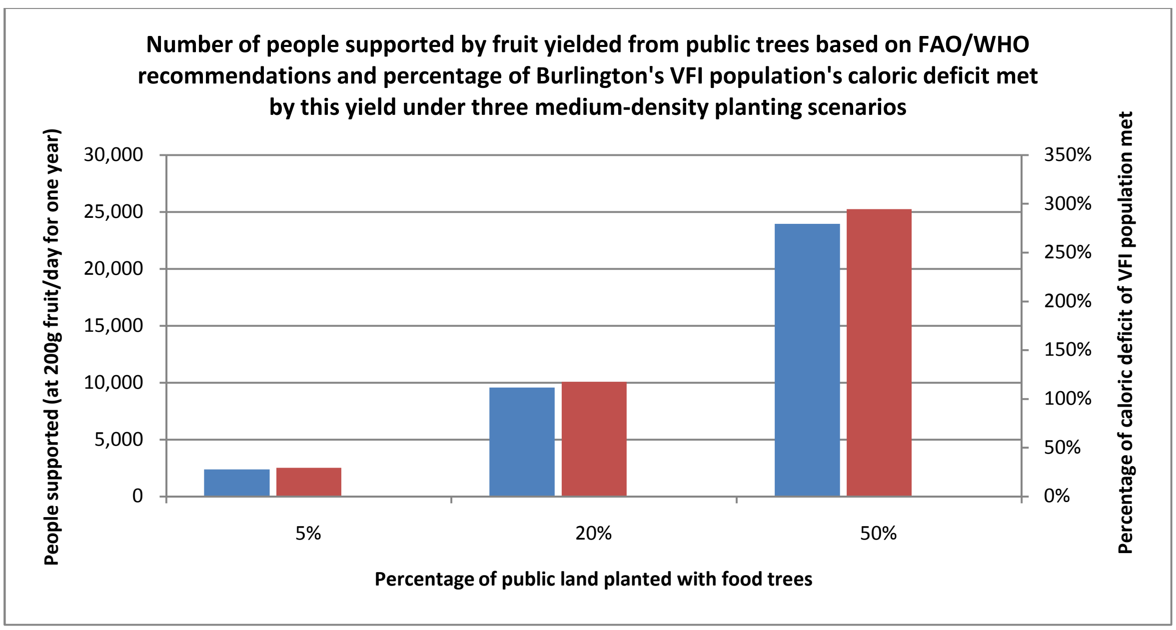

Figure 16: Number of people supported by public food trees based on the FAO/WHO (2004) recommendation of 200g of fruit per day (Blue), and percentage of VFI caloric deficit (Red) by under three planting coverage scenarios (5%, 20% and 50%) assuming medium-density planting.

Planting Coverage Scenario (High-Density):	Low	Medium	High
Acres of urban public park land available	446	446	446
Percentage of public park land planted with food trees	5%	20%	50%
Total number of acres planted with food trees	22	89	223
Number of trees to plant per acre	485	485	485
Total number of trees planted	10,816	43,262	108,155
Fruit yield potential (kilograms/year)	235,479	941,914	2,354,785
Fruit yield potential (metric tons/year/acre)	10.6	10.6	10.6
Fruit yield potential (kilocalories)	129,513,190	518,052,759	1,295,131,898
Number of people supported per year (by WHO/FAO standards)	3,226	12,903	32,257
Percentage of very food insecure (VFI) population's caloric deficit met	40%	159%	397%

Table 14: Potential yield of apple trees planted on public land at high-density under three coverage scenarios, the capacity of this yield to meet Burlington's VFI yearly caloric deficit, and the capacity of this yield to supply the public with fruit in quantities recommended by the FAO/WHO (2004)

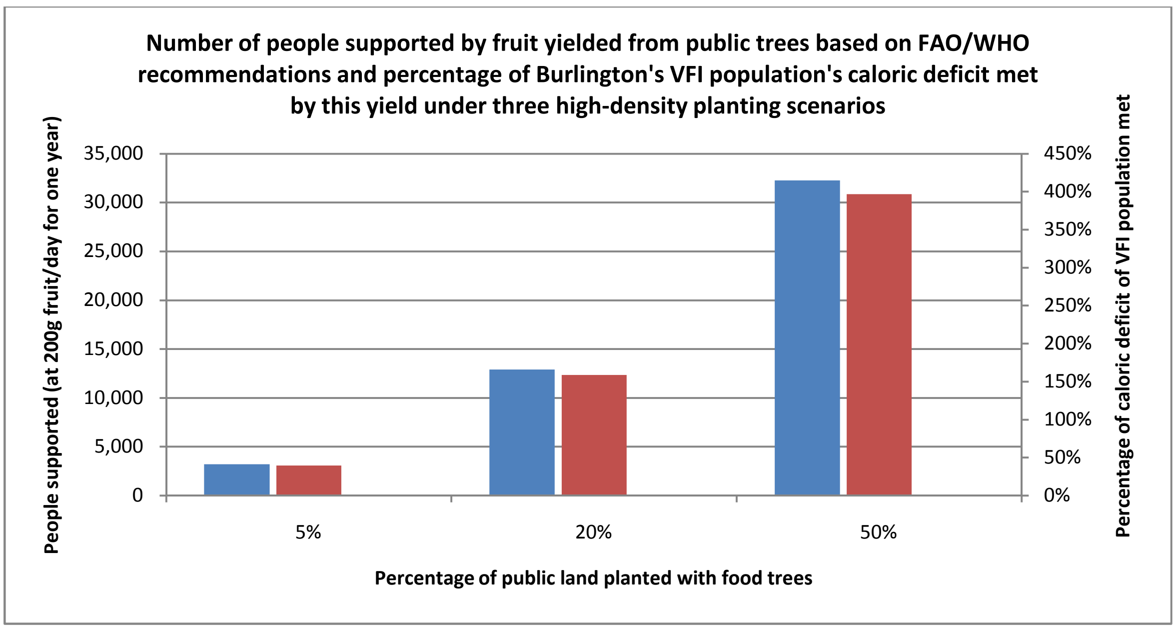

Figure 17: Number of people supported by public food trees based on the FAO/WHO (2004) recommendation of 200g of fruit per day (Blue), and percentage of VFI caloric deficit (Red) by under three planting coverage scenarios (5%, 20% and 50%) assuming high-density planting.

3.3.3 Implementation cost

Given the large number of trees required to meet the caloric deficit of the VFI population in Burlington (approximately 27,000 trees), or the daily requirements for the entire population of Burlington as recommended by the FAO/WHO (approximately 110,000 trees), the logistics and economics of implementation must be considered. The most convenient and cost-effective way to procure food trees would likely be to collaborate with wholesale tree nurseries selling bare-root trees. Table 15 gives examples of what some common fruit and nut trees currently cost in the United States when purchased in quantities of 500 or more. Prices for berry bushes and groundcovers including raspberries, blackberries, strawberries and blueberries range from $0.70 each to $5.30 each, with blueberries being the most expensive (NBF 2011).

Latin name	Common name	Max Height (feet)	Price (each)	Height (inches)
Aronia melanocarpa	Aronia berry	6'	$1.50	12-18"
Castanea dentata	American chestnut	100'	$2.48	24-36"
Cornus mas	Cornelian cherry	20'	$0.08	12-18"
Corylus americana	Hazelnut	10'	$2.37	24-36"
Diospyros virginiana	American persimmon	60'	$0.64	6-12"
Juglans ailantifolia	Heartnut	50'	$1.68	18-24"
Prunus armeniaca	Apricot	25'	$0.71	24-36"
Prunus avium	Mazzard cherry	40'	$0.30	1-3"
Prunus nigra	Plum	15'	$0.40	18"+
Sambucus melanocarpa	Elderberry	12'	$1.17	6-12"

Table 15: Prices for bare-root fruit trees from a wholesale nursery. Source: http://www.lawyernursery.com/

At these prices, it may cost Burlington anywhere from $20,000 to $140,000 for the food tree stock to meet the needs of their VFI population depending on what mix of species is chosen. Higher quality genetics often demand a premium, although there may be opportunities to collaborate with government and university breeding programs to acquire free plants (this is discussed further in Section 4.5.2). The cost of labor and materials is difficult to estimate given that municipalities could potentially utilize significant numbers of volunteers for planting. Additionally, the role of private and public funding for UFF projects should not be underestimated; for instance, the London Orchard project has received significant funding from the City of London, Lush, the Lottery Fund, and the Forestry Commission (LOP 2011), and the New York City Million Tree project has received funding from Toyota, BNP Paribas and Consolidated Edison (NYCMT 2011).

In addition to providing freely accessible public produce, urban food-trees have a number of additional economic benefits including pollution control, carbon sequestration, and potential income derived from non-timber forest products (NTFPs). There are numerous studies on the economic value of urban tree services; Table 16 summarizes a number of these.

Urban Tree Values	Range per tree	Type	Source
NTFPs	$4-103 / year	Product trees only	Community Resources 2000
Energy Savings	$1-$32 / year $17-$25 / year	Street and yard trees shading southern walls and windows	American Forests 1995
Pollution Control	$0.04 - $2 / year	All urban trees	McPherson et al. 1994
Carbon Sequestration	$0.03 - $2.25 / year	All urban trees	McPherson et al. 1994

Table 16: Estimated values for urban tree services and products. Source: Bentrup et al. 2001

3.4 What species should municipalities consider for urban food forestry?

3.4.1 Climate-change resilient food trees for urban food forestry

Selecting appropriate trees and shrubs for urban areas is a difficult task given the uniquely harsh growing conditions found in cities (Roloff et al. 2009). Selecting urban trees is further complicated by anticipated global climate change, which is likely to involve more extreme weather conditions, especially periods of heat and drought (Schmidhuber & Tubiello 2007). To assist decision makers in selecting appropriate woody species in cities given predicted changes in climate, Roloff et al. (2009) developed a Climate-Species-Matrix (CSM) which analyzes 250 urban woody species used in Central European urban parks and gardens. Each species is ranked using four degrees of drought resistance and winter robustness from a scale of 1 to 4, with 1 being the most tolerant. This matrix is intended to help urban planners avoid making species selections that could result in high tree mortality, poor vitality, and considerable economic and ecological costs (Roloff 2009).

As suggested by Roloff (2009), the CSM is intended to provide a basis for discussion and supplementation for further research dependent on individual requirements; I used the paper as a starting point for developing a *Climate-Food-Species-Matrix* (CFSM), which identifies food-bearing species among the 250 analyzed and expands the list to include additional species. Extracting food-producing species took place in two stages. During the first, I cross-checked each species with the Plants for a Future database (PFAF 2010), the USDA's National Plant Germplasm System Database (GRIN), and university horticultural extension publications, especially Purdue University's Center for New Crops & Plant Products (PUNCR 2011). The first pass resulted in the identification of 63 edible species representing approximately 25% of the original list (see Appendix A for a list of these species). Criteria for edibility were lenient in the initial pass and included even trees that are considered "famine foods" (i.e. to be eaten when all other food sources fail).

The second pass involved researching each of these 63 species to determine which have been cultivated or bred specifically for a source of human food. Several species are well-known to be cultivated for human consumption (such as plums and persimmons), while others (such as the serviceberry and hawthorn) required more significant research. A total of 22 species were identified during the second pass (shown in Table 17), representing approximately 9% of the original list.

Climate-Food-Species-Matrix

Latin name	Common name	Height	Drought tolerance	Hardiness
Cornus mas L.	Cornelian-cherry	Up to 10m	1	1
Lycium barbarum L.	Barberry matrimony-vine	Up to 10m	1	1
Lycium chinense Mill. var. chinense	Chinese boxthorn	Up to 10m	1	1
Diospyros lotus L.	Date plum	>10m	1	2
Sorbus domestica L.	Service tree	>10m	1	2
Prunus armeniaca L.	Apricot	Up to 10m	1	2
Prunus cerasifera Ehrh. subsp. cerasifera	Cherry plum	Up to 10m	1	2
Prunus fruticosa Pall.	European dwarfcherry	Up to 10m	1	2
Morus alba	White mulberry	>10m	1	3
Prunus dulcis (Mill.) D.A.Webb.	Almond	Up to 10m	1	4
Amelanchier arborea (F. Michx.)Fernald	Downy serviceberry	Up to 10m	2	1
Hippophae rhamnoides L. subsp. rhamnoides	Sea buckthorn	Up to 10m	2	1
Carya ovata (Mill.) K.Koch Shagbark hickory	Shagbark hickory	>10m	2	2
Castanea sativa Mill.	Sweet chestnut	>10m	2	2
Corylus colurna L.	Turkish hazel	>10m	2	2
Diospyros virginiana L.	Persimmon	>10m	2	2
Pyrus communis L.	Common pear	>10m	2	2
Mespilus germanica L.	Medlar	Up to 10m	2	2
Morus nigra L.	Black mulberry	>10m	2	3
Juglans regia L. subsp. regia	Common walnut	Up to 10m	3	3
Corylus avellana L.	Common hazel	Up to 10m	3	1
Carya illinoinensis (Wangenh.) K.Koch	Pecan	>10m	4	2

Table 17: Climate-Food-Species-Matrix containing commercially-grown food trees appropriate for urban areas, extracted from the Roloff et al.'s (2009) Climate-Species-Matrix, ranked by drought tolerance and cold hardiness.

In addition to these 22 species, I created my own addendum of 47 additional species, drawing from personal knowledge, as well as the three sources used to evaluate the edibility of the original CSM species. I chose to give a specific temperature hardiness rating for each of these, and to only state 'Yes' or 'No' for Drought Tolerance, since this was often the only information available. Additionally, I rank the species in terms of edibility based on my own four criteria. Table 18 shows the results of this effort; highlighted species are part of genuses included in the original CSM, and species marked with stars are actinorhizal (nitrogen-fixing).

Climate-Food-Species-Matrix Addendum

Latin name	Type of plant	Common name	Commercially cultivated for food?	Widely recognized and marketed?	Palatable when eaten raw?	Can be eaten without special preparation?	Edibility Rating	Hardy to (degrees Celsius)	Drought tolerant?
Ficus carica	Short tree	Fig	Yes	Yes	Yes	Yes	5	-15	Yes
Rubus fruticosus	Short bush	Blackberry	Yes	Yes	Yes	Yes	5	-25	Yes
Rubus idaeus	Short bush	Raspberry	Yes	Yes	Yes	Yes	5	-40	No
Fragaria × ananassa	Groundcover	Strawberry	Yes	Yes	Yes	Yes	5	-30	No
Vaccinium angustifolium	Short bush	Lowbush blueberry	Yes	Yes	Yes	Yes	5	-40	Yes
Rubus chamaemorus	Groundcover	Cloudberry	Yes	Yes	Yes	Yes	5	-40	No
Vaccinium corymbosum	Tall bush	Highbush blueberry	Yes	Yes	Yes	Yes	5	-40	Yes
Ribes nigrum	Short bush	Black Currant	Yes	Yes	Yes	Yes	5	-20	No
Ribes glandulosum	Short bush	White currant	Yes	Yes	Yes	Yes	5	-40	No
Vitis labrusca	Vine	Grape	Yes	Yes	Yes	Yes	5	-30	Yes
Prunus persica	Short tree	Peach & nectarine	Yes	Yes	Yes	Yes	5	-20	No
Malus domestica	Tall tree	Apple	Yes	Yes	Yes	Yes	5	-40	No
Diospyros kaki	Short tree	Persimmon	Yes	Yes	Yes	Yes	5	-10	No
Pyrus pyrifolia	Short tree	Asian pear	Yes	Yes	Yes	Yes	5	-18	Yes
Ribes uva-crispa	Short bush	Gooseberry	Yes	Yes	Yes	Yes	5	-20	No
Sambucus nigra	Tall bush	Elderberry	Yes	Yes	Yes	Yes	5	-25	No
Ziziphus zizyphus	Tall tree	Jujube	Yes	No	Yes	Yes	4	-25	Yes
Amelanchier alnifolia	Short tree	Saskatoon	Yes	No	Yes	Yes	4	-20	Yes
Asimina triloba	Large bush	Pawpaw	Yes	No	Yes	Yes	4	-20	No
Eriobotrya japonica	Tall tree	Loquat	Yes	No	Yes	Yes	4	-10	Yes
Ugni molinae	Short bush	Tazziberry	Yes	No	Yes	Yes	4	-10	Yes
Corylus americana	Short tree	American Filbert	Yes	Yes	Yes	No	4	-20	Yes
Vaccinium vitis-idaea	Groundcover	Lingonberry	Yes	Yes	No	Yes	4	-35	No
Actinidia arguta	Vine	Hardy Kiwi	No	No	Yes	Yes	3	-12	No
Ribes x culverwellii	Short bush	Jostaberry	No	No	Yes	Yes	3	-18	No
Acca sellowiana	Short bush	Feijoa	Yes	No	Yes	No	3	-12	Yes
Araucaria araucana	Tall tree	Monkey puzzle	Yes	No	Yes	No	3	-10	No
Schisandra chinensis	Vine	Schisandra	Yes	Yes	No	No	3	-17	No
Elaeagnus multiflora*	Tall bush	Goumi, Gumi	No	No	Yes	Yes	3	-35	Yes
Lonicera caerulea	Short bush	Haskap, Honeyberry	No	No	Yes	Yes	3	-40	No
Sorbopyrus auricularis	Tall tree	Shipova	No	No	Yes	Yes	3	-20	No
Prunus tomentosa	Short tree	Nanking cherry	No	No	Yes	Yes	3	-40	Yes
Shepherdia argentea*	Short bush	Buffalo berry	No	No	Yes	Yes	3	-35	Yes
Vitis rotundifolia	Vine	Muscadine grape	Yes	No	No	Yes	3	-20	Yes
Cydonia oblonga	Short bush	Quince	Yes	No	No	No	2	-15	No
Gaultheria shallon	Short bush	Shallon	No	No	No	Yes	2	-20	Yes
Viburnum trilobum	Tall bush	High bush cranberry	No	No	No	Yes	2	-40	Yes
Aronia melanocarpa	Short bush	Aronia, Chokeberry	Yes	No	No	No	2	-35	Yes
Cudrania tricuspidata	Short bush	Che	No	No	Yes	No	2	-12	Yes
Opuntia compressa	Short bush	Eastern prickly pear	No	No	Yes	No	2	-30	Yes
Apios americana	Tuber	Ground nut	Yes	No	No	No	2	-35	No
Myrica pensylvanica*	Short bush	Northern Bayberry	No	No	No	Yes	2	-40	Yes
Cornus kousa	Short tree	Japanese dogwood	No	No	No	No	1	-20	Yes
Arbutus unedo	Short tree	Strawberry tree	No	No	No	No	1	-12	Yes
Vaccinium macrocarpum	Groundcover	American cranberry	No	No	No	No	1	-30	No
Caragana arborescens	Tall bush	Siberian pea tree	No	No	No	No	1	-40	Yes
Hovenia dulcis	Tall tree	Japanese raisin	No	No	No	No	1	-15	Yes

*Actinorhizal plants (nitrogen-fixing) **Special preparation includes peeling, shelling, cooking, etc. Highlighted species are part of genus' in original matrix

Table 18: Climate-Food-Species-Matrix addendum, containing additional food trees that could be utilized in urban food forestry, ranked by edibility. Large Tree = >10m; Short tree = >6m, up to 10m, Large bush = >3m, up to 6m; Short bush = >0.25m, up to 3m; Groundcover = <0.25m

While some of the species in the CFSM are not tolerant of drought, they may occupy specific niches in food forests which to not necessitate this trait. For instance, the paw-paw tree (Asimina triloba) is particularly intolerant of drought, but it is also highly tolerant of shade and moist conditions; thus, this species could be used for sub-canopy food production in heavy shade where the rate of evapotranspiration is lower and ambient humidity is higher, thereby reducing the need for drought tolerance. Additionally, while some species like are not particularly cold hardy (like the tazziberry), they could utilize urban microclimates which are sheltered, benefitting from waste heat from buildings, thereby creating a synergism where the building benefits from added insulation, and the plant is able to survive in a location not normally possible.

4. DISCUSSION

4.1 Overview

The results of my research indicate that UFF is a promising urban landscape design strategy for improving urban food security which is cost effective and has additional social, ecological and economic benefits. UFF is unique among other forms of urban agriculture in that it is based upon the use of woody perennial species, which allows for low-maintenance, high-output food production.

This section explains in greater detail how UFF can be used as a landscape design strategy to increase the resilience and sustainability of urban social ecological systems. I begin by examining UFF through the lenses of sustainability science and landscape ecology, then analyze UFF using Ahern's (2011) five strategies for building urban resilience capacity. Next, I focus on the multifunctional aspect of UFF, utilizing Lovell & Johnston's (2009) framework and give examples of how UFF can contribute to building social, ecological, and economic capital in urban areas, with particular attention paid to food security. Finally, I cover some practical considerations of UFF for municipal governments, including discussions about available resources and techniques to enhance UFF as well as limitations and potential problems.

4.2 Theoretical Perspectives on UFF

According to Termorshuizen & Opdam (2009:1037), landscape ecology (LE) is "in a position to become the scientific basis for sustainable landscape development", but in order to do so it must include a valuation component and be suitable for use in collaborative decision-making at a local scale. The perceived need to incorporate these components into LE research is indicative of a gap between research and application in LE that has been recognized some scholars, who call for the implementation of theory in landscape design (Lovell & Johnston 2009). There is also a growing consensus that LE research should focus on the concept of landscape services as a unifying common ground where scientist from various disciplines are encouraged to cooperate in producing a common knowledge base for landscape design (Termorshuizen & Opdam 2009; Wu 2006; Musacchio 2011; Nassauer & Opdam 2008). This position is shared by the field of sustainability science (SS), which is concerned primarily with "use-inspired basic research" that serves to advance both useful knowledge and informed action by creating a dynamic bridge between the two (Clark & Dickson 2003) and aims to provide knowledge co-produced by scholars and practitioners to assist decision making aimed at sustainable development (Kates et al. 2001).

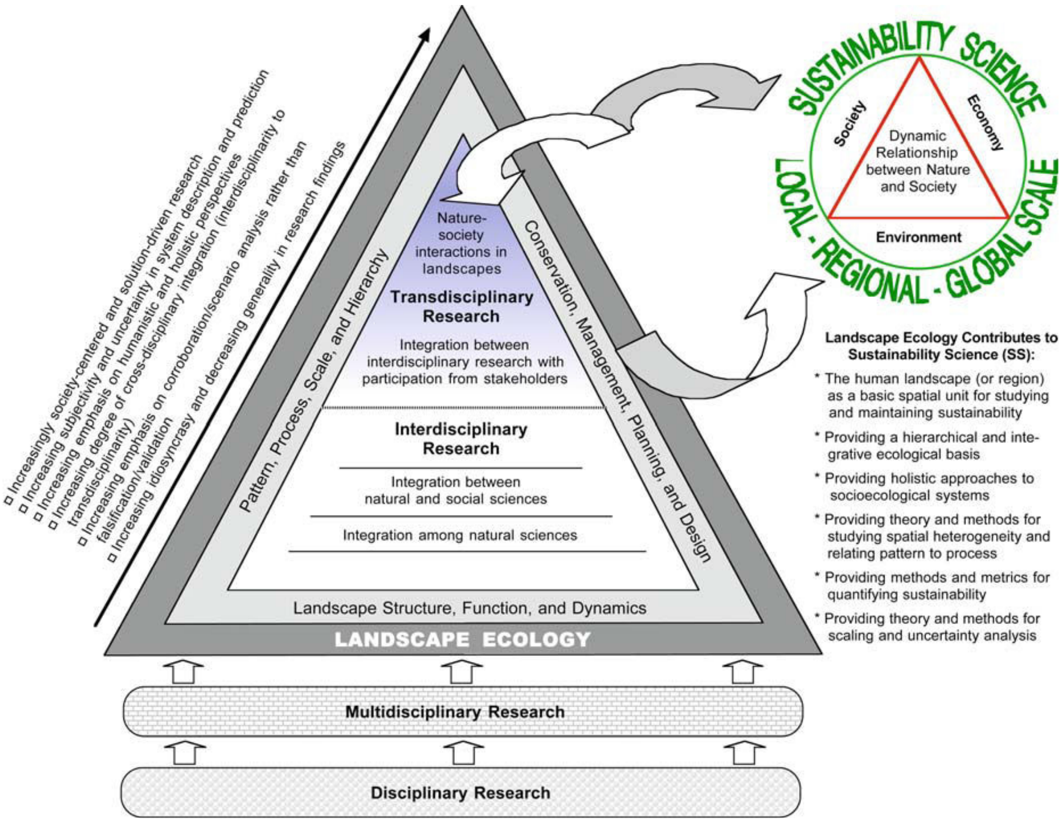

Figure 18: A hierarchical and pluralistic view of landscape ecology and its relationship to sustainability science (Wu 2006)

There has been a growing recognition of the overlapping research priorities of landscape ecology and sustainability science among academic scholars (Clark & Dickson 2003; Nassauer & Opdam 2008; Wu 2006; Ahern 2011). Figure 18 illustrates the relationship and overlap between LE and SS; the greatest opportunity for information sharing between these fields occurs at the transdisciplinary end of the LE research spectrum (Wu 2006), which is the area where UFF could provide case study material for research in both fields. At its core, UFF can be understood as a solution-oriented multifunctional landscape design approach aimed at building the resilience and adaptive capacity of urban social-ecological systems. Contemporary landscape ecology literature suggests that there is a need for new forms of landscape planning which bridge theory and practice to create reproducible and measurable landscape service performance outcomes in terms of ecological, social, and economic capital (Termorshuizen & Opdam 2009; Musacchio 2011; Lovell & Johnston 2009). UFF represents a landscape design strategy that might provide a bridge between theory and practice and incorporates tangible landscape services, some of which are measurable (e.g. caloric output per unit of land). While a full discussion of the potential contributions of UFF to SS and LE is difficult given the lack of well-established UFF projects, I will briefly elucidate my position by examining the contributions of UFF to the suite of five urban planning and design strategies for building urban resilience proposed by Ahern (2011), which integrates concepts from LE, SS, and resilience theory. These five strategies include *multifunctionality*, *redundancy and modularization*, *bio- and social-diversity*, *multi-scale networks and connectivity*, and *adaptive planning and design*. Each of these is discussed below.

4.2.1 Multifunctionality

Landscape multifunctionality is achieved through the intertwining and combining of functions to create landscapes that are efficient spatially and economically (Ahern 2011). By increasing the number of functional attributes, multifunctional landscapes benefit from the support of social constituents and stakeholders associated with the functions provided (Ahern 2011). UFF as a land-use is characterized by all of the widely cited benefits of urban forestry (e.g. carbon sequestration, air purification, erosion control, urban beautification, wildlife habitat, social psychological health, energy savings and storm-water runoff mitigation (Konijnendijk 2005)), as well as providing additional functions, including food production, social capital building through food tree harvesting and planting initiatives, and stimulating social and institutional innovation (discussed further in Section 4.3)

4.2.2 Redundancy and Modularization

Redundancy and modularization are achieved when multiple landscape components provide similar or backup functions which spread risk across time and space (Ahern 2011). UFF meets this criterion by providing an additional urban food production system that itself has built in redundancies and backup functions (i.e. multiple food trees fruiting at the same time with different pollination requirements, climatic tolerances, etc). Fraser et al. (2005) have pointed out the importance of redundancy within urban food systems, arguing that diversifying urban food supply sources is critical to building resilience against future urban food system shocks. UFF provides several backup functions: preserving genetic stock of valuable food crops (discussed in Section 4.5.1), creating pollinator habitat (discussed in section 4.5.3), and providing an immediate source of food during times of compromised access (for example, during economic downturns food insecurity rises and donations to food banks decrease; public produce can potentially buffer resultant donation shortages).

4.2.3 Biological and Social Diversity

Biodiversity, along with social, physical, and economic diversity, supports urban resilience by providing a "library of knowledge", some of which has known utility, while other portions remain in wait for their value or function to be appreciated (Lister 2007 in Ahern 2011). When a city contains a greater number of species performing a similar function (e.g. a diverse population of pollinators), there is a greater likelihood of sustaining a wider range of conditions, which increases capacity to recover from disturbance (Ahern 2011). UFF meets this criterion by increasing the diversity of flora within urban centers to include previously underutilized plant species, which lend themselves not only to human food security, but also wildlife food security. This creates new habitat and food sources which can support a greater diversity of wildlife.

4.2.4 Multi-scale networks and connectivity

Lack of connectivity is often a primary cause of malfunction or failure in urban support systems; thus, multi-scale connectivity is important when planning for functions that operate at multiple scales (e.g. walking trails that link with bus routes in the urban transport system) (Ahern 2011). By retrofitting existing urban forestry and greenway infrastructure in urban areas with food-trees, highly connected multifunctional corridors can be constructed which could act simultaneously as recreational areas, wildlife corridors, noise barriers, and shelterbelts in addition to being a source of public produce. Bentrup et al. (2001) refer to such multifunctional networks as ecobelts, which are depicted in Figure 19. A description of different functions served by each section in this diagram (e.g. A-A, B-B) can be found in Appendix C; real-world examples from the city of Lund, Sweden can be found in Appendix D.

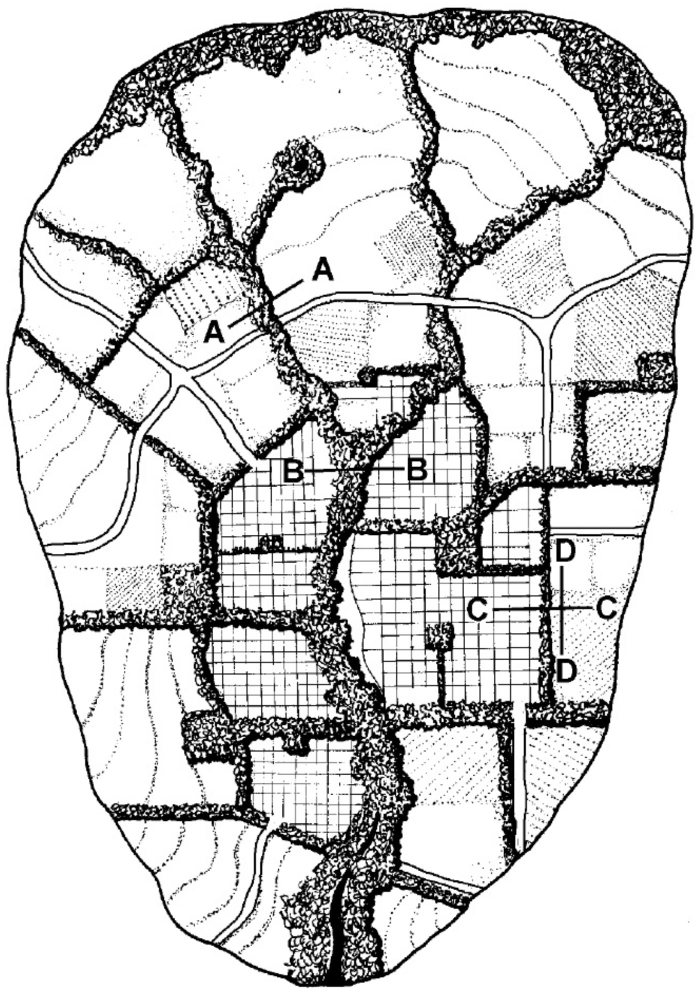

Figure 19: Conceptual ecobelt plan for watershed. Such ecobelts can be retrofitted to create "foodbelt" networks in cities. Source: Bentrup et al. 2001

Ahern (2011:343) states that "connectivity can be considered a primary generator of sustainable urban form built around blue-green networks that support biodiversity, hydrological processes, pedestrian transportation, climatic modification, neighborhood identity, and aesthetic enhancement". Ecobelts exemplify these traits and additionally offer production functions by contributing food and other non-forest timber products (NFTPs) to the community. In the context of UFF, such networks can be thought of as *foodbelts*.

4.2.5 Adaptive planning and design

According to adaptive planning and design principles, making decisions with imperfect knowledge about change and potential disturbances presents an opportunity to "learn-by-doing" (Holling 1978 in Ahern 2011). Within the adaptive planning model, urban designs can be seen as "hypotheses" of how a policy or project will influence specific urban processes or functions; such policies and designs become experiments from which to gain new knowledge through monitoring and analysis (Ahern 2011). UFF represents a landscape design strategy well suited to adaptive planning since it lends itself to monitoring and public feedback through volunteer initiatives like geo-wikis which can serve as an ongoing and constantly updating source of feedback. By analyzing feedback from food banks, urban foresters, arborists, landscape architects, urban planners and the general public, and monitoring activity and usage of public food trees, UFF can be piloted as a "safe-to-fail" landscape design experiment, as discussed by Lister (2007) and Ahern (2011).

Table 19 summarizes the points made above and lists specific strategies that might be employed at a local scale of UFF design to meet municipal planning goals stemming from resilience capacity building criteria.

Urban resilience capacity building strategy	Municipal landscape planning goal	Specific UFF landscape planning strategies contributing to goal
1. Multifunctionality	Maximize spatial efficiency and number of urban forest landscape services	Utilize nitrogen-fixing trees to build soil fertility (see Table 18), utilize public green roofs, utilize permaculture techniques to stack food-producing vegetation vertically (see Section 4.5.2)
2. Redundancy and modularization	Create backup stock of crop germplasm and pollinators	Incorporate high-value and rare food species from government and university breeding programs into the urban forest; incorporate urban beekeeping and bat houses; utilize grafting to reduplicate germplasm
3. (Bio and social) diversity	Maximize urban biodiversity	Increase diversity of food crops in urban forest (e.g. using Climate-Food-Species-Matrix); plant flowers for every season to maximize pollinator diversity
4. Multi-scale networks and connectivity	Create "food corridors" and "foodbelts" to mitigate urban food insecurity	Retrofit existing green infrastructure like greenbelts, vegetative buffers and parks; utilize geo-wiki mapping initiatives and GIS to map foodbelts
5. Adaptive planning and design	Collect and analyze local data to determine capacity of urban food forest	Utilize geo-wiki maps and fruit harvest data collected from food-tree harvest initiative annual reports to document municipal agriculture yields; gather feedback from public through food banks and geo-wikis

Table 19: Summary of urban resilience capacity building strategies from Ahern (2011) with examples of goals and strategies that municipalities could employ

4.3 Specific Contributions of UFF to Urban Sustainability

Perhaps the most prominent feature of UFF is its multifunctionality. This section builds upon the work of Lovell & Johnston who developed a framework for modifying landscapes to improve performance by integrating ecological principles into landscape planning and design to create landscape features that contribute to urban sustainable development (Lovell & Johnston 2009).

Landscape multifunctionality in the context of sustainable development can be understood as a landscape designed to provide multiple environmental, social and economic functions (Wiggering et al. 2003 in Lovell & Johnston 2009). Rather than aiming for multifunctionality, anthropogenic landscapes are often designed to serve a single function such as cropland for food production or parks for recreation; Figure 20 illustrates how various landscape types can be perceived in relation to their economic, environmental, and social contributions to society (Lovell & Johnston 2009).

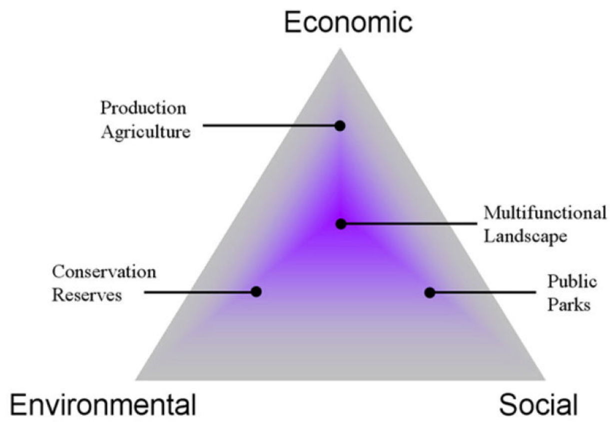

Figure 20: Conceptual diagram of multifunctional landscape framework within economic, environmental and social dimensions. Source: Lovell & Johnston (2009)

The following sections offer specific examples of how UFF can potentially contribute to social, ecological, economic capital.

4.3.1 Social Capital: Volunteerism & Public Engagement

Capra (1997) developed a conceptual framework for describing the link between ecological communities and human communities. This framework forms the basis of *ecoliteracy*, the degree to which one understands principles of organization of ecological communities. According to King (2008), agri-ecological systems provide unique opportunities for people to reconnect people with people and people with food, thus opening up spaces for ecoliteracy to develop through shared and reflective learning. UFF is an example of such an urban agri-ecological system, weaving together not only food security and urban trees, but also introducing the concept of public produce which lends itself to reflective learning as citizens reevaluate the role of public space.

The unique ability of UFF to build urban social capital is evidenced by the three types of emergent initiatives identified in Section 3.2: food-tree planting, mapping, and harvesting. These initiatives offer unique ways for urban citizens to interact with strangers, build connections with the food insecure population through food banks, and engage in participatory mapping projects which assist municipalities and contribute to the utilization of public fruit. Examples of projects which have demonstrated social capital building are the London Orchard Project and the Ben Nobleman Community Orchard.

4.3.2 Ecological Capital: Biodiversity

In addition to the ways in which UFF contributes to urban biodiversity directly (described in Section 4.2.3), there are a number of indirect ways which can be described using Colding's (2006) concept of ecological land-use complementation (ELC). Put simply, ELC holds that land uses in urban green patches can synergistically interact to support specific urban functions, especially biodiversity, when clustered and organized in appropriate configurations (Colding 2006:46). Colding puts forth six guiding principles for implementing ELC at local levels; for the sake of brevity, I will touch upon only two of these guiding principles.

The first is that newly developing urban areas should be designed to maximize the clustering together of different types of urban green patches to diversify habitat and promote complementation and supplementation functions for the benefit of biodiversity (Colding 2006:52). In addition to being well-suited to newly developing urban areas, UFF represents a new type of green patch for urban planners to utilize that improves the food security of both humans and wildlife. Secondly, Colding (2006) recommends planning so that *emergent ecological functions* of land-use are realized and so that the diversity of pollinators, seed dispersers and pest-regulators is maximized. This guideline overlaps with UFF in that these three categories of biodiversity are synergistic with food trees in that they improve agricultural productivity.

These two points of overlap between ecological land-use complementation principles and UFF illustrate how emerging urban planning strategies for urban biodiversity can overlap with strategies for improving urban food security with UFF as the common link.

4.3.3 Economic Capital: Product Innovation & Entrepreneurship

Urban food forestry can serve as a catalyst to stimulate innovative product development by making highly-bred perennial food-producing species widely accessible. Many of the species in the CFSM have demonstrated considerable economic potential as food, supplement and cosmetic products. *Lycium barbarum* (commonly known goji berry) is one such example; in the past decade the fruit of this shrub has been touted as a "superfood" owing to its high nutrient density and an increasing number of peer-reviewed medical publications demonstrating anti-tumor and immune-enhancing properties (Seeram 2008). The haskap berry is another example; Canadian production has increased rapidly in the past few years, leading to the founding of the Haskap Canada Association. Hundreds of acres are now under production, mainly for export to Japan where the berries are highly prized; Canadian demand is now increasing due in part to farmers markets and innovative products like haskap ice-cream; it is also being researched for anti-cancer properties (CTV 2010). Many other such examples of recent fruit-derived product innovation exist, including products from the tazziberry (*Ugni molinae*), seabuckthorn (*Hippophae rhamnoides*), and paw paw (*Asimina triloba*); Figure 21 shows a number of fruits with demonstrated product development potential.

Figure 21: Examples of species with demonstrated product innovation potential. From left to right: tazziberries, haskaps, seabuckthorn oil, and paw paw fruit. Sources: http://tazziberry.com; http://haskap.ca; http://usa.weleda.com; http://www.ars.usda.gov

The University of California (UC) Davis olive oil project is one example of a recent product innovation arising from public food trees. Walkways, bike paths and other public spaces on the UC Davis campus contain around 2,000 olive trees which historically have been a nuisance for ground crews and pedestrians (UCD 2011). The director of the university's Buildings and Grounds Division initiated the olive oil project, which began in 2004, to avoid problems from fallen olives. The 2007 harvest of olives yielded around 800 gallons of oil (3,000 liters) and sold out in a few months, generating close to $80,000 in profit (Nordahl 2009). Using their olive oil, the university has also begun creating lotions, soaps and balms, shown in Figure 22.

Figure 22: Products created from olive oil pressed from publicly accessible trees on the UC Davis campus. Source: http://oliveoil.ucdavis.edu/

Product innovation could be encouraged by municipalities by labeling trees, as is common in botanical gardens, with public signs offering background information such as species name, common uses and nutrient profile.

4.3.4 Food Security

In addition to these three examples of potential contributions to urban sustainable development, UFF can have a potentially profound impact on urban food security and public health. UFF is a fundamentally unique approach to food production in that it takes place on public land, thereby offering *public produce* as a community resource. This strategy has implications for each of the four primary dimensions of food security identified by the FAO (2002), which are depicted as a flowchart in Figure 23. This section briefly describes how UFF can impact each of these four dimensions within a developed urban context.

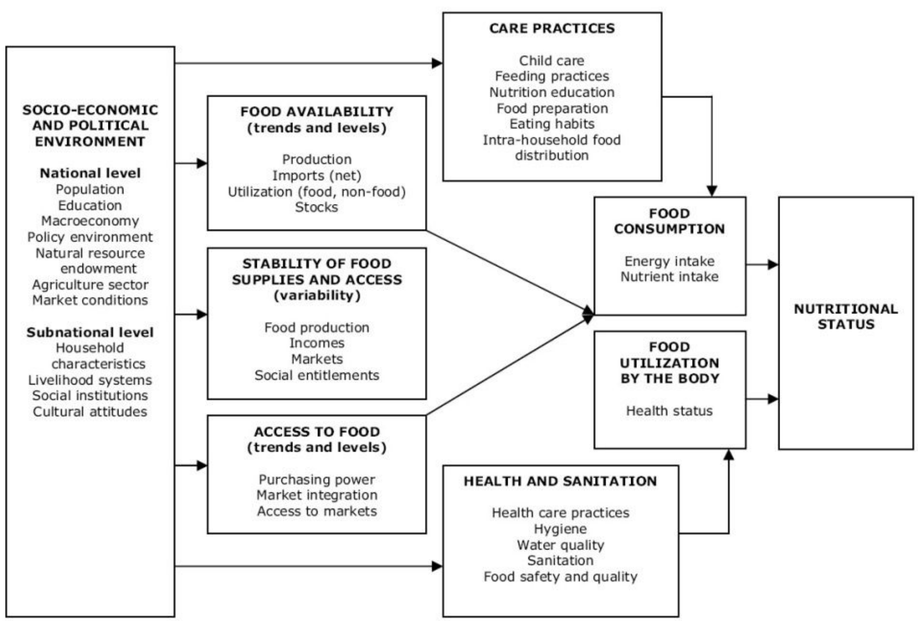

Figure 23: Conceptual framework for understanding food security and possible causes of poor nutritional status. Source: FAO 1998

Food availability refers to the quantity of adequate quality food available through domestic production or inputs (FAO 2011). UFF contributes to food availability in a number of ways both in the short-term and long-term. In the short-term, urban food trees provide freely-available fruits, berries and nuts that are at their peak of nutrient content and can be eaten without preparation, or preserved for later use. In the long-term, UFF can potentially impact food availability by acting as a stock of plant genetics (discussed in Section 4.5.1) and preserving stocks of pollinators (discussed in Section 4.5.3).

Food access is determined by one's access to adequate resources (entitlements) for acquiring appropriate foods for a nutritious diet (FAO 2011). Amartya Sen identified three kinds of entitlements: direct entitlements (food produced by family or individual), indirect entitlements (food obtained from markets from earned wages), and transfer entitlements (food obtained via charity or donation) (Fraser et al. 2005; Sen 1980). Public produce represents an exception to these entitlements, although it could loosely be considered a transfer entitlement. UFF impacts access both by circumventing the need for purchasing high-cost produce and also by acting as a potential source of income from the sale of NTFPs (refer to Table 16).

Food stability is closely related to both access and availability and refers to the ability of one to access food in the face of sudden shocks (e.g. economic or extreme weather events) (FAO 2011). UFF affects food stability on multiple levels. On the individual level, public food trees can provide food either through direct harvesting or food donated to food banks by way of volunteer harvesting initiatives. UFF also acts as a buffer against shocks to transport systems and large-scale crop failures from extreme weather events or contamination (e.g. from E. coli). UFF is somewhat limited in its provision capacity given its seasonality, but this can be offset to some degree by preservation via cold storage, canning or dehydrating.

Food utilization is the degree to which food is utilized and contributes to the nutritional status of the individual, as well as the safety of the food (FAO 2011). UFF can play a role in increasing utilization of fruits by making produce available that might otherwise be unaffordable or inaccessible (e.g. for people living in food deserts). Additionally, since public produce is grown within the city it potentially has a higher nutritional value since it has not been transported and stored before being consumed.

While UFF is able to positively impact these four dimensions of food security, it is important to recognize its fundamental limitations as a contributor to food security. Public produce will likely remain a supplementary source of food rather than a primary source given the preference of annual grain crops (e.g. corn, wheat and rice) as a food source in most cultures. Nevertheless, in cases where individuals lack access or availability of high quality fruits and nuts, UFF could play a substantial role in meeting daily requirements. It is also worth mentioning that consuming wild foods is generally seen as a coping strategy to meet food needs (Maxwell et al. 2003), however public produce does not fit the definition of wild food since it is consciously planted for the purpose of being picked.

In order to maximize the utilization of and access to public produce grown in UFF landscape features, there are a number of practical considerations that municipalities must face including planting areas, planting designs, tree selection, and pollination. These aspects are discussed in the following section.

4.5 Resources and techniques available to municipalities for UFF

A number of well-established resources and techniques are available to municipalities to optimize the resilience and productivity of UFF landscape features. These resources and techniques include breeding initiatives and germplasm repositories, urban beekeeping, green roofs, and planting techniques inspired by agroforestry and permaculture. This section briefly covers these topics in the context of UFF and relates them to elements of sustainability and resilience.

4.5.1 Genetic resources

Plant genetics are critically important to the success of urban food forestry since they influence the flavor, size, disease resistance, harvestability, nutritional value, and other important characteristics of fruit. Decades of breeding programs sponsored by national governments, universities, nurseries, nonprofits, and farms worldwide have yielded a wealth of useful species that could be leveraged by urban planners to improve urban food security and public health. To illustrate, I will briefly describe three genetic resources as they relate to UFF: the USDA Agricultural Research Institute's National Genetic Resources Program (NGRP), the Arbor Day Hazelnut Project, and the University of Saskatchewan Fruit Genebank.

The USDA National Genetic Resources Program was authorized by U.S. Congress in 1990 and was charged with the responsibility of acquiring, characterizing, preserving, documenting, and distributing germplasm important to food production (USDA ARS 2010). The NGRP has 21 genebanks located across the United States which house over 450,000 food crop species, many of which are actively being cultivated and improved (USDA ARS 2010). One project is concerned with developing dwarf apple rootstocks which are highly productive, low maintenance, and are more resistant to pests and disease; these advances have led to dwarf apple trees increasingly in popularity among commercial growers in recent years (USDA 2003). Figure 24 shows an example of a mature dwarf apple tree, which provides easy access to high quality fruit. UFF can not only benefit from this genetic resource, but also act as a backup stock for USDA genebanks. An additional benefit is that the USDA gives away plant stock at no cost (USDA ARS 2010).

Figure 24: Gennaro Fazio, director of the apple rootstock breeding project of the ARS Plant Genetics Resource Unit of the USDA next to a dwarf apple tree in Geneva, New York. Photo by Peggy Greb. Source USDA (2003)

Another large government-sponsored breeding program and germplasm repository is the University of Saskatchewan's Prarie Fruit Genebank which specialized in developing cultivars of haskap, dwarf sour cherries, saskatoons, hazelnuts, and several other crops listed in the Climate-Food-Species-Matrix (Tables 17 and 18). This Program has been breeding and selecting cold hardy plants for superior fruit quality and yields for over 80 years using genetics gathered from countries worldwide (USFP 2007). The dwarf sour cherry program has thus far released six cultivars of cherry trees that are highly suitable for UFF given their high yields, tolerance to drought and cold, and fruit quality. Figure 25 shows one example of these cherries, a cultivar called 'Juliet', which has 5g fruits ideal for eating fresh or processing into juice or baked goods (USFP 2007) which could generate high public demand in a well-situated UFF landscape feature.

Figure 25: 'Juliet' cultivar of dwarf sour cherry, bred by the University of Saskatchewan; an example of high quality genetics ideal for public food tree plantings. Source: USFP 2007

In addition to government-sponsored programs, a number of non-profit organizations are actively breeding food tree species that could be used in UFF. The non-profit Arbor Day Foundation has a number of active plant breeding projects including the Hybrid Hazelnut Consortium (HHC). The goal of the HHC is to develop high-yielding, low-input hazelnut cultivars that are competitive with annual crops for food, animal feed and bio-energy and are adapted to global climate change (ADF 2011). This project will span from 1995 to 2034 and include periodic releases of new resilient breeds to markets, with the objective of expanding the areas in which hazelnuts are suited to grow in the US (Figure 26). The ADF is constantly looking for partners for their research and encourages individuals and organizations to purchase plants for testing new selections and collecting data (ADF 2011).

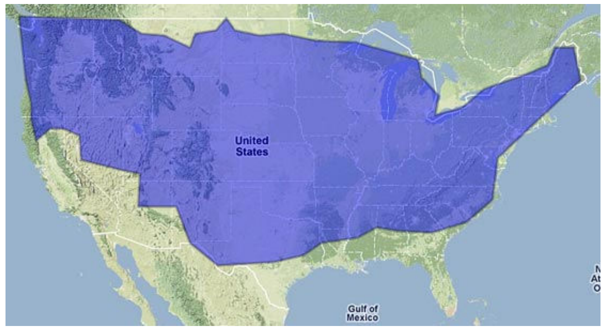

Figure 26: Potential hazelnut growing area in the United States, made possible by breeding efforts. Source: ADF 2011.

These three projects are examples of the hundreds of projects worldwide devoted to perennial food plant breeding which are ideally suited for collaboration with municipal governments through UFF projects.

4.5.2 Design strategies: Orchard management, agroforestry and permaculture

In addition to cultivar selection, UFF productivity can benefit from strategies used in other tree-based agricultural practices, most notably orchard management, agroforestry and permaculture.

Orchard management practices can benefit UFF by providing insights into pruning, grafting, and high density planning strategies.

Figure 27: Techniques used in orchard management that could be applied to urban food forestry. Left: Espaliered pear orchard. Middle: High yielding espaliered pear tree in urban area, making use of vertical space, Right: "2-n-1" grafted apple tree with two varieties on the same tree.
Sources: http://americangardenhistory.blogspot.com/2009/09/trees-espalier.html, http://growingwithstarkbros.com

Figure 27 shows an example of an "espaliered" orchard (left) and an example of how this pruning technique can be applied to an urban setting to create high yielding trees on very little land (middle). Grafting is another common horticultural technique used in orchard management, where the tissue of one plant is fused with another. This technique has been adopted by the nursery industry which uses it to create fruit trees bearing multiple varieties on the same plant, as shown in above.

Unlike most monoculture orchards, agroforestry combines multiple tree, bush, crop and sometimes animal species to maximize output by leveraging synergistic interactions (AFTA 2011). There are five basic kinds of agroforestry: alley cropping, silvopasture, riparian buffers, windbreaks and forest farming. Concepts from forest farming are particularly relevant to UFF. As shown in Figure 28, forest farms combine specialty shade-tolerant forest products such as blueberries and ginseng with overstory crops like pecans and sugar maples to maximize output per unit of land (USDA 1997). Nitrogen-fixing trees are also occasionally integrated into agroforestry and agroecology systems to build soil fertility and improve crop yields (Danso, Bowen & Sanginga 1992), a technique which could also easily be implemented into UFF landscape features.

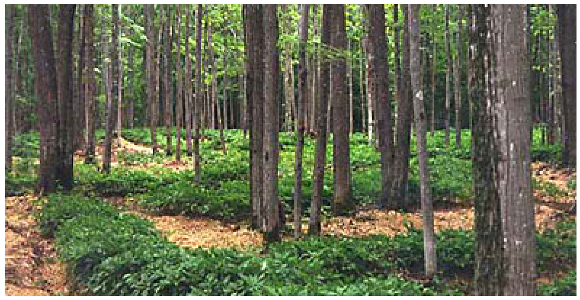

Figure 28: Specialty food crops being grown in shade underneath forest cover in a forest farming system. Source: http://www.unl.edu/nac/forestfarming.htm

Like forest farming, permaculture is concerned with maximizing output of landscapes with minimal inputs. However, permaculture is significantly more holistic in its approach, as is suggested by the portmanteau of "permanent" and "culture". Permaculture was developed by Bill Mollison and David Holmgren as a design system aimed at creating functional landscapes which provide sustainable food, resource and community systems based on nature's patterns and relationships (King 2008; Holmgren 2006).

Since its inception in the 1970s, a large body of permaculture literature has been developed which integrates concepts from landscape architecture, agroforestry, and ecology. *Food forestry* (also referred to as *forest gardening*) is a common technique employed in permaculture, which utilizes multiple layers of vegetation that are often synergistic to maximize productivity, as shown in Figure 29. These agricultural systems are high-yielding and low maintenance but do not lend themselves well to mechanized harvesting, hence their absence from large-scale agricultural systems. An analogy of a vertically-stacked, high-productivity, low-maintenance agricultural design from the realm of annual crop agriculture is the *three sisters* companion planting technique used by Native Americans. This system consists of growing squash, corn and climbing beans together which work synergistically on a number of levels: corn provides a trellis for the beans, which fix nitrogen into the soil and provides amino acids that corn and squash are lacking, and squash plants act as a groundcover, retaining soil moisture (Hemenway 2000).

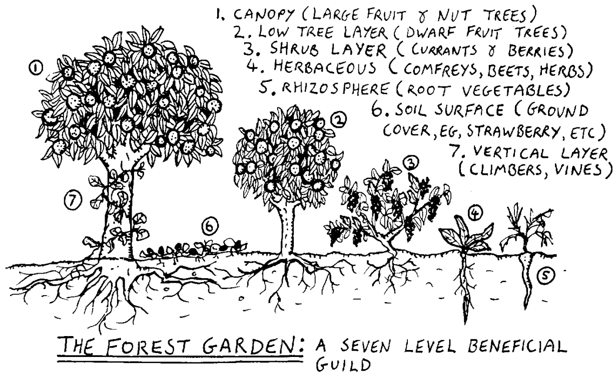

Figure 29: Seven layers of a food forest/forest garden. These layers can be combined to maximize spatial productivity and increase multifunctionality in UFF landscape features. Source: www.grahamburnett.net

Permaculture is intended to be implemented in virtually any climatic region where humans have settled, and there are a variety of resources available specifically on food forest design that could be utilized for UFF. The Permaculture Research Institute has established a number of large-scale model projects worldwide which detail how food forests can be designed and implemented in even the harshest conditions, which can provide knowledge useful for similarly harsh urban conditions with compacted, nutrient-depleted soils.

4.5.3 Urban Beekeeping

Regardless of how well an UFF landscape feature is designed, pollinators play a large role in determining agricultural productivity. Urban beekeeping is a growing movement worldwide which directly addresses this issue and offers a synergism with UFF. A number of high profile projects have been established around the world, such as the on top of the Paris opera house (Figure 30, left), the Fairmont Hotel in Toronto and the Royal Lancaster Hotel in London. Popularity has grown so quickly in some cities that entire websites have emerged devoted to mapping, educating and distributing bees (Figure 30, right). Urban beekeeping benefits urban food security in at least three ways. First, it creates a stock of urban bees that acts as a backup for collapsing colonies in rural farming areas. For largely unknown reasons, urban bees are far less susceptible to colony collapse disorder; in the French countryside bee losses can be as high as 50% per year, where is in the city they are less than 5% (Cimino 2008). Second, bees pollinate urban food trees, thereby increasing their yields. Third, bees produce large crops of honey; the hives atop the Paris opera house produce 450 kilograms of honey per year which is sold in the gift shop (Cimino 2008).

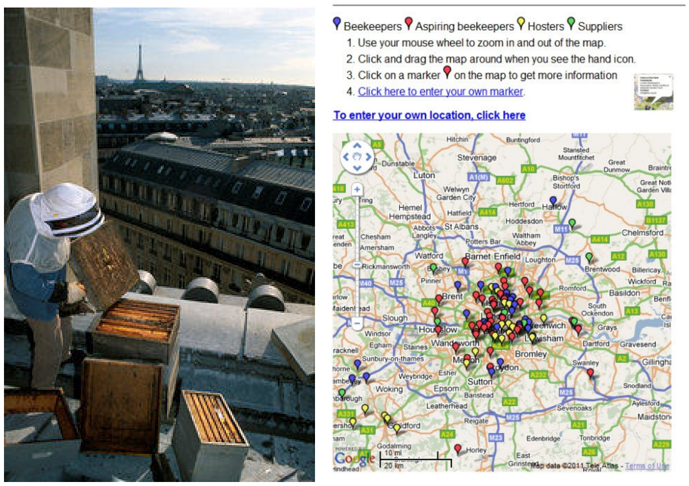

Figure 30: Left: Urban beekeeper Jean Pacton with urban beehives atop the Paris Opera Garnier. These hives yield approximately 450kg of honey each year. Source: Picturetank 2008. Right: Urban beekeeping geo-wiki in London, Source: http://www.urbanbees.co.uk

Urban beekeeping is synergistic with UFF initiatives since urban trees provide more fodder for bees, which allows for larger bee populations and more honey production. Thus, the relationship between bees and trees in UFF landscape features is *interfunctional*, in that the multiple functions provided by each interact symbiotically. Such interfunctional relationships should be sought out wherever possible within multifunctional landscapes to maximize productivity. Toward this end, municipalities can foster bee colony health by planting food forests which maximize the time of year when flowers are available to bees, consequently maximizing the amount of time fruit is available to humans.

4.5.4 Green Roofs

In addition to urban beekeeping, rooftops are being utilized for growing a variety of other plants ranging from grasses to food crops, usually referred to as "green roofs". Green roofs are urban landscapes which providing ecosystem services like storm-water management, regulation of building temperatures, reduced urban heat-island effects, and increased wildlife habitat (Oberndorfer et al., 2007). The Greenroof & Greenwall Projects Database lists 1,215 such projects, covering over 2.3 million square meters of urban roof and walls worldwide (GRGW 2011). These projects including public rooftop parks (Chicago City Hall), greenhouses (Montreal's Lufa Farms) and grapes vines for wine production (Toronto's Fairmont Hotel).

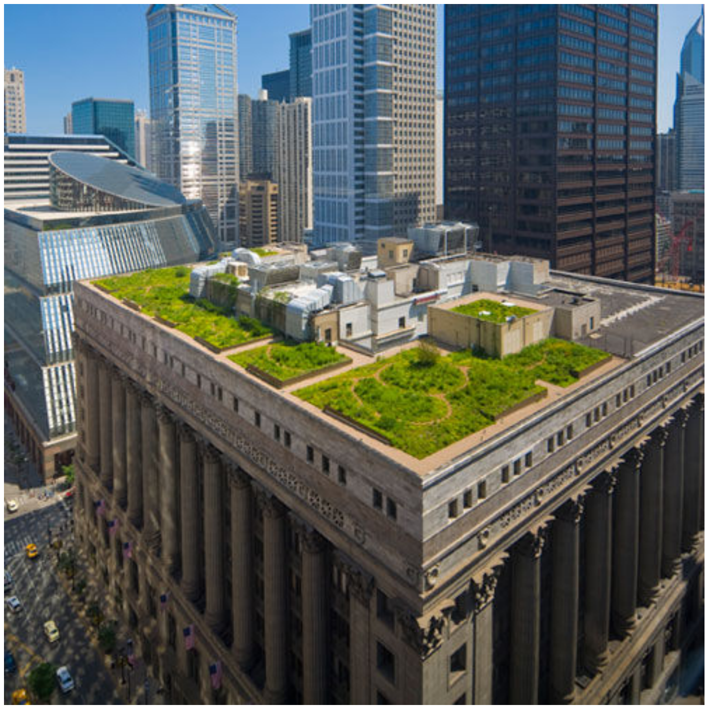

Figure 31: Green roof atop Chicago's Cultural Center and City Hall, which is open to the public and incorporates urban beehives. Source: http://www.explorechicago.org/city/en/about_the_city/green_chicago/Green_Roofs_.html

Figure 31 shows a public green roof park planted on top of Chicago's City Hall, which contains over 20,000 plants of more than 150 species including 100 shrubs, 40 vines, and 2 trees, as well as a number of urban beehives (City of Chicago 2010). This green roof is approximately 1,885 square meters, which is relatively small when considering a number of projects around the world exceed 50,000 m^2 (e.g. the Daimler-Chrysler project in Berlin, Germany) (GRGW 2011). UFF could be incorporated into publicly-accessible green roofs like Chicago's City Hall and potentially produce considerable amounts of public produce. Just as urban beekeeping and green roof plantings are interfunctional, UFF is interfunctional with both of design elements, increasing the nutrient cycling of green roofs and benefitting from the additional exposure to sunlight and excellent drainage offered by rooftops.

4.6 Limitations and potential problems with UFF

While UFF has potential to improve urban food security as well as contribute to other aspects of natural, social, and economic capital, it has a number of potential limitations and complications. This section briefly covers a number of these concerns and discusses potential solutions.

Underutilization of fruit is one concern of UFF. If cities were to aggressively pursue public food tree planting, there is a risk that large amounts of food may go unutilized and fall to the ground to rot, potentially causing issues with excessive scavenger wildlife or unsightliness. Proper placement (i.e. planting in parks versus overhanging roadways or pedestrian paths) is an important step to avoiding problems with spoiled fruit. Additionally, by collaborating with volunteer organizations and actively publicizing fruit maps, municipalities can reduce the risk of excess fruit spoilage.

Food trees are also limited in terms of their potential impact on food security. While some people do survive exclusively on fruits and nuts ("fruitarians"), most people allocate only a small portion of their diet to these foodstuffs. While UFF will ideally increase intake of fruits amongst the public, it is important to bear in mind the maximum amount of produce a given community can handle and plant accordingly, ideally in stages. Landscape planners in developed regions can learn from organizations that focus on large-scale fruit tree planting projects in developing countries such as Trees for the Future (www.plant-trees.org), which has planted over 65 million trees since 1988 and the Fruit Tree Planting Foundation, which routinely plants several thousand fruit trees in a given area as part of development or community-building projects (FTPF 2005).

The risk of introducing new invasive species into cities is a potential ecological and economic threat. A number of the most potentially useful species for urban food forestry are listed as having invasive potential in a number of areas across North America and Europe. One potential solution is to take advantage of plants bred to be non-invasive by nurseries and the government breeding programs (USDA 2009). It is also important to note that there is considerable debate over the definition and threat of invasive species among horticulturalists (Niemiera 2009).

Contamination of fruits via atmospheric or soil-borne pollutants is another potential problem with urban food trees, however this risk has been addressed by numerous reputable soil scientists and appears to be minimal. For example, Dr. Johnathan Leake of the University of Sheffield points out that while urban land may be contaminated, many of these toxins are chemically bound up in soil and are not taken up by plants (Abundance 2009). More importantly, studies have found that fruit is normally one of the least contaminated parts of a plant, with more toxins accumulating in woody and leafy matter (Abundance 2009; Nordahl 2009). This implies that food trees play a particularly important role in UPA, since most urban farms presently focus on vegetable crops which are more susceptible to heavy metal contamination (e.g. leafy vegetables, root crops, broccoli, or cabbage); such areas might be better suited to fruit production with perennial woody species.

5. CONCLUSION AND FURTHER RESEARCH

Urban food forestry represents an emergent multifunctional land-use that stimulates cooperation between scientists, practitioners, municipal governments and the general public. As such, it is a strategy able to produce innovative knowledge that is co-created by these entities for the common goal of sustainable urban development. There are a number of tangible and measurable ways in which UFF contributes to social, ecological and economic capital including the formation of innovative public engagement opportunities (e.g. participatory mapping geo-wikis), collaborative landscape design projects, fruit and nut donations to food banks and charities, and product innovation. By incorporating food production into the public landscape, UFF fosters knowledge sharing and collaboration between local governments, plant breeding programs, academia, and the general public.

UFF is fundamentally distinct from other forms of urban agriculture, which have tended to focus on annual vegetable crops that are not accessible to the public. By focusing on perennial food crops, UFF systems are more resilient to extreme weather conditions including drought, flooding and cold. Additionally, UFF is well suited to retrofitting existing green infrastructure networks like greenways and park systems to create “foodbelts” that benefit both humans and urban wildlife. By growing public produce, UFF contributes to food equity and positively impacts each of the four primary dimensions of food security.

As evidenced by the increasing number of non-profit, grassroots and municipal initiatives, UFF is gaining popularity. In this thesis, I have expounded upon this trend and contributed to both the practical and theoretical knowledge base of landscape ecology and, by extension, sustainability science. Furthermore, I have demonstrated the feasibility of meeting the caloric deficit of the food insecure population of Burlington, Vermont by implementing UFF on public land. These calculations contribute to the current lack of quantitative analysis of urban agriculture yields, particularly with regard to perennial food crops in developed urban areas.

These contributions open up a variety of research opportunities particularly well suited LE and SS, but also human ecology, urban ecology, landscape architecture, and urban forestry. The multiple functions of UFF projects overlap with existing regional and international initiatives concerned with public health, climate change, storm-water runoff, air quality, agriculture and biodiversity, creating numerous opportunities for leveraging funding for UFF research. When combined with the abundant source of underutilized urban public and semi-public land, as well as the obvious interests of prominent private sponsors, there are many opportunities for the establishment of large-scale foodbelt networks for on-going adaptive planning projects.

Far from being a panacea to urban food insecurity, UFF should for now be seen at best as a small part of the solution. How big a role it will play in urban food security will take many years to determine. In the meantime, it would be advantageous for municipalities to learn from innovative urban forestry management plans which incorporate local food security into their vision and planning goals, such as those in British Columbia. The success or failure of these pioneers will be a testament to the viability of UFF as a landscape design strategy for building the adaptive capacity of urban food systems and contributing to urban sustainable development.

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7. APPENDICES

Appendix A: Results from second iteration of academic journal article search

Journal	Search criteria	Returned Results (# of articles)	Articles relating public trees and urban food security
Urban Forestry & Urban Greening	"food"	74	0
	"food security"	1	1
	"subsistence"	2	0
	"fruit"	23	0
	"urban agriculture"	32	0
	"green roofs"	8	0
	"agroforestry"	4	0
	"orchard"	11	0
	"pomology"	1	0
	"permaculture"	1	0
Agroforestry Systems	"food security", urban	28	0
	"forest garden"	19	0
	"forest farming"	39	0
Landscape and Urban Planning	"food security"	30	0
	"fruit trees"	61	0
	"community orchard"	3	0
	"forest garden"	4	0
Arboriculture & Urban Forestry	"food"	58	0
	"fruit"	54	0
	"food security"	2	0
Urban Ecosystems	"food security"	6	0
	"permaculture"	1	0
	"forest garden"	3	0
	"fruit"	49	0
Landscape Ecology	"food security"	11	0
	"agroforestry"	39	0
	"forest garden"	1	1
	"fruit trees"	12	0

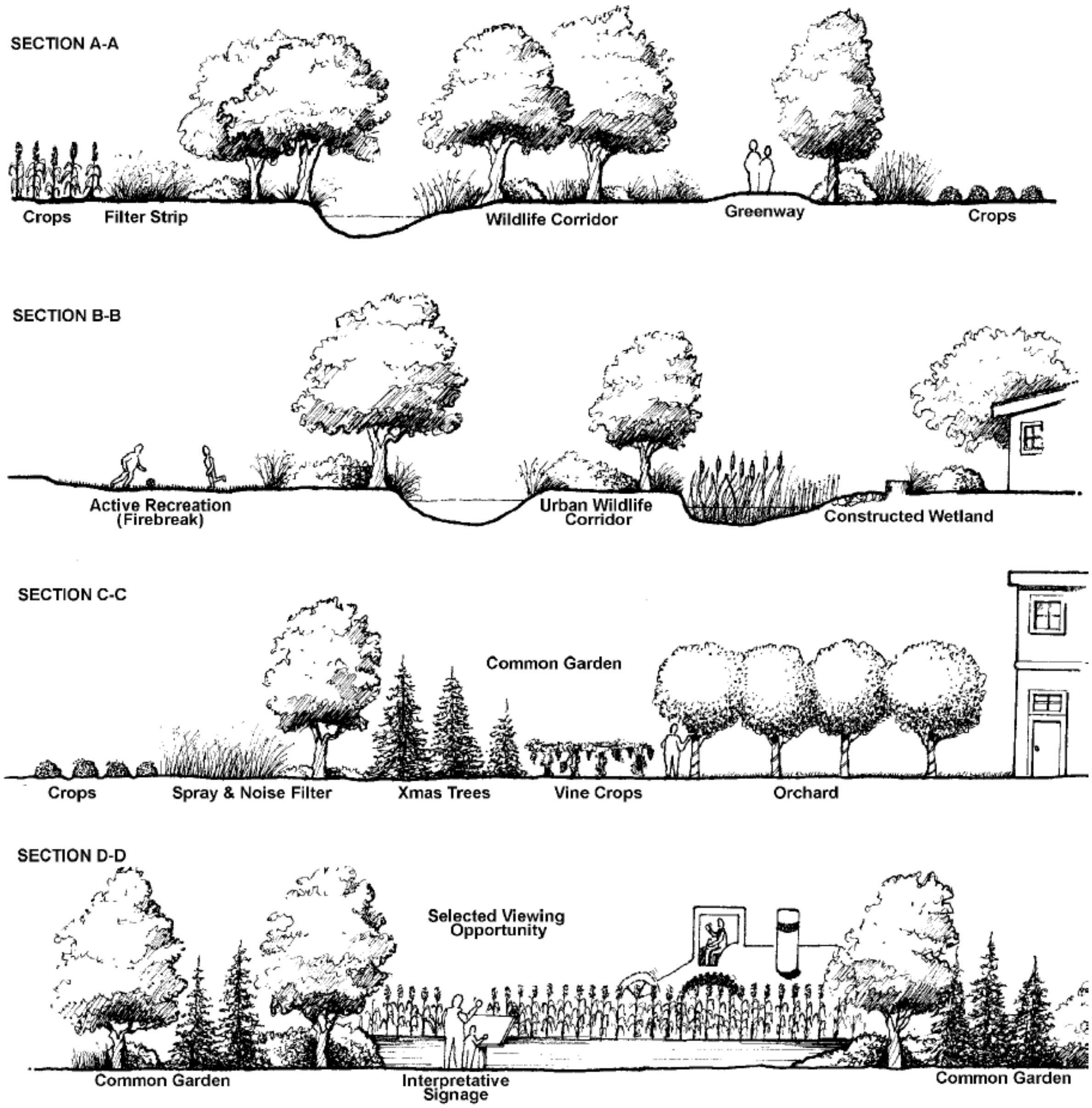
Appendix B: First iteration of Climate-Food-Species-Matrix

The 63 species listed in the table below were extracted from the Climate-Species-Matrix created by Roloff, Korn & Gilner (2009), and were determined to have edibility qualities based on PFOF 2010.

Latin name	Common name	Height	Drought tolerance	Hardiness
Acer negundo L. subsp. negundo	Ashleaf maple	>10m	1	1
Juniperus communis L. subsp. Communis	Common juniper	>10m	1	1
Juniperus scopulorum Sarg.	Rocky Mountain red-cedar	>10m	1	1
Juniperus virginiana L.	Eastern red-cedar	>10m	1	1
Prunus avium (L.) L.var. avium	Bird cherry	>10m	1	1
Sorbus aria (L.) Crantz	Chess-apple	>10m	1	1
Sorbus badensis Düll.	Baden servicetree	>10m	1	1
Robinia pseudoacacia	Black locust	>10m	1	1
Caragana arborescens Lam.	Siberian peatree	Up to 10m	1	1
Cornus mas L.	Cornelian-cherry	Up to 10m	1	1
Lycium barbarum L.	Barberry matrimony-vine	Up to 10m	1	1
Lycium chinense Mill. var. chinense	Chinese boxthorn	Up to 10m	1	1
Crataegus laciniata Ucria (C. orientalis Pall.)	Oriental thorn	Up to 10m	1	1
Crataegus wattiana?	Watt thorn	Up to 10m	1	1
Prunus mahaleb L.	Mahaleb cherry	Up to 10m	1	1
Rosa canina L.	Dog rose	Up to 10m	1	1
Rosa corymbifera Bork.	Bush rose	Up to 10m	1	1
Acer rubrum L.	Red maple	>10m	1	2
Carya tomentosa (Lam. exPoir.)Nutt.	Mockernut hickory	>10m	1	2
Celtis occidentalis L.var. occidentalis	Hackberry	>10m	1	2
Diospyros lotus L.	Date plum	>10m	1	2
Ginkgo biloba L.	Ginkgo	>10m	1	2
Gleditsia japonica	Japanese honeylocust	>10m	1	2
Pinus bungeana Zucc.ex Endl.	Bunge's pine	>10m	1	2
Pinus ponderosa Douglas ex C.Lawson	Ponderosa pine	>10m	1	2
Sorbus domestica L.	Service tree	>10m	1	2
Sorbus latifolia (Lam.) Pers.	Broadleaf whitebeam	>10m	1	2
Sorbus torminalis (L.) Crantz	Wild servicetree	>10m	1	2
Elaeagnus angustifolia L. var. angustifolia	Russian-olive	Up to 10m	1	2
Prunus armeniaca L.	Apricot	Up to 10m	1	2
Prunus cerasifera Ehrh. subsp. cerasifera	Cherry plum	Up to 10m	1	2
Prunus fruticosa Pall.	European dwarfcherry	Up to 10m	1	2
Morus alba	White mulberry	>10m	1	3
Pinus armandii Franch.	Chinese white-pine	>10m	1	3
Pinus coulteri D. Don	Big-cone pine	>10m	1	3
Crataegus azarolus L. var. azarolus	Azarole	Up to 10m	1	3
Pinus monophylla Torr. et Frem.	Single-leaf pinyon	>10m	1	4
Cercis siliquastrum L.	Judas-tree	Up to 10m	1	4
Poncirus trifoliata (L.) Raf.	Hardy orange	Up to 10m	1	4
Prunus dulcis (Mill.) D.A.Webb.	Almond	Up to 10m	1	4
Malus tschonoskii (Maxim.) C.K.Schneid.	Pillar apple	>10m	2	1
Tilia cordata Mill.	Small-leaf lime	>10m	2	1
Amelanchier arborea (F. Michx.)Fernald	Downy serviceberry	Up to 10m	2	1
Crataegus monogyna Jacq. subsp. Monogyna	Common hawthorn	Up to 10m	2	1
Hippophae rhamnoides L. subsp. rhamnoides	Sea buckthorn	Up to 10m	2	1
Carya ovata (Mill.) K.Koch Shagbark hickory	Shagbark hickory	>10m	2	2
Castanea sativa Mill.	Sweet chestnut	>10m	2	2
Corylus colurna L.	Turkish hazel	>10m	2	2
Diospyros virginiana L.	Persimmon	>10m	2	2
Pyrus communis L.	Common pear	>10m	2	2
Pyrus pyraster Burgsd.	Wild pear	>10m	2	2
Mespilus germanica L.	Medlar	Up to 10m	2	2
Morus nigra L.	Black mulberry	>10m	2	3
Broussonetia papyrifera (L.) Vent.	Paper mulberry	>10m	2	4
Acer saccharinum L.	Silver maple	>10m	3	1
Corylus avellana L.	Common hazel	Up to 10m	3	1
Crataegus laevigata (Poir.) DC.	English hawthorn	Up to 10m	3	1
Fagus sylvatica L.	European beech	>10m	3	2
Malus sylvestris Mill.	Crab apple	Up to 10m	3	2
Juglans regia L. subsp. regia	Common walnut	Up to 10m	3	3
Prunus padus L. subsp. padus	Bird cherry	>10m	4	1
Carya illinoinensis (Wangenh.) K.Koch	Pecan	>10m	4	2
Carya laciniosa (F. Michx.)Loudon	Shellbark hickory	>10m	4	3

Appendix C: Conceptual ecobelt sections

The below image accompanies Figure 19 and provides a number of conceptual sketches illustrating possible landscape functions and ecological services provided by ecobelts (Bentrup et al. 2001)



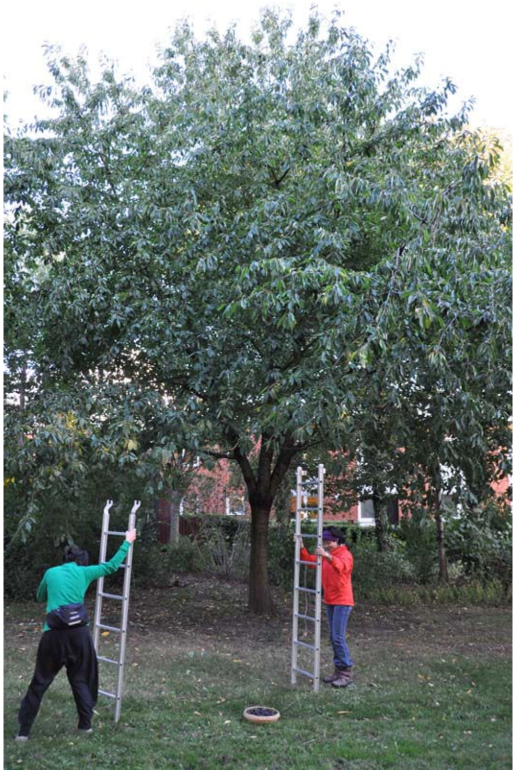
Appendix D: Landscape examples from Lund, Sweden

The following three images provide examples of areas well suited to urban food forestry and areas of opportunity to retrofit existing urban green infrastructure with food trees.

The above image shows a low-maintenance forested strip between a grassy strip and two pedestrian paths; a number of paths pass through this wooded strip. This area is perfectly suited for a linear urban food forest given its location in a high pedestrian traffic area, its low maintenance requirements (i.e. no mowing) and its width which facilitates sunlight penetration and ease of access to fruit. Countless such areas exist in Lund, many of which already contain food trees, including hazelnuts, apples, currants, and blackberries. However, the produce of these trees is often difficult to reach or located in areas that are prohibitively difficult to access. Furthermore, access to food could be improved by planting trees with useful traits, such as thornless blackberries and dwarf apples.

Both of the images on this page depict ideal areas for urban food tree plantings. The top image shows an area where red maples are already growing and could be utilized for harvesting syrup. This area could be stacked with a number of additional vertical forest layers to maximize productivity (e.g. strawberries as a groundcover, haskaps as short bush, shade-tolerant paw paws as a large bush)

The bottom image depicts what a low-density planting of trees looks like; this area could be mulched and planted with short and tall bushes to reduce maintenance costs and provide public produce.

The images above show public produce personally harvested by myself and two friends in Lund. The picture to the left is a publicly-accessible black cherry (Prunus serotina) tree, which is one of many located in this area. Approximately 5kg of cherries were harvested in less than 20 minutes, in addition to the blackberries, which were also growing on public land.

Appendix E: Glossary

This glossary is intended to clarify terms used in the thesis which may not be familiar to the reader and to provide additional information for terms that may not have been clearly defined. In cases where the source is not part of the Reference list (Section 6), I have provided the source after the definition. In cases where no source appears, definitions are original to this thesis and were developed by myself.

Agroforestry
"An intensive land management system that optimizes the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock."
Source: AFTA 2011

Adaptive Capacity
"Adaptive capacity in ecological systems is related to genetic diversity, biological diversity, and the heterogeneity of landscape mosaics; in social systems, the existence of institutions and networks that learn and store knowledge and experience, create flexibility in problem solving and balance power among interest groups play an important role in adaptive capacity." "Systems with high adaptive capacity are able to re-configure themselves without significant declines in crucial functions in relation to primary productivity, hydrological cycles, social relations and economic prosperity. A consequence of a loss of resilience, and therefore of adaptive capacity, is loss of opportunity, constrained options during periods of re-organisation and renewal, an inability of the system to do different things. And the effect of this is for the social-ecological system to emerge from such a period along an undesirable trajectory."
Source: Resilience Alliance. 2002. *Adaptive Capacity*. (Online) URL:
http://www.resalliance.org/index.php/adaptive_capacity

Annual plant
Annual plants "germinate, blossom, produce seed, and die in one growing season. They are common in environments with short growing seasons. Most desert plants are annuals, germinating and flowering after rainfall. Many common weeds, wild flowers, garden flowers, and vegetables are annuals. Examples of annuals include tomatoes, corn, wheat, sunflowers, petunias, and zinnias."
Source: The American Heritage Science Dictionary. 2005. Houghton Mifflin Company.

Developed countries / cities
The term "developed" in this thesis is not intended to reflect a value judgment, rather it is used instrumentally in the same way as it is used by the UN, who states, "The designations "developed" and developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process." For the sake of simplicity, "developed cities" refer to those located in countries designated as having very high human development according to the UN's Human Development Index (see http://hdr.undp.org/en/statistics/)
Source: United Nations. 2010. *Standard Country or Area Codes for Statistical Use.* (Online) URL:
http://unstats.un.org/unsd/methods/m49/m49.htm

Ecological Capital
"Assets in their role of providing natural resource inputs and environmental services for economic production; generally considered to comprise three principal categories: natural resource stocks, land and ecosystems. All are considered essential to the long-term sustainability of development for their provision of "functions" to the economy, as well as to mankind outside the economy and other living beings." (Synonymous with "Natural Capital")
Source: Organization for Economic Co-operation and Development (OECD). 2005. *Glossary of Statistical Terms*. (Online) URL: http://stats.oecd.org/glossary/detail.asp?ID=1730

Food tree
Any perennial tree or bush that produces fruits or nuts edible by humans; in some parts of this thesis, *food tree* includes perennial vine and groundcover species as well.

Food Security
Food security "exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life. Household food security is the application of this concept to the family level, with individuals within households as the focus of concern."
Source: Food and Agriculture Organization. 2003. *Trade Reforms and Food Security: Chapter 2. Food Security: concepts and measurement.* (Online) URL:
http://www.fao.org/docrep/005/y4671e/y4671e06.htm

Geographic information systems (GIS)
"A computer system capable of capturing, storing, analyzing, and displaying geographically referenced information; that is, data identified according to location. Practitioners also define a GIS as including the procedures, operating personnel, and spatial data that go into the system."
Source: United States Geological Survey (USGS). 2007. *Geographic Information Systems*. (Online) URL: http://egsc.usgs.gov/isb/pubs/gis_poster/

Geo-wiki
Any internet-based map which allows visitors to make changes, contributions or corrections. Geo-wikis are a form of participatory and collaborative mapping.
Source: Merriam-Webster Dictionary. 2011. (Online) URL:
http://www.merriam-webster.com/dictionary/wiki

Germplasm
"Living tissue from which new organisms can be grown. Plant germplasm is normally in the form of seeds of plants, but can also be part of a plant (leaf, stem, pollen, or embryo) that can be cultured into a whole plant. All germplasm contains genes and other materials that control inheritance."
Source: United States Department of Agriculture (USDA). 2007. *National Germplasm Resources Laboratory.* (Online) URL: http://www.ars.usda.gov/SP2UserFiles/Place/12751500/ngrlflyer.pdf

Interfunctional
When two or more functions part of a multifunctional landscape have a symbiotic and synergistic relationship (i.e. they enhance the effectiveness or productivity of each other), they are said to be *interfunctional*. For example, a fruit trees and urban beehives represent distinct functional elements in a multifunctional park landscape; these two elements are interfunctional in that they support and enhance one another. On the other hand, a walking path and a playground have a lower degree of interfunctionality in that they do not directly enhance the functional output of one another. (Original term)

Landscape ecology
An interdisciplinary science of landscape heterogeneity, where heterogeneity refers to multiscaled structures composed of intertwining patchiness and gradients in space and time, aimed at studying and improving relationships between human development and ecological processes.
<u>Source:</u> Wu 2006

Landscape service
Any service directly provided by a landscape which contributes to the social, economic, or ecological capital of the surrounding community. For instance, a public park might contribute to air quality, lead to the formation of community groups, and provide tourist revenue to a community. These three contributions can be thought of as landscape services.
<u>Source:</u> Termorshuizen & Opdam 2009

Multifunctional landscape
An anthropogenic landscape designed to provide a diversity of ecological, social, and economic services for the community in which it exists. These services might include ecosystem services, tourist revenue, or opportunities for social interaction.
<u>Source</u>: Lovell & Johnston 2009

Municipal agriculture
Any form of agriculture in which the municipal government plays an active role – either by planting, maintaining, or otherwise assisting members of the public in establishing urban agricultural projects which are aimed at providing *public produce.*
<u>Source</u>: Nordahl 2009

Permaculture
"The conscious design and co-creative evolution of agriculturally productive ecosystems and cooperative and economically just social systems which have the diversity, stability and resilience of 'natural' systems. It is the harmonious integration of landscape and people providing their food, energy, shelter and other material and non-material needs in a sustainable way."
<u>Source</u>: Hemenway 2000

Perennial plant
Any herbaceous plant which "survives winter and drought as underground roots, rhizomes, bulbs, corms, or tubers. Woody perennials, including vines, shrubs, and trees, usually stop growing during winter and drought. Asters, irises, tulips, and peonies are familiar garden perennials."
<u>Source</u>: The American Heritage Science Dictionary. 2005. Houghton Mifflin Company.

Public produce
Any fruit or vegetable grown as part of a municipal agriculture project that is freely available to all members of the public in the community which it was produced. While public produce is intended to be equally accessible to all members of the community, there still may be barriers to acquiring it due to transportation logistics, disabilities, or other preventative factors.
Source: Nordahl 2009

Resilience
"The long-term capacity of a system to deal with change and continue to develop. For an ecosystem such as a forest, this can involve dealing with storms, fires and pollution, while for a society it involves an ability to deal with political uncertainty or natural disasters in a way that is sustainable in the long-term"; in other words, resilience is "the capacity of a system to continually change and adapt yet remain within critical thresholds."
Source: Stockholm Resilience Center. 2007. (Online) URL:
http://www.stockholmresilience.org/research/whatisresilience.4.aeea46911a3127427980004249.html

Social Capital
"Networks and norms that facilitate cooperative action."
Source: Putnam (1995) in Costanza et al. 2007. Quality of Life: An Approach Integrating Opportunities, Human Needs, and Subjective Well-Being. *Ecological Economics* **61**:267-276

Social-ecological system
"A social-ecological system consists of a bio-geo-physical unit and its associated social actors and institutions. Social-ecological systems are complex, adaptive and delimited by spatial or functional boundaries surrounding particular ecosystems and their problem context."
Source: Deutsche Gesellschaft für Humanökologie (DGH). 2008. *DGH Symposium 2008 : Definitions.* (Online) URL: http://www.dgh2008.org/definition.html

Sustainability / sustainable development
"Meeting the needs of the present without compromising the ability of future generations to meet their own needs."
Source: World Commission on Environment and Development (WCED). 1987. *Our Common Future*. New York: Oxford University Press.

Urban Forest
"The sum of all woody and associated vegetation in and around dense human settlements, ranging from small communities in rural settings to metropolitan regions." This includes vegetation planted in both public and private urban areas.
Source: Miller, R.E. 1988. Urban *Forestry, Planning and Managing Urban Greenspaces*. New Jersey: Prentice Hall.

Urban forestry
"A planned and programmatic approach of the development and maintenance of the urban forest, including all elements of green infrastructure within the community, in an effort to optimize the resulting benefits in social, environmental, public health, economic, and aesthetic terms, especially when resulting from a community visioning and goal-setting process."
Source: American Planning Association (APA). 2009. *Planning the Urban Forest: Ecology, Economy and Community Development*. Published by APA Planning Advisory Service.

Urban food forest
The portion of the *urban forest* comprised of *food trees*. This term can also refer to a specific landscape design element which is designed with the primary intention of providing *public produce*. Such design elements are typically a form of municipal agriculture in that they take place on public land and involve active participation on the part of public officials.

Urban food forestry
A multifunctional landscape design strategy which aims at creating highly productive, low-maintenance patches of perennial vegetation primarily intended to provide food for humans and also provide secondary *landscape services* such as wildlife habitat, carbon sequestration, air purification, and recreation opportunities. In an urban context, urban food forestry combines activities related to *urban forestry* and *urban/peri-urban agriculture* to create a hybrid system of perennial-based *municipal agriculture* aimed at providing *public produce.*

Urban/peri-urban agriculture
"The growing of plants and trees and rearing of livestock within or on the fringe of cities (intra-urban and peri-urban agriculture, respectively), including related input provision, processing and marketing activities and services."
Source: Smit et al. 1996 in De Zeeuw et al. 2011

Urban forestry management plan (UFMP)
A municipal planning document which puts forth goals and strategies for fulfilling a municipality's vision for their *urban forest.* (Also called an *urban forestry master plan*)