MULTIFUNCTIONALITY OF COMMUNITY GARDENS AND FOOD FORESTS IN VANCOUVER, CANADA

by

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Abstract

Urban food production systems such as community gardens and food forests are being promoted for their ability to provide multiple benefits, including food security, social cohesion, connection to nature, and climate change adaptation. Yet it is unclear whether and how people experience multiple benefits, or what factors are associated with higher levels of multifunctionality and different ecosystem services. In addition, while food forests are burgeoning in cities, there is still inconsistency in what constitutes urban food forestry in the scientific literature. To address these gaps, I first conducted a scooping review to examine ways in which the biological and functional characteristics of urban food production systems that involve trees in Northern America and Europe are described in the peer-reviewed literature. Secondly, I investigated the trade-offs and synergies between perceived provisioning and cultural ecosystem services that are valued by community gardeners in Vancouver, Canada. Finally, I identified bundles of provisioning, cultural, and regulating ES that are associated with similar biophysical and social characteristics of community gardens in Vancouver. To do so, I conducted a cross-sectional survey of 366 gardeners from 50 sites, 26 structured interviews with garden representatives, land use mapping, and tree inventory of 1,445 woody plants. The results of my research revealed that the current definition of “urban food forestry” includes a range of treed food systems with or without herbaceous plants that can provide multiple services. In Vancouver, community gardeners experience synergies between cultural services, and even between food and cultural services, with few perceived trade-offs. Lastly, while forest-like, large food forests with both individual plots and communal space for growing food seem to be the most multifunctional, small gardens may play an important role in promoting a sense of belonging and food sharing. My findings suggest that multifunctionality could be achieved in urban food production systems but requires strategic design (e.g., providing sufficient space for trees), management (e.g., a mix of individual and collective), and support of gardens (e.g., volunteers, technical assistance, resources). Moreover, different types of community gardens should be considered in order to best fit local contexts and meet different needs of communities.

Lay Summary

Community gardens and food forests provide many different benefits that are important to the well-being of urban residents. Yet what characterizes urban food forestry is not well defined. Moreover, there is a lack of understanding of the factors that foster the flow of multiple types of benefits ('multifunctionality') from community gardens and food forests. This research found that there are a range of urban food production systems involving trees that have different biological and functional characteristics. It also observed many synergies between important benefits provided by community gardens and food forests such as between food production and social cohesion, and between the aesthetic value and carbon sequestration. Finally, the study identified three important design and management factors that characterize multifunctional food production system including high tree canopy cover, large garden size, and management of communal and individual space for growing food.

Preface

This dissertation is my original work. I was the main contributor to the question identification, design, field research, data analyses and writing of this PhD dissertation. This work was supported throughout by my co-supervisors, Drs. Jeanine Rhemtulla and Cecil Konijnendijk, and my two committee members Drs. Christiana Miewald and Lorien Nesbitt. All data are original and were obtained from field research conducted in the city of Vancouver, Canada, in 2019. Chapter 2 was supported by a former Master's student Moritz Kramer, and the fieldwork and mapping work for Chapters 3 and 4 were assisted by former undergraduate student of Forestry Taelynn Lam and five volunteers from the Faculty of Forestry at the University of British Columbia. The research presented in Chapter 3 and Chapter 4 was approved by the Behavioural Research Ethics Board of the University of British Columbia (UBC BREB Number: H19-01480) in accordance with Canada's Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans.

Chapter 2 was conceived by me with the strategic input of Drs. Cecil Konijnendijk and Jeanine Rhemtulla. Together we identified the research questions and developed the methodologies. I undertook data collection, analysis and writing with the assistance of Moritz Kramer and feedback from Drs. Cecil Konijnendijk and Jeanine Rhemtulla at every stage. Drs. Christiana Miewald and Lorien Nesbitt were not on my supervisory committee while I was working on Chapter 2. A version of Chapter 2 has been published in the journal of Urban Forestry & Urban Greening. Citation: Park, H., Kramer, M., Rhemtulla, J. M., Konijnendijk, C. C., 2019. Urban food systems that involve trees in Northern America and Europe: A scoping review. *Urban Forestry & Urban Greening 45*, 126360. https://doi.org/10.1016/j.ufug.2019.06.003.

Chapter 3 and Chapter 4 were designed by me with the strategic input of Drs. Cecil Konijnendijk, Jeanine Rhemtulla, Christiana Miewald, and Lorien Nesbitt. Field data were obtained by me, my research assistant Taelynn Lam, and five other volunteers form the Faculty of Forestry, UBC. I analyzed the collected data and wrote the chapters with the support of Drs. Cecil Konijnendijk, Jeanine Rhemtulla, Christiana Miewald, and Lorien Nesbitt. These two chapters will be submitted to a journal as appropriate.

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List of Key Concepts

Allotment garden	Shared Garden in which each gardener has his or her own plot.
Canopy cover	The area of land covered by tree canopy, often expressed as a percentage of total land area and usually measured from the aerial perspective.
Collective management	Entire garden space is communally managed for growing food and there are no plots assigned to individual gardeners. This management type is often found in community orchards.
Community garden	Land managed by a non-profit society or a group of individuals and used for growing plants and harvesting food or ornamental crops. Community gardens can involve individual, collective or mixed management.
Ecosystem disservices	Outcomes of ecosystem functioning that negatively affect human well-being.
Ecosystem services	Benefits that people obtain from ecosystems.
Ecosystem service bundles	Sets of ecosystem services that appear together repeatedly.
Food forests	Multistorey, perennial, polycultural food production systems
Function	In ES research, functions and services are not considered as interchangeable. According to the cascade model of ES, ecological functions (e.g., slow passage of water) are the origin of services for humans (e.g., flood protection). These services lead to human benefit and valuation of those services (e.g., willingness

	to pay for wetland protection). Despite the usefulness of the cascade model, cultural ecosystem service researchers have generally struggled to adapt their inquiries to the cascade model, and the concept of "ecological functions" in relation to "ecosystem services" can be confusing for people who use or manage ecosystems on the ground. In the green infrastructure literature, functions are often used in a fuzzy way, often meaning the same as services, and functional attributes include purposes, uses, and services of green infrastructure. The agroforestry literature refers to functions as the role of ecological components in particular woody plants, including productive (e.g., food) and protective functions (e.g., shade). In line with the latter disciplines, the terms 'functions' and 'services' are used interchangeably in the dissertation, except for 'ecological functions'.
Green infrastructure	The interconnected network of natural and semi-natural elements capable of providing multiple functions and ecosystem services, encompassing positive ecological, economic and social benefits for humans and other species.
Individual management	All plots are assigned to individual gardeners and there is no communal space for growing food. This management type is found in allotment gardens.

Mixed management	A mix of plots assigned to individual gardeners and communal space for growing food. This is the most common management type in community gardens on public land in Vancouver.
Multifunctionality	The capacity of green infrastructure or green space to deliver multiple functions, services, and benefits simultaneously. Multifunctionality aims at intertwining or combining different functions and services thus using limited space more effectively.
Place attachment	Emotional and functional bonds that a person develops with a particular physical and social setting.
Practice	In this dissertation practice refers to a field of study or practice with which food production systems are associated or related: for example, urban agriculture, urban forestry, agroforestry, food forestry, and community gardening.
Sense of belonging	The experience of being valued, needed or important.
Social cohesion	The feeling and experience of being connected to one another in social spaces; social cohesion also increases the effectiveness of these spaces, especially in urban areas where space is limited and scarce.
Synergies	A synergy occurs when two or more ecosystem services increase simultaneously.
Trade-offs	A trade-off between ecosystem services occurs when increasing the magnitude of one service leads to a decrease in another service.

Urban food production systems	Food production units specific to a locality and a physical boundary. They are socio-ecological systems that are managed for food production in urban or peri-urban areas including but not limited to commercial farms, small-scale subsistence farms, community gardens, and rooftop gardens.
Urban forestry	The planning, establishment and management of trees and associated vegetation for the purpose of improving urban environments.
Urban green space	Area within a city that is vegetated.
Urban vegetation	All outdoor vegetation in urban environments.

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Dedication

To my parents, for trusting in me and inspiring my profound sense of adventure and wonder. Your love is forever to be remembered.

Chapter 1: Introduction

A major challenge for cities today and in the future is to ensure the well-being of all urban inhabitants (TEEB, 2011). By 2050, 68 percent of the global population is expected to live in urban areas (UN, 2018). Urban vegetation and green space have long been studied for their range of ecosystem services (ES) that are important for the health and well-being of residents in cities (Donovan et al., 2013; Escobedo and Nowak, 2009; TEEB, 2011). Increasing such vegetation and urban green spaces is proposed as one of pathways to building sustainable cities that address the critical needs of people in, for example, the Global Assessment on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Butchart et al., 2019).

For many cities, increasing green space is not an easy task. The global urban population is expected to nearly double by 2050 (UN, 2017) and thus also the need for land to build essential infrastructure such as housing and roads. In cities with limited land, land development for infrastructure can cause further loss, degradation and/or fragmentation of urban vegetation and green space (Haaland and Konijnendijk, 2015), consequently affecting access to green spaces as well as to their services and benefits. Considering the need for housing and other important infrastructure on the one hand and the need for public green space on the other, urban planners and policy makers are facing significant challenges given they are encouraged to strive for densification and compact communities (Artmann et al., 2017). In addition, people with a variety of backgrounds, values and needs live and share resources in cities, and therefore different ways to reconcile multiple interests, values and forms of uses of green space should be integrated in green space management and urban planning (Butchart et al., 2019).

Managing green spaces for multifunctionality has come to prominence in the fields of urban forestry, urban agriculture and nature-based solutions in order to maximize the use of limited land and to address different social and environmental challenges in cities while avoiding unsustainable urban sprawl (Artmann and Sartison, 2018; Belaire et al., 2022; Hansen et al., 2019; Konijnendijk and Gauthier, 2014). Multifunctionality aims at effectively combining and delivering a set of different desired functions in the same space or landscape (Hansen and Pauleit, 2014). The UN's New Urban Agenda urges compact cities to promote multifunctional green spaces such as parks and gardens for improving social interaction and inclusion, human health and well-being as well as cultural expression and dialogue among people from different backgrounds (UN, 2017). Food production systems are socio-ecological systems that are managed for food production in urban or peri-urban areas. They are specific to a locality and a physical boundary (Specht et al., 2014). For example, community gardens and food forests are being promoted for their potential for not only provisioning ES (e.g., vegetables, fruits) (Gregory et al., 2016) but also cultural ES (e.g., social cohesion, connectedness to nature, learning, aesthetic value) (Camps-Calvet et al., 2016; Menconi et al., 2020; Pourias et al., 2016; Veen et al., 2015) and regulating ES (e.g., stormwater runoff control, provision of shade during hot day time) (Edmondson et al., 2014; Gittleman et al., 2017; Speak et al., 2015) in proximity to where people live and work.

Meeting the many different needs of different people can be challenging in a limited space, especially when one type of use or one service competes with other uses or services for land area (Hansen et al., 2019). For example, large trees in green spaces can provide regulating ES such as shade for people to rest and socialize during hot summer days; yet the shade from large trees can also limit space for growing vegetables in gardens (Speak et al., 2015). Similarly, dedicating a whole garden space solely to individual plots may allow gardeners to maximize the space for growing their own food, but it can limit the opportunity for people to increase social interaction and cohesion through working together in a communal space (Langemeyer et al., 2018). As such, managing multifunctional systems can involve choices between important values and functions, and these choices can affect "which services people can get or lose at the same time" (Lee and Lautenbach, 2016, p. 342). Therefore, green spaces should be strategically designed and managed, informed by a sound understanding of the capacity of the spaces to provide different sets of ES so as to enhance desired multifunctionality and meet the different needs of people.

1.1. Knowledge gap

1.1.1 Lack of understanding of ES associations in small urban green spaces

The concept of ES — "benefits that people obtain from ecosystems" (MEA, 2005, p. v) — was popularized by global initiatives involving the scientific communities of ecology and environmental economics in order to raise public awareness of the important benefits that people derive from biodiversity and ecological functions and processes (Barnaud and Anttona, 2014). The Millennium Ecosystem Assessment (MEA, 2005) classified ES into four groups, which have been widely adopted by scientists and practitioners for assessing the benefits of nature to people: a) provisioning ("products obtained from ecosystems"); b) regulating ("benefits obtained from the regulation of ecosystem processes" such as air quality control); c) cultural ("nonmaterial benefits" obtained through human-nature interaction such as educational values); and d) supporting services (services "necessary for the production of all other services" such as primary production, soil formation) (p. 40). The concept of ES has been commonly framed as a cascade model or stock-and-flow model that positions biophysical factors such as soil fertility and groundwater recharge as the supply of ES, and social factors such population density or food consumption per capita as demand for ES. This model has been useful for researchers to assess changes in demand and supply for certain ES such as clean water over time and identify the potential impacts of socio-economic and land use changes on the ratio between supply and demand (e.g., Kroll et al., 2012).

When ecosystems produce multiple ES, quantifying ES associations is critical for forecasting "the impact of environmental changes and management on ES supply and thus on ES beneficiaries" (Mouchet et al., 2014, p. 300). ES associations can be characterized as either a trade-off or a synergy (Bennett et al., 2009). A trade-off between ES occurs when the increasing provision of one service is associated with the decrease in another service. A synergy occurs when both ES increase simultaneously or are positively associated. Such associations can be assessed between a pair of ES (i.e., a pairwise comparison) or as bundles of multiple ES which detect “sets of ecosystem services that appear together repeatedly” (Raudsepp-Hearne et al., 2010, p. 5242). Amongst the four ES groups, supporting services are often excluded in ES assessments in order to avoid the problem of double-counting of ES as these services are underlying ecological processes and functions that support all other ES (Paetzold et al., 2010).

Many ES studies have shown that globally intensive agriculture and urbanization are two key societal drivers for changes in landscapes and the supply of ES in the present and toward the future (Turner et al., 2014). Global food systems alone are responsible for 80 % of global deforestation (UNCCD, 2022), reducing important regulating ES such as carbon storage and sequestration, and flood and climate regulation (Barral et al., 2020). Agricultural lands with intensive monocultural practices are often associated with lower cultural ES values and regulating ES while forested lands are commonly associated with higher cultural and regulating ES (Queiroz et al., 2015; Turner et al., 2014). Urbanization often leads to replacement of agricultural lands or to deforestation and forest degradation. Densely populated urban areas tend to provide low carbon storage and crop production yet they exhibit a high demand for cultural services such as recreation (Queiroz et al., 2015; Renard et al., 2016).

Existing ES studies have limitations for understanding multifunctionality in urban green space. Many ES studies have focused on ES trade-offs and synergies that are found in large landscapes at coarse scales (e.g., municipal, regional level), and consequently they tend to miss variabilities in the structure and functions of small urban green spaces (Colding et al., 2006; Derkzen et al., 2015; Langemeyer et al., 2018). Even ES assessments in urban areas have largely focused on a single ES category only, mostly regulating services of urban forests and trees (Grafius et al., 2016; Haase et al. 2014; Nesbitt et al., 2017) and only recently cultural ES (Menconi et al., 2021). As a result, there is a lack of empirical understanding of how small green spaces provide multiple

ES of different categories—provisioning, regulating, and cultural. Given that promoting multifunctional green spaces in compact cities has become an essential consideration in the global urban agenda and urban green space management (UN, 2017), a sound understanding of multifunctional green spaces is much needed at this time regardless of their size.

1.1.2 Limitations of the concept of ES in understanding human-nature relationships that underpin the production of ES

The concept of ES has been widely adopted since the 1990s to raise awareness of the importance of natural ecosystems to societies (Costanza et al., 1997; Daily, 1997). However, it has also been the subject of important critiques. One of the major criticisms is its cascade model of Haines-Young and Potschin (2010), which focuses on ecological factors such as soil type and tree cover to model the production of ES (i.e., supply of ES) while focusing on humans as beneficiaries of ES, and social, cultural, and economic factors to model demand of ES or benefits of ES (Braat and De Groot, 2012). This approach to assessing ES production inevitably excludes people's values, skills, and management regimes and technology that are involved with co-production of ES (Reyers et al, 2013). Furthermore, it isolates culture and cultural services as if they were products of nature (Chan et al. 2012).

Another important criticism is the utilitarian-value framing of nature and focus on market-based rationales for conservation, which fails to embody different values that people have toward nature such as intrinsic values and relational values (Braat and De Groot, 2012; Gómez-Baggethun and Ruiz-Pérez, 2011). Intrinsic value refers to "the worth of nature itself" (Chan et al., 2018, A1). Relational value refers to "preferences, principles and virtues about human-nature relationships" (Chan et al., 2018, p. A1). Such relational values are reflected in the new umbrella conception of Nature's Contributions to People (NCP) (Chan et al., 2018). NCP recognizes different ways in which material and non-material benefits are co-produced by nature and people and "the central role that culture plays in defining all links between people and nature" (Díaz et el., 2018, p. 270). A recent study in Metro Vancouver, Canada illustrated how new immigrants' place attachment and deep relational values to local green spaces were shaped by their pre-existing identities and values associated with family as well as their perception of outdoor places as Canadian identity, which could support immigrants' adaptation process in Canada (Ono et al., 2021).

Critics of the concept of ES argue that diverse actors in ecosystem management may value nature in different ways that do not consider nature as a service provider. Some critics thus avoid ES language and refer to services or ES as nature's benefits or contributions (e.g., Klain et el., 2014). In this study, I refer tp such nature's benefits or contributions to ES. For example both food and cultural services are perceived by gardeners as benefits. I do not differentiate the concept of ES from the concept of benefits as per the cascade model, and I use ES and benefits interchangeably (Costanza et al., 2017). My research did not start with an intention or proper design to address the limitations of the MEA framework or test or promote the new NCP framework in the context of community gardening. However, it is important to highlight the limitations of the MEA framework and note that many cultural ES studied in my research can be understood as relational values toward nature rather than pure benefits of nature.

1.1.3 Unchallenged assumption that urban food production systems are multifunctional

Urban food production systems are unique green spaces where urbanization and agriculture intersect. Community gardens are promoted as an element of urban agriculture or green infrastructure to mitigate and adapt to climate change (e.g., Paris Climate Change Protection Plan, 2007) as well as to enhance local food production, access to nature, and social cohesion (Pauleit et al., 2019). Further, food forests that combine such urban agriculture and urban forestry are emerging in Northern American and European cities. Food forestry is "the skill and art of growing food in a way that replicates nature", for example, by creating multiple vertical layers of perennial and annual plants that interact with one another and by promoting the ecological processes of a natural forest (e.g., nutrient cycling) (Walker, 2015, p.7). Including trees in community gardens can enhance cultural ES such as the sense of connectedness to nature and the aesthetic value (Speak et al., 2015; Speak et al., 2022). Trees can also diversify provisioning ES such as by providing tree crops and materials for making paper, musical instruments, or crafts (Konijnendijk and Park, 2019). Thanks to their potential multifunctionality, urban food forests are increasingly gaining interest in global urban food or urban forestry policies (e.g., FAO, 2016), municipal urban forest plans, and community projects (e.g., City of Vancouver, 2012).

Yet we have little empirical evidence that shows how community gardens and food forests provide regulating, cultural and provisioning ES at the same time (Pinto et al., 2022; Thiesen et al., 2022). Existing empirical studies often focus on a singular service or one category of ES, for example food production (e.g., Alaimo et al., 2008) or social cohesion (e.g., Veen et al., 2015). Only a handful of studies, mostly in European cities, have assessed the supply of regulating ES of urban food production systems (Edmondson et al. 2014; Gittleman et al., 2017; Schafer et al., 2019) or regulating ES together with food-provisioning and cultural ES (Camps-Calvet et al., 2016, Dennis and James, 2016a; Park et al., 2019; Speak et al., 2015). To date, only one study (Langemeyer et al., 2018) identified the bundles of regulating, cultural and provisioning ES values in allotment gardens and collective gardens in an urban area. This study highlighted that these gardens differ in their forms and shapes, and as a result in their mix of ES that can benefit people. As multifunctionality is being considered an essential planning approach across different fields (of green infrastructure, urban forestry, urban agriculture and nature-based solutions), the many and potentially simultaneous benefits of community gardening should be thoroughly examined and well understood among decision-makers and the public who design and/or manage the space (Artmann and Sartison, 2018; Maćkiewicz, B., Asuero, 2021).

1.1.4 Need for a sound understanding of enabling factors for multifunctional small green spaces in cities

A good understanding of what enables multifunctionality is also essential for informing green space planning and management (Sarabi et al., 2019). A study by Langemeyer et al. (2018) in Barcelona, Spain found that higher levels of connectedness to nature and food production were associated with large allotment gardens while strong social cohesion and place attachment were associated with small, collectively-managed gardens. In addition to garden characteristics, gardeners' characteristics such as motivation, income, education can affect which ES is experienced or valued (da Silva et al., 2016; Veen et al., 2016). Yet ES assessments often fail to take both garden and gardener characteristics including values, motivations, and their demand into account for identifying factors that may explain the multifunctionality of small green spaces.

A better understanding of multiple factors could inform urban planning and green space management of a mix of small green spaces with different sets of multiple ES in different places so as to meet the diverse needs of urban residents (Aamir et al., 2021; Amorim et al., 2021). Community gardens and food forests are often managed within limited budgets, resources, and space. A sound understanding of multifunctionality and its enabling factors in such green spaces can help community members and organizations to strategically use their limited resources, space and budget while avoiding undesired trade-offs (Langemeyer et al., 2018).

1.1.5 Inconsistent articulation of the concept of urban food forestry

Despite the increasing adoption of the concept of urban food forestry in policies and scientific literature (e.g., FAO, 2016; Koe et al., 2017), the concept itself is inconsistently articulated in the scientific literature. Clark and Nicholas (2013) first introduced the term "urban food forestry" into the scientific literature as a multifunctional use of food trees that combines benefits of urban forestry, urban agriculture, and agroforestry by using monocultural planting of apple trees as an example. But other scientific articles (e.g., McLain et al., 2012; Park et al., 2018; Rohwer and Marris, 2016) as well as the grey literature (e.g., Bukowski and Munsell, 2018) emphasize the planting of polycultural perennial multistorey systems as a key element that distinguishes food forestry from other types of food production practices such as orchards or monocultural planting of one tree species. The inconsistent use of the concept can hinder accurate assessments of urban food forestry and comparison to other fields such as agroforestry, urban forestry, and urban agriculture, which could ultimately impede scientific understanding of the practice of urban food forestry. It could also hamper clear communication among scientific communities and practitioners in urban green spaces who provide consultation, design, or manage multifunctional food forests for the public.

1.2 Vancouver as a case study

The city of Vancouver, Canada, is an appropriate case study, thanks to its strong public interest in community gardening and food forestry, a diversity of garden designs and management approaches that reflect a range of values and purposes, and the need for strategic design and management of such systems in the city. City policies have been promoting both community gardening and food forestry (including the planting of fruit trees) to improve food security and access to green spaces, and to increase tree canopy cover (e.g., Greenest City Action Plan, 2012; Healthy City Strategy, 2014; Local Food Action Plan, 2013; Vancouver Food Strategy, 2013). Over the past decade, the number of community gardens and orchards has significantly increased from just over 25 sites in 2006 (Seto, 2011) to approximately 137 sites on public and private lands as of December 2019. Past surveys show that gardeners participate for various reasons including not only food production but also health, sense of belonging, recreation, learning and care of nature (e.g., Bwika, 2011; Lowcock, 2014; Seto, 2011).

Community gardens and food forests in Vancouver exhibit a variety of design and management approaches. Vancouver shows three predominant management approaches: 1) individual management that has individual plots for growing food and no communal growing spaces (i.e., allotment gardens); 2) collective management of communal growing spaces with no individual plots (e.g., orchards); and 3) a mix of these two management approaches in gardens with both individual and communal growing spaces (Drake and Lawson, 2015). Community gardens in Vancouver are primarily grass-root initiatives managed by groups of local gardeners or non-profit organizations (e.g., Environmental Youth Alliance, Village Vancouver). These groups and organizations have “a considerable amount of freedom and diversity in the way the gardens develop” (Chisholm, 2008, p. 95). At the same time, community members can provide their suggestions as to garden design and maintenance through a consultation process with the public and City staff. In addition, public inputs including complaints about community gardens are presented to community gardens so that they can adapt or address public concerns.

Despite the increasing public interest in community gardens and food forests, these systems are not without challenges. The current supply of gardens and gardening plots are well below the demand, and residents often wait for several years for access to a community garden plot. Still such spaces are considered an “urban fallow” or a temporary option for using vacant spaces and profiting from urban regeneration processes (Korsunsky, 2019). In the process of land development, existing gardens often become subject to reduction in size, relocation, or dislocation (City of Vancouver, 2014). In addition, most public gardens that are managed by volunteer groups are faced with lack of resources, funding and organizational and managerial capacity. Strategic design and management of such green spaces is thus imperative to meet the community’s needs within the limited resources and capacity.

1.3 Research Goals and Dissertation Overview

The overarching goal of this dissertation is to help policy makers, green space managers, and community organizations and members strategically design and implement multifunctional community-based food production systems in cities. The objectives of this dissertation are threefold: 1) to assess the current state of knowledge on urban food forestry and identify future research needs; 2) to discuss how community gardens and food forests provide multiple ES as perceived by gardeners, and how the perceived ES trade off or synergize in such green spaces; and 3) to determine the characteristics of gardens and gardeners associated with different sets of perceived ES.

My dissertation comprises three research chapters—Chapters 2, 3 and 4—which have their own introduction, methodology, results, and discussion, followed by a concluding chapter (Chapter 5), bibliography and appendices. As the three main chapters are ‘stand-alone’ contributions that will have been submitted as research articles, they share some similar material on urban food production systems, community gardens in Vancouver, ES, and multifunctionality. There may thus be some overlapping content across the chapters. Chapter 3 analyzes trade-offs and synergies between provisioning and cultural ES using pairwise comparison while Chapter 4 analyzes ’bundles’ of provisioning, cultural and regulating ES.

Chapter 2, a version of which has been published in the journal *Urban Forestry and Urban Greening*, examines the structure and function of urban food systems or practices that involve trees in Northern American and European cities, as discussed in the academic literature. Its intention is to shed light on the concept of “urban food forestry” and to assess the current scientific knowledge and identify future research opportunities in order to advance the practice of using woody plants in food production systems. With this intention, this chapter investigated three research questions:

1) With what field of study do the authors of the scientific literature associate urban food systems that involve trees in Northern America and Europe?
2) What is the composition and vegetation structure of food systems with trees studied in the literature?
3) What are the functions of these systems as described in the literature?

This chapter was informed by a scoping review of the peer-reviewed English-language scholarly journal articles that study food systems and practices that involve trees in urban areas in Northern America and Europe.

Chapter 3 examines how gardeners experience trade-offs and synergies among provisioning and cultural ES in community gardens and food forests in Vancouver, Canada. I asked two research questions:

1) What are the patterns of trade-offs and synergies among provisioning and cultural ES that are perceived by gardeners in community gardens and food forests?

2) What characteristics of gardens and gardeners are associated with trade-offs or synergies of the perceived ES?

This chapter was informed by a cross-sectional survey of 342 participants from 50 community gardens and food forests, a series of interviews with 26 garden representatives (e.g., coordinators, board members, chairs or presidents, managers) who spoke for a total of 42 gardens, and land use mapping of the gardens. This study included a range of community gardens of different sizes, vegetation structures (with or without trees) and management styles (individual, collective or mixed management). Trade-offs and synergies between pairs of ES were assessed using pairwise comparison.

Chapter 4 describes different baskets of provisioning, cultural, and regulating ES that are associated with biophysical and social characteristics of community gardens and food forests. In this chapter I asked two questions:

1) What ecosystem service bundles exist across community gardens and food forests in Vancouver?
2) What biophysical and social factors are associated with the different bundles of ES?

This chapter was informed by the data collected for Chapter 3 and additional tree inventory data from 50 gardens. This chapter used ES bundle analysis, which captures the patterns of trade-offs and synergies among multiple ES (provisioning, cultural and regulating) rather than just between pairs of provisioning and cultural ES (as was done in Chapter 3).

Chapter 5 summarizes the key findings of the dissertation and discusses the study's limitations, contributions, significance, implications for policies and practice, and opportunities for future research.

Chapter 2: Urban food systems that involve trees in Northern America and Europe: A scoping review

2.1. Introduction

2.1.1 Growing attention to food trees and food forests in urban landscapes

Interest in integrating fruit and nut trees in urban landscape management in Northern America (i.e., Canada and USA) and Europe is growing, with the aim to provide ecosystem services (ES) that are important for human well-being (Clark and Nicholas, 2013; McLain et al., 2012). Recent case studies in Europe suggest that planting trees in allotment gardens and community gardens can improve recreational services and regulating services (e.g., carbon storage), and/or provides fruit (e.g., Borysiak and Mizgajski, 2016; Breuste and Artmann, 2015; Cabral et al., 2017; Speak et al., 2015). Beyond planting individual trees, creating "food forests"—multistorey, perennial, polycultural food systems (Park et al., 2018)—in urban areas is gaining scholarly and public interest for their multiple benefits (e.g., Rohwer and Marris, 2016; Riolo, 2019). The Beacon Food Forest in Seattle, USA, for example, aims for multifunctionality by providing a local food source, improving regulating ES (e.g., carbon storage, runoff management, air quality), and cultivating community connections (McLain et al., 2012). The Food and Agriculture Organization of the United Nations advocates developing policies and regulations to facilitate "food forestry" in urban and peri-urban areas (FAO, 2016).

Food forestry is "the skill and art of growing food in a way that replicates nature", for example, by creating "the multiple vertical layers" of perennial and annual plants that interact with one another and by promoting the ecological processes of a natural forest (e.g., nitrogen-fixation, carbon sequestration, nutrient cycling) (Walker, 2015, p.7). Food forestry, which is also called 'forest gardening', is considered a type of agroforestry (Crawford, 2010; Jacke and Toensmeier, 2005; Park et al., 2018). The origins of food forestry are associated with tropical food forests (Hills, 1988) or homegardens, one of the oldest agroforestry practices in tropical, rural regions (Park et al., 2018). Tropical homegardens have long been a traditional means to provide food and other subsistence resources (e.g., medicine, building materials) to rural households (Kumar and Nair, 2006; Mohri et al., 2013). Beyond tropical, rural regions, food forests are burgeoning in *other habitats*—e.g., cities in Northern America and Europe—as household gardens (Park et al., 2018), school gardens (Askerlund and Almers, 2016), therapeutic gardens (Sidenius et al., 2017), community food forests (Bukowski, 2014), and community gardens in urban parks (e.g., McLain et al., 2012; Park et al., 2018). These urban food forests are also known as forest gardens (e.g., Almers et al., 2018; Askerlund and Almers, 2016; Stoltz, 2018).

The term "urban food forestry" was first introduced into the scientific literature by Clark and Nicholas (2013) as a way of "leveraging urban forestry for food security" (Clark, 2011, p.2). The authors define "urban food forestry" as the "intentional and strategic use of woody perennial food producing species in urban edible landscapes" (Clark and Nicholas, 2013, p. 1652). This concept highlights the use of food trees (i.e., fruit and nut trees) for their multifunctionality in urban landscapes, and encompasses any forms or use of food trees in urban landscapes. The term has since been adopted by other studies (e.g., Russo et al., 2017; Riolo, 2019)

2.1.2 Urban food forestry: food forestry versus the use of food trees in urban landscapes

To date, the scholarly literature does not consistently articulate the distinction between food forestry and "urban food forestry" (*sensu* Clark and Nicholas, 2013). The most apparent differences between these two conceptualisations lie in the use of multistorey vegetation structure and food trees (Figure 2.1). Food forestry aims to create and manage multistorey, polycultural systems (Park et al., 2018). On the other hand, "urban food forestry" of Clark and Nicholas (2013) encompasses a range of different food tree systems and practices from street trees to orchards to multistorey, polyculture systems which have food trees in urban landscapes. According to Clark and Nicholas (2013), planting apple trees along a street or a monoculture apple orchard in a city is "urban food forestry" as they involve food trees. However, these would not be considered food forestry, which involves complex vegetation structure and composition (Park et al., 2018).

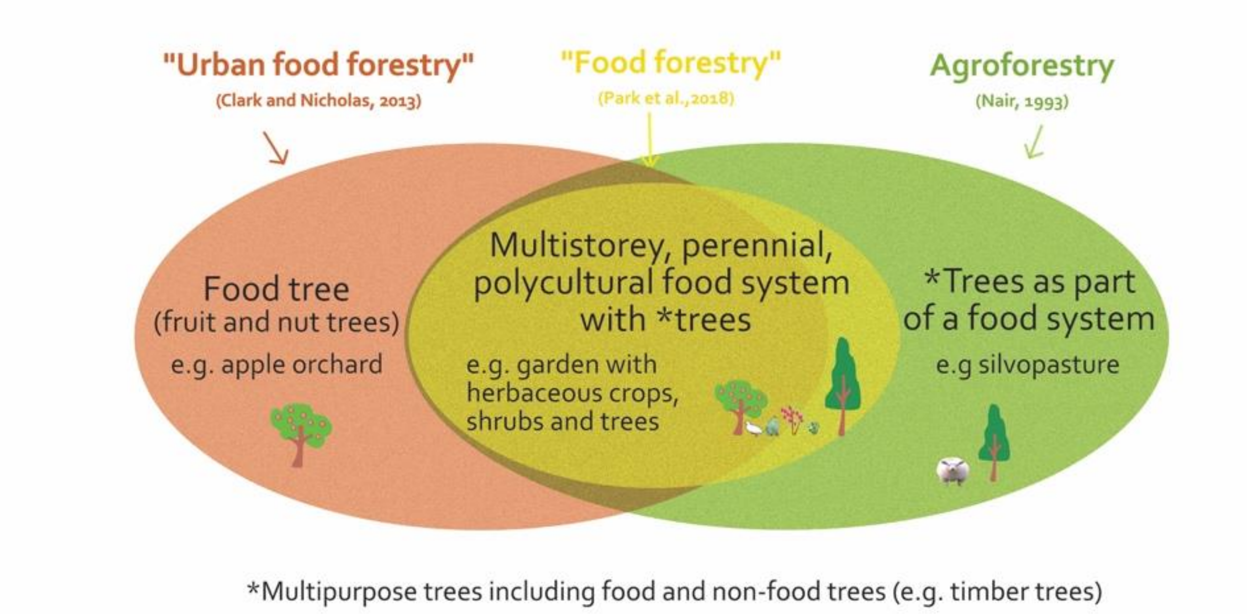


Figure 2.1 Conceptual visualisation of food practices that involve trees in urban areas

Food forestry and "urban food forestry" differ in their association to agroforestry. Food forestry is a type of agroforestry (Park et al., 2018), which is defined as the "deliberate integration of trees with agricultural crops and/or livestock either simultaneously or sequentially on the same unit of land" (Nair, 1993, p. 13). On the other hand, "urban food forestry" is more closely related to urban forestry with the purpose of improving local food security and is supposed to "combine elements of urban agriculture, urban forestry, and agroforestry" (Clark and Nicholas, 2013, p. 1649). The practice may be considered agroforestry but only when food trees are integrated with other production practice(s) within the same unit of land.

2.1.3 Multifunctionality of food forestry and "urban food forestry"

Food forestry and "urban food forestry" aim for multiple functions in both similar and different ways. Food forestry involves non-food trees as well as food trees for their productive and protective functions within a defined system while "urban food forestry" is primarily concerned with food-producing trees planted across a landscape. Also, the multifunctionality of food forestry results not only from trees and but also from the forest-like system created that exhibits diverse vegetational composition and structure, and the ecological processes of a young woodland or a forest in its early-or-intermediate successional stage in temperate climates (e.g., nutrient cycling) (Park et al., 2018). On the other hand, "urban food forestry" highlights the contribution of food trees to increasing landscape multifunctionality through the provision of food and other benefits that urban trees generally provide (e.g., air quality, temperature and stormwater runoff control). To date, however, we lack a comprehensive overview of functional attributes (e.g., the purpose, use, and ecosystem services provided) (Koc et al., 2017) of urban food forests and other food practices and systems that involve trees in urban areas of Northern America and Europe (Clark and Nicholas, 2013; Wortman and Lovell, 2013).

2.1.4 Study scope

A clear, consistent understanding of the concept of urban food forestry is important for advancing knowledge and practice of urban food forestry as well as for communicating among scientists and practitioners. In order to clarify and conceptualise how the scientific literature addresses food production systems that involve trees in Northern America and Europe, we conducted a scoping review to answer three questions: 1) with what field of practice do the authors of the scientific literature associate urban food systems that involve trees in Northern America and Europe?; 2) what is the composition and vegetation structure of the food systems with trees studied in the literature?; and 3) what are the functions of the systems studied in the literature?

2.2 Methods

With the assistance of former forestry graduate Moritz Kramer, I led a scoping review to identify peer-reviewed English-language scholarly journal articles that study food systems/practices that involve trees in urban areas (including cities, suburbs, peri-urban, urban fringe, and towns) in Northern America (Canada and USA only) and Europe. The review followed the JBI Scoping Review methodology as outlined in the 2015 Joanna Briggs Institute Reviewers' Manual. The objectives, questions, inclusion/exclusion criteria and methods for this review were documented in advance in a protocol as advised in the Manual (The Joanna Briggs Institute, 2015).

2.2.1 Document selection

I selected English keywords that are commonly used to describe food systems or practices that involve trees in urban areas, including keywords used by Clark and Nicholas (2013) and Russo et al. (2017). The final search query used was:

“alley crop*” or agroforest* or allotment* or “backyard garden*” or “community garden*” or “domestic garden*” or “edible forest*” or “edible garden*” or "edible green infrastructure" or "edible urban greening" or “edible landscap*” or "edible urban forest*" or farm* or “forest farm*” or “food forest*" or “food tree*” or “fruit tree*” or "forest garden*" or "forestry food production" or homegarden* or "home garden*" or “improved fallow” or “nut tree*” or "permaculture garden*" or orchard* or “school garden*” or “riparian buffer” or silvopasture or ”tree garden*” or “windbreak*”

AND

“town” or “urban” or “city” or “cities”

A keyword search was conducted on 12 January 2018 in the Web of Science Core Collection, Scopus and Agricultural & Environmental Science Database (AESD). Then, we (i.e. Moritz Kramer and I) imported the resulting documents to Mendeley (reference management software) and screened them in three phases (Figure 2.2) according to the inclusion and exclusion criteria (Table 2.1). We excluded the articles of Park et al. (2018) and of Clark and Nicholas (2013) in our review. Details of each phase and the search query of each database used are provided in Appendix A.1.

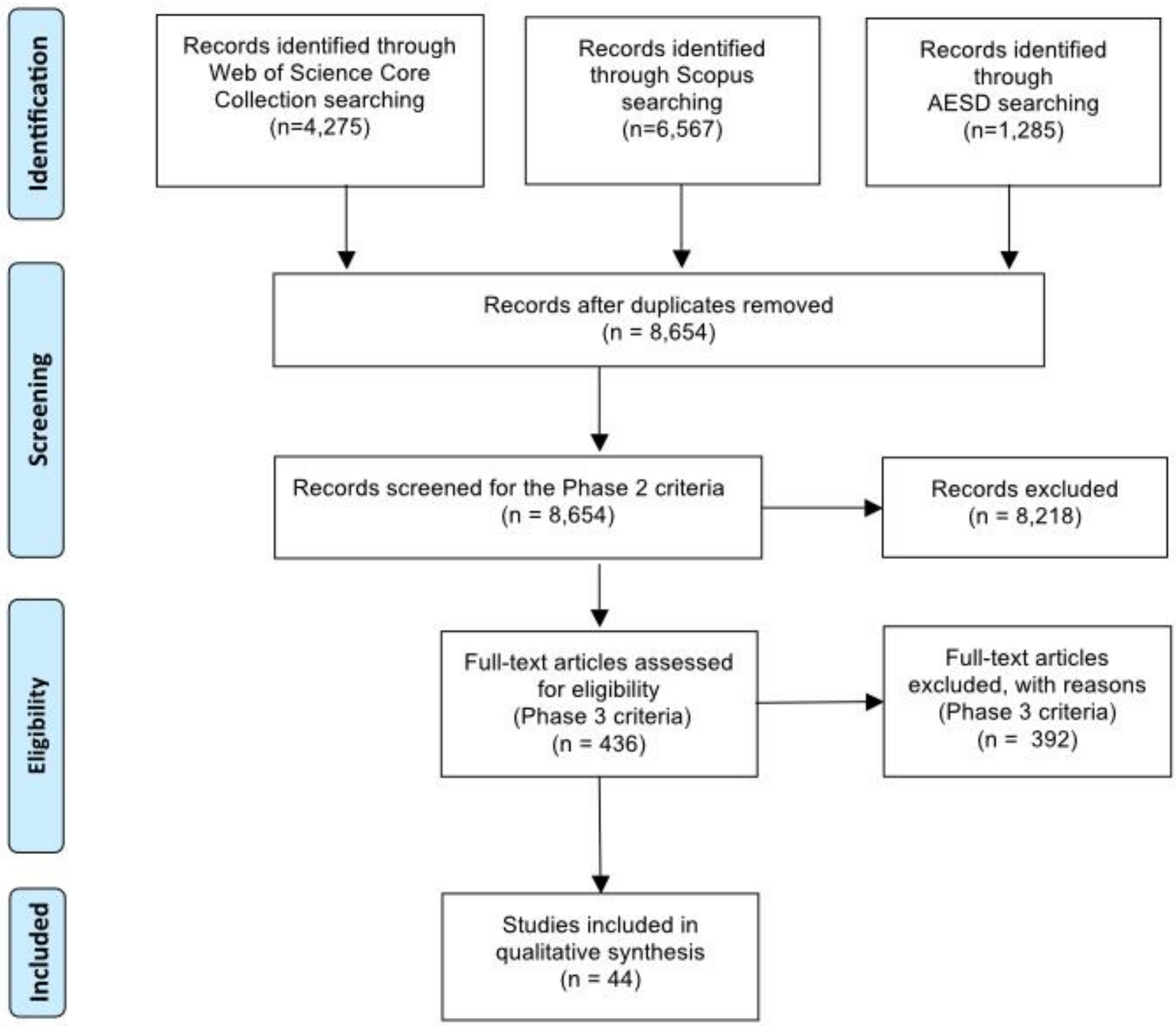


Figure 2.2 Search results diagram based on Moher et al., 2009 (adapted PRISMA 2009 FLOW diagram)

2.2.2 Document review

We exported the selected articles in CSV format with their bibliographic information from Mendeley to NVivo (qualitative data analysis software) and deductively coded full texts of the articles, using the set of predetermined questions (Appendix A.2). The questions were largely comprised of four parts:

- article: authors, year of publication, study location, name of journal and methods
- terms used in article: terms to refer to the system or a practice studied
- description of the studied system or practice: structure of the system (e.g., nature of biological components, spatial/temporal configuration of trees, vegetation layer) socio-economic management, location and scale
- functional attributes (purpose, use, service) of the studied system and tree including ecosystem service (ES) and benefits to well-being and biodiversity, and ecosystem disservice

Table 2.4 Inclusion and exclusion criteria for document selection

	Inclusion criteria	Exclusion criteria
Phase 1: Keyword search in the title, abstract, keyword, and subject headings		
	English	Non-English
	Published up to 12 January 2018	Published after 12 January 2018
	Available in: Web of Science Core Collection; Scopus; Agricultural & Environmental Science Database	Not available via Web of Science Core Collection; Scopus; Agricultural & Environmental Science Database
	Review and primary research articles (peer-reviewed, scholarly journal publication)	Others (e.g., meetings, proceedings)
	Studied systems located in Canada, USA, and European region including Turkey and Russia	Studied systems located elsewhere
Phase 2: Title and abstract review (full-text review if necessary) to select the studies of food systems that involve trees		

	Canada, USA, and Europe	Others (e.g., Asia, Africa, Latin America), Global, unspecified
	Urban, peri-urban, suburban, urban fringe, town, city, cities	Rural, unspecified
	Abstracts that use most relevant terms such as food forest, forest garden, homegarden, home garden, fruit and nut trees, orchard, community garden, and examples of agroforestry systems	Abstracts that do not meet the two criteria: use of specific terms and explicit indication of the use of trees (e.g.,fruit crops without indication of the presence or use of trees)
	Abstracts that did not use the key terms above, but those that clearly indicate studied systems or practices involve trees for food production or in a food production system	
Phase 3: Full-text review to select the studies whose vegetation description is sufficient for us to categorise studied systems according to vegetation structure described		
	Articles that have description of vegetation that includes trees within the unit of a system(s) (e.g., home gardens) or practice studied	Articles that discuss food trees in only some of green spaces and food production areas studied
		Articles that only mention key terms (see the Inclusion criteria in the Phase 2) but do not explain the vegetation characteristics

2.2.3 Classifications of systems and practices

2.2.3.1 Structural attributes

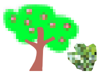
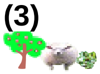
Agroforestry and green infrastructure are classified primarily according to their structure and function (Nair, 1993; Koc et al., 2017). For structure, we categorised the food systems and practices based on the description of vegetation layers (trees, shrubs and herbaceous plants) and food trees (for fruit and nut) provided in the peer-reviewed scientific articles. According to these two criteria, we created three groups: “food tree”, “trees as part of a food system” and “multistorey food system with trees”. Then we further divided them to six subgroups: (i) food trees only; (ii) food trees with other food production unit(s); (iii) food system with food trees; (iv) multistorey (trees, shrubs, herbaceous plants) food system with food trees; (v) multistorey (trees, shrubs, herbaceous plants) food system with unspecified trees; and (vi) food system with unspecified trees (Table 2). Subgroup (ii) was created during the analysis for examples where we could not determine whether the system described fit into (i) or another group due to scales, ambiguity of integrated management and interactions of different components: for example, a production area where an orchard and vegetable farms/gardens coexist but in different parts of the area.

Subgroups (i), (ii), (iii) and (iv) are “food tree” groups that represent systems or practices of “urban food forestry” that use food trees as defined by Clark and Nicholas (2013). Subgroups (iii), (iv), (v), and (vi) belong to the “trees as part of a food system” group. Finally, subgroups (iv) and (v) belong to the “multistorey, polycultural food production area with trees” group (i.e., food forestry as defined by Park et al., 2018). This categorization was solely based on our interpretation of the vegetation description given in the articles, and we do not imply that all studied examples of the subgroups (iii), (iv), (v), (vi), (iv) and (v) are agroforestry or food forestry systems or practices. When the presence or the use of all trees, shrubs and herbaceous plants was explicitly mentioned in the articles, we categorised these to subgroups (iv) or (v). When the presence of shrubs was not explicitly mentioned for the food systems that have trees and vegetable/herbaceous plants, we categorised them as subgroup (iii) or (vi). Moreover, when the purpose of trees was unrelated to food or not mentioned, we categorized studied examples to the “unspecified tree” subgroup (v) or (vi).

In addition, we adopted the agroforestry classification criteria from Nair (1993) for the “nature” (composition) of the biological components and arrangement of trees. The nature of biological components includes: a) trees, b) trees and agricultural crops, c) trees and livestock, and d) trees, agricultural crops, and livestock (see the left-hand column of Table 2.2).

Table 2.5 Mapping of the examples of food systems that involve trees. Unspecified trees (or U-trees) are trees whose edibility is not explicitly mentioned in the articles. The number in the parenthesis refers to the number of articles that we categorized for each system. A few articles study more than one example of the same system group or different groups. We cite a few examples of each type, but see Appendix A.3 for all examples included in the classification.

		Food trees (40)				*Unspecified trees (5)	
					A multistorey food system with trees (8)		
				Trees as part of a food system (16)			
Com-ponent	Tree arrange-ment	(i) Food trees only (24)	(ii) Food trees with other food units (9)	(iii) Food system with food trees (6)	(iv) Multistorey food system with food trees (5)	(v) Multistorey food system with U-trees* (3)	(vi) A food system with U-trees* (3)
(a)Trees (24)	Grouped (13)	Orchard (e.g. Foo et al., 2014)					
	Unknown (e.g. green spaces, street planting) (11)	Urban greening (McLain et al., 2012); Urban foraging (Hurley and Emery, 2018)					
(b)Trees &crops (21)	On boundaries (2)				Multifunctional buffers (Wortman and Lovell, 2013)		Community garden (Kurtz, 2001)

	Grouped (7)	Educational garden (Giacche et al., 2017)			Community garden (Irvine et al., 1999)	
	Unknown (12)	Arboretum (Anderson, 2016)	Intercropping (Williams and Gordon, 1992)	Forest garden (Askerlund and Almers, 2016)	Public-Access Community Gardens (Bendt et al., 2013)	Agricultural park (Masson et al., 2013)
(c)Trees & livestock (3) 	On boundaries (1)		Fruit trees in pastures (Lange et al., 2008)			
	Unknown (2)		Silvipasture (Williams and Gordon, 1992)			
(d)Trees, crops & livestock (3) 	Grouped (2)	Eco-village (Newman and Nixon, 2014)				
	Unknown (1)	High-rise farm (Komisar et al., 2009)				

2.2.3.2 Functional attributes (purpose, use, service)

We categorized the functional attributes (i.e., the purpose, use, or services provided) of the studied systems and practices (Koc et al., 2017) into the four ES categories—i.e., provisioning, regulating, cultural, and supporting services—of the Millennium Ecosystem Assessment (MEA, 2005). These four categories have been adopted in recent studies in agroforestry (e.g., Jose, 2009; Fagerholm et al., 2016) and green infrastructure (Koc et al., 2017). We additionally coded benefits to well-being and biodiversity (incl. habitat value) by following the MEA framework, ecosystem disservices (Shackleton et al., 2016), and trade-offs and synergies between functional attributes, as discussed in the studied articles. Our approach to classifying urban food systems differed from Russo et al. (2017) who developed the typology of edible green infrastructure, as we focused on urban systems in Northern America and Europe and included articles that discuss only cultural services of the studied systems or practices.

2.2.3.3 Systems and practices

We expected to find articles that studied a food production system as well as ones that focused on a practice (for example, the use of food trees). For this scoping review, a "system" refers 1) to food production unit(s) that are specific to a locality and a physical boundary (e.g., household garden) as defined in the studied literature, and 2) to the use of trees across a large area (e.g., street planting) with or without the combination with other land uses. We understand that the use of trees with other land use types is generally considered a practice rather than a system in the field of agroforestry (Sinclair, 1999). Yet, it was difficult for us to strictly distinguish a system from a practice solely based on descriptions provided in the articles. In this review paper from now on, a "practice" refers to a field of study or practice with which the authors of the studied articles associate the "system": for example, urban agriculture, urban forestry, and community gardening.

2.3 Results

2.3.1 Overview of selected articles

A total of 44 peer-reviewed scholarly articles were selected for review. Articles were published from 1987 to 2018 (January), representing research conducted in urban, peri-urban or urban fringe settings in Northern America and Europe (Figure 2.3). Overall, 19 studies (43%) were conducted in Northern America (Fig. 3), with 13 studies (30%) were from the USA. The remaining 25 papers came from Europe (57%), with Italy as the most prominent study location with a total of four papers, followed by Spain, Germany, the United Kingdom, and Türkiye (all with three research articles). Articles covered mostly field surveys (12 papers, all based in Europe), followed by interviews (7 papers). Other methods included spatial analysis (6 papers), participant surveys (5 papers), participant observation (4 papers), literature reviews (5 papers), case studies (3 papers), multi-criteria analysis (2 papers), scenario planning (2 papers), and focus group discussions (1 paper). For two papers, methods were not clearly described. Ten articles, including three case studies, used more than one method.

Figure 2.3 World map showing countries included in our scoping review of literature on urban food production systems with trees in Northern America and Europe

2.3.2 Food practices

Urban agriculture (incl. peri-urban agriculture) and community gardening were the most common practices with which the authors of the articles associate the studied systems. Urban agriculture was associated with five subgroups (i), (ii), (iii), (iv), and (v) by 23 articles even though urban agriculture was not included in our search query. Community gardening was associated with five subgroups (i), (ii), (iv), (v), and (vi) by seven articles and agroforestry with three subgroups (iii), (iv), and (vi) by five articles. Some authors identified community gardening (Irvine et al., 1999) and agroforestry (La Rosa et al., 2014) as a form of urban agriculture.

The “food trees only” subgroup (i) was primarily associated with urban agriculture and different fields related to urban forestry. Fruit orchards and olive groves were associated with urban (peri-urban) agriculture, while other forms of fruit tree plantations, for example trees on streets and in domestic gardens and urban parks, were associated with urban greening (e.g. Lange et al., 2008; McLain et al., 2012) and urban foraging (Larondelle and Strohbacha, 2016; Hurley and Emery, 2018). Agroforestry was not mentioned in this subgroup. The other five subgroups (ii), (iii), (iv), (v), and (vi) were associated with agroforestry (e.g., Askerlund and Almers, 2016), home gardening (e.g., Gray et al., 2014) and permaculture (e.g., Newman and Nixon, 2014), as well as urban agriculture (e.g., Wortman and Lovell, 2013) and community gardening (e.g., Kurtz, 2001).

None of the articles specifically mention “urban food forestry” and “food forestry” as a type of practice. Only McLain et al. (2012) and Askerlund and Almers (2016) use the terms “food forest” and “forest garden”, respectively. However, McLain et al. (2012, p. 192) describe the Beacon Food Forest as a public food system for multiple purposes (see Introduction) that is based on “permaculture principles of integrated agroforestry woodland food systems.” Askerlund and Almers (2016) describe the Holma forest garden in Sweden as a system that resembles “multi-layered forest edges” and is inspired by tropical agroforestry practices (p.187).

2.3.3 Structure of food systems

The vegetation structure and biological components criteria were effective in differentiating the subgroup (i) “food trees only” from the “trees as part of a food system” subgroups (iii), (iv), (v), and (vi) (Table 2.3). Most articles described either food systems of trees only or systems of both trees and herbaceous plants. Twenty-four articles described the subgroup (i) of “food tree only” including community and commercial orchards, street trees, and individual trees in domestic gardens, parks, and urban forests. Almost half of these articles were from the USA. Sixteen articles studied the “trees as part of a food system” subgroups (iii, iv, v and vi) including home gardens, agricultural parks, pedagogical garden, intercropping farms, and urban farms. Interestingly, community gardens were mentioned in all four subgroups of the “trees as part of a food system”. Most examples of the “multistorey, polyculture food production area with trees” (iv and v) were found to be community or public gardens (e.g., Kurtz, 2001; Bendt et al., 2013). Wortman and Lovell (2013) discuss the use of multifunctional buffers of trees and shrubs in urban farms.

Subgroup (ii) encompassed a wide spectrum of nature and arrangement of biological components in urban landscapes. Examples included the Yarrow Ecovillage in Canada, which had an apple orchard, vegetable farms and hens in the farmlands (Newman and Nixon, 2014), and a proposed “high-rise farm” project consisting of multiple indoor floors of fruit trees, vegetables, chickens, and cows for a restaurant in the building (Komisar et al., 2009). Scales and socio-economic management approaches also widely varied among the systems studied in the literature. An educational garden with a total cultivated area of approximately 650 m^2 in Italy in which students grew vegetables had a small orchard for students (Giacche et al., 2017). On the other hand, the *Parc Agrari del Baix de Llobregat*, an agricultural park on the urban fringe of Barcelona, had farmlands of approximately 2,900 ha (Dorda and Berenguer, 2008) and was managed by a consortium comprising the county council, provincial council, fourteen municipalities, and private entities. Both commercial farming and informal gardening took place in the park (Pirro and Anguelovski, 2017).

Table 2.6 Summary of structure and functional attributes of urban food systems with trees studied in the 44 articles

● Number of articles for each category	Food trees				Unspecified trees (u-trees)	
			Trees as part of a food system			
				Multistorey food system with trees		
Vegetation composition & structure	Food trees only (i)	Food trees with other food units (ii)	Food system with food trees (iii)	Multistorey food system with food trees (iv)	Multistorey food system with u-trees (v)	Food system with u-trees (vi)
Number of literature	●●●●●●●●●●●●●●●●●●●●●●●●	●●●●●●●●●	●●●●●●	●●●●●	●●●	●●●
Examples	Orchard, street trees	Urban park, educational garden	Home garden, intercropping	Community garden, forest garden, farm	Community garden	Community garden, agricultural park
Associated field:						
Urban agriculture	●●●●●●●	●●●●●●	●●●●	●	●	●
Community gardening	●●●	●		●●	●●●	●●
Urban forestry	●●	●				
Agroforestry			●●	●●		●
Others	Urban foraging, gardening	Permaculture, civic agriculture	Gardening			
Functions						
Food production	●●●●●●●●●●●●●	●●●●●●●	●●●●●●	●●●●	●	●●
Cultural ES (learning; recreation, connection to nature)	●●●●●●●	●●●●	●●●	●●●	●●	●●●
Regulating ES	●●	●		●●		●●
Social relations	●●●	●●	●	●●	●	●●
Urban habitat	●●●●●●●	●●●	●	●	●●	●
Others	Health	Job creation	Beautification	Soil formation		Wood materials
Synergies of functions (of trees)	Fruit+ beautification	Fruit+ social interaction	Profit generation + land regeneration	Fruit+windbreaks +air pollutant control +beautification; Fruit +shade +privacy		Biodiversity +wood materials +carbon sequestration
Trade-offs of functions			Microclimate regulation vs vegetable production	Children learning vs crop security (vandalism)	Depth of ecological knowledge vs breath of participants	
Factors for trade-offs			Size and tree canopy		Governance and management	
Ecosystem disservices						
Food safety	●	●	●			
Trade-offs of functions			●●	●	●	●
Others:	New disease, treefall		Tree maintenance on farmlands, crop damage	Vandalism		

2.3.4 Functions of food systems

Thirty-nine out of 44 articles mentioned functional attributes (purpose, use, service) (Koc et al., 2017), which were categorised as ES and benefits to well-being and biodiversity. The functional criteria of ES and benefits to biodiversity and well-being were not effective in classifying food systems studied in the literature. This was largely due to the fact that most studies included in our review did not intend to systematically analyse all ES or benefits of the systems, but they rather discuss specific functional attributes of interest. Also, we did not find significant differences in ES and benefits among the six subgroups.

Provisioning services (food production) were predominantly studied; the six subgroups shared several common ES and benefits: food production, cultural services (recreation, education, connection to nature), good social relations, and habitat value. Food trees were valued for food production as well as for cultural and regulating services, and habitat value. For example, food trees and shrubs planted along the boundaries of urban farms could function as multifunctional buffers, which protect crops from winds and contaminated aerosols (Wortman and Lovell, 2013). Food trees improve aesthetic values of urban farms and gardens (Kortright and Wakefield, 2011; Wortman and Lovell, 2013). In community gardens, food trees provide shade and block views from the outside, which create a sense of enclosure for relaxation (Kurtz, 2001). In combination with agroforestry, agricultural parks may provide wood for heating and building, to create environmental corridors, and to provide regulating services in terms of urban heat island effect and carbon sequestration (Masson et al. 2013).

The systems with more complex vegetation structure and biological compositions revealed potential interactions among their functional attributes and interactions between trees and different biological components within the system. Home gardeners valued aesthetic effects and regulating services of trees (e.g., controlling air quality and urban heat island impact) in their gardens; on the other hand trees were a limiting factor for vegetable production (Kortright and Wakefield, 2011). Fruit trees in pastures could add aesthetic value but trees planted in the middle of the pastures were considered obstacles for maintenance, and farmers preferred that the trees be planted on boundaries (Lange et al., 2008). Williams and Gordon (1992) suggested a synergistic interaction between trees and livestock/crops in intercropping systems that use grazing livestock to control competition for tree establishment, while trees in return provide fodder when reforesting former agricultural lands before land development.

Nuanced trade-offs between functional attributes were attributed to design, governance (mostly, actor groups), and management of community gardens. Community gardens that had trees functioned as a space for local residents to grow food, learn, connect to nature, and build community connections (Barthel et al., 2010; McLain et al., 2012). Kurtz (2001) suggested that a large-scale allotment (individual) garden might be a better space for gardeners to grow food and feel a sense of connection to nature on their own terms but may not easily meet expectations for “sociability and community-building”, in comparison to a small, collectively managed garden. Bendt et al. (2013) discussed a potential trade-off between the depth of ecological knowledge retained by participants and the range of public audiences who benefit from educational services in community gardens and suggested this trade-off might be influenced by the division of labour and responsibilities, decision structure, and public engagement of community gardens.

The most prominent ecosystem disservice across the subgroups was concern for food safety around fruit trees and vegetables grown in polluted urban soils and affected by air pollution (Sembratowicz et al., 2010; Kortright and Wakefield, 2011; Hurley and Emery, 2018). In addition, food trees can fall and pose a safety risk to people due to shallow urban soils. Yet, some food trees such as navel orange (*Citrus sinensis*) and mango (*Mangifera indica*) were found to have high wind tolerance in urban areas (Duryea et al., 1996). Fruit trees could also introduce new diseases into the urban ecosystem (McLain et al., 2012).

2.4 Discussion

2.4.1 Distinction between the use of food trees and food forestry in urban landscapes

In the current scientific literature, urban food forestry is variously interpreted as the use of food trees in urban landscapes (Clark and Nicholas, 2013) rather than as food forestry in urban settings (Park et al., 2018). The concept of "urban food forestry" (*sensu* Clark and Nicholas, 2013) includes a wide range of food systems with trees from (but not limited to) street trees to orchards, to silvopastoral systems to multistrata polyculture systems (Park et al., 2018) such as "urban food forests" (Riolo, 2019) or "edible forest gardens" (Almers et al., 2018). Food forestry is based on the concept of tropical homegardening—"intimate plant associations of trees and crops and consequent multistory canopy configuration" (Kumar and Nair, 2006, p. 2)—, which was advocated so as to address the ontological confusions arising due to the emergence of homegardens outside their "traditional" rural habitat into urban and commercial settings in tropical regions (Kumar and Nair, 2006). We do not intend to promote the use of any particular terminology as we recognize that it requires consideration and comparison of examples from a range of literature including grey literature, and books, and consultation with practitioners (Hällfors et al., 2014). Instead, the review explores a wide range of food production systems with trees that can fall under "urban food forestry" (sensu Clarke and Nicholas, 2013) and offers a conceptual framework to categorize different systems. It also shows how the concept of "urban food forestry" is not consistent with the concept of "food forestry" (*sensu* Park et al., 2018).

2.4.2 Functions and potential drivers

Recent case studies in Europe indicate distinctive advantages of practicing food forestry in urban environments, which may help to differentiate food forestry from other types of "urban food forestry" such as orchards and street trees. According to Riolo (2019), the complex biological structure and composition in the "Picasso Food Forest" in Italy stimulates a "sense of wonder, exploration, curiosity". The author suggests that the food forest project provides an opportunity for people to gain “a greater understanding of ecological processes that are at the base of food forest design and functioning.” An interesting observation was made in a Swedish urban school garden which is designed to be a “forest garden” (Almers et al., 2018). The structural and compositional diversity of the garden allows diverse activities and tasks in which children can participate and learn. This school garden requires less watering and produces crops in more seasons than other traditional school gardens primarily planted with annual vegetables. In addition, Stoltz (2018) argues that diversity in forest gardens can prompt experiences in diverse sensory dimensions (e.g., refuge, rich in species). Forest gardens can promote social activities and interactions when they are managed as community gardens, which can promote human health (Stolz, 2018). Even though focusing on rural and commercial settings, a recent study by Kreitzman et al. (2022) shows that in the U.S. Midwest woody perennial polycultures farms have higher biodiversity and ecosystem functions than adjacent conventional soy or corn fields despite the lower yield especially in the early development stage. They suggest that woody perennial polycultures in the temperate north might play a role for promoting sustainable agricultural landscapes over time.

However, our review did not find empirical evidence that compares functions of different urban food production systems that involve trees. Rather, the review reiterates the multifunctionality of food trees and urban food systems that involve trees (e.g., food production, habitat value, cultural and regulating services) and reveals potential trade-offs between their functions in complex food systems (Speak et al., 2015). Design, governance, and management of food systems may explain subtle differences in ES provided by these systems and trade-offs among functions (Drake and Lawson, 2015; Gregory et al., 2016; Cabral et al., 2017). Urban food systems such as community gardens encompass diverse systems of differing biological components and vegetation structure in urban environments including (but not limited to) community orchards, gardens with primarily annual vegetables, and gardens with trees, annual plants, and shrubs (Bendt et al., 2013; Clark and Nicholas, 2013). Community gardens can also be characterised by different management types (e.g., individual, collective, mixed) (Drake and Lawson, 2015) or by goals and functions (Bendt et al., 2013; Langemeyer et al., 2018; Kurtz, 2001; Rishbeth, 2004). Like other social-ecological systems, understanding of both social and ecological contexts will help to properly assess and compare different multifunctional urban food systems with trees. Empirical studies will help to understand how different ES trade off or synergise within such food systems with trees and what factors drive such interactions. The limitations of this scoping review and recommendations are discussed in Chapter 5 ‘Conclusions’.

Chapter 3: Human–nature interactions enable multifunctionality in urban food production systems in Vancouver, Canada

3.1 Introduction

In North America and Europe, there is growing interest in urban food production systems such as community gardens for their ability to provide multiple ES (Camps-Calvet et al., 2016; Menconi et al., 2020; Semeraro et al., 2021). In many case studies, both food and cultural ES are found to be the primary motivations or benefits of community gardening (e.g., da Silva et al., 2016; Newell et al., 2022). Community gardens are important sources for fresh and culturally important produce (Gregory et al., 2016), and community gardeners are found to consume vegetables and fruits more often than those who do not participate in community gardening (Alaimo et al., 2008; Gregory et al., 2016). Moreover, community gardens can beautify urban neighbourhoods (Langemeyer et al., 2018) and improve social cohesion (Veen et al, 2015), social connection, reciprocity, and trust (Birky and Strom, 2013; Teig et al., 2009), and contribute to people's mental and physical health (Kingsley et al., 2009; van den Berg et al., 2010). In addition, food forests that involve a variety of trees and shrubs are flourishing as a form of community gardens or part of urban public parks (McLain et al. 2012; Park et al., 2018). By planting trees in community gardens, certain cultural ES such as the sense of connectedness to nature and the aesthetic value can be enhanced (Hemmelgarn and Munsell, 2021; Speak et al., 2015). Trees can also diversify provisioning ES such as tree crops and materials for making paper, musical instruments, or crafts (Konijnendijk and Park, 2019). Thanks to their potential to provide both food and cultural ES that are important to the well-being of urban residents, community gardens and food forests are increasing being incorporated into small pockets of urban green spaces such as parks, rooftop gardens, and underutilized private properties (Goździewicz-Biechońska and Brzezińska-Rawa, 2022).

3.1.1 Multifunctionality cannot be assumed

Cities are faced with many challenges such as food insecurity, social isolation, and lack of opportunities to regularly connect with nature (Gaston et al., 2020; My Health and My Community, 2014; Soga and Gaston, 2016). A survey of over 400 community garden organizations in the US and Canada showed that community gardening provides at least two or more benefits (Drake and Lawson, 2015). The most significant benefits were food and cultural services such as food production and nutrition and social engagement as well as environmental benefits. Moreover, 75% of respondents reported more than one benefit of community gardening, which show multiple values of gardeners toward community gardens. This survey suggests that community gardens can provide food and other ES that are important to people who live and work in cities.

The ability of community gardens and food forests to deliver multiple ES is not guaranteed (Langemeyer et al., 2018). As I discussed in Chapter 2, these systems vary in their biophysical and social form, goals, and consequently their functions (Langemeyer et al., 2018). Previous studies suggest that there may be a trade-off in these systems between food production and certain cultural ES such as social cohesion. For example, Langemeyer et al. (2018) and Kurtz (2001) discuss that gardeners view large allotment gardens as a good place to produce food and connect with nature but less so to cultivate social cohesion and place attachment. On the other hand, gardeners in small, collectively-managed gardens may value the sense of community or community-building aspects of community gardening rather than food production (Langemeyer et al., 2018; Kurts, 2001). In addition, trees can create shade and limit space for growing vegetables despite the other benefits they provide such as tree crops, aesthetics, and connectedness to nature (Speak et al., 2015). Meanwhile, Dennis and James (2016a, 2016b) found neither significant positive nor negative relationships between potential food yield and other cultural services.

3.1.2 Multiple factors are at play in production of ES

Multiple factors influence the production and perception of ES benefits provided by gardens (Table 3.1). These include characteristics of gardeners, such as income, education, gardening practices. ES benefits are also shaped by the biophysical and management characteristics of gardens, including garden size, trees, and type of management.

People with diverse socio-economic characteristics (e.g., education, income) engage in community gardening (da Silva et al., 2016; Gregory et al., 2016; Veen et al., 2015). The socio-economic characteristics of gardeners, particularly income, are often strongly associated with people's demand for different ES, people's motivations for commmunity gardening (da Silva et al., 2016) or types of plants that gardeners grow (Clarke and Jenerette, 2015). For example, gardeners with lower income tend to show higher reliance on community gardens for growing food (Seto, 2011; da Silva et al., 2016; Gregory et al., 2016). Community gardens in neighbourhoods with higher median income may have a larger percentage of area planted with ornamental plants than those in neighbourhoods with lower median income (Clarke and Jenerette, 2015). Da Silva et al. (2016) found that in Portugal, unemployed or unskilled workers or people with large families tended to report food security more than education and recreation as their main motivations for community gardening, while people with "upper and intermediate professions" tended to value food security as well as recreation, education, environmental concerns and health concerns. The authors did not imply a trade-off among these motivations; yet they suggested the city create gardens of different sizes, structures and management types to accommodate different needs of different people.

Gardeners' capacity such as time invested in gardening is also associated with their motivation or perceived benefits of community gardening. In the UK, gardeners who spent more time in community gardens tended to value the chance to meet neighbours more than those who spent less time (Dunnett and Qasim, 1999). Further, distance from the locations of homes to gardens (or whether their community gardens are located in their neighbourhood) in conjunction with type of garden management may influence the extent to which gardeners experience social cohesion (Veen et al., 2015). Within the same garden or food forest, gardeners can have different interests and goals, which may cause land use and management conflicts among gardeners. For example, some gardeners may be happy to attend to communal space and share apples or other food crops harvested from the communal space with other gardeners and non-gardeners while others may not (Delshammar et al., 2016).

Management approaches and food trees may affect the supply of perceived ES in community gardens. Food trees are often collectively maintained, and the fruit crops are shared among garden members; therefore, food trees may imply some extent of collective values of community gardening. Trees in community gardens can increase the supply of regulating services and aesthetic value of the gardens. On the other hand, trees limit spaces for vegetable production (Cabral et al., 2017; Speak et al., 2015). Such elements of garden design—individual/shared plots and food trees—are closely connected to management of community gardens and may influence the ways in which community gardens of a certain management type provide ES and benefits and trade-offs among them.

In conjunction with management and food trees, the size of gardens can mediate trade-offs between the supply of regulating services such as shade and provisioning services (Cabral et al., 2017; Speak et al., 2015). Gregory et al. (2016) found that the size of gardens was positively correlated with the number of edible plant species growing in gardens with individual plots but that there was no correlation between garden size and the number of edible plant species in collectively-managed gardens. The size of gardens alone may not be a strong driver of ES or associations among ES (Rogge et al., 2018). Therefore, both the garden size and garden management (e.g., collectively-managed small garden, large individual-plot oriented garden) may together facilitate some of trade-offs or synergies between some ES (Kurtz, 2001; Langemeyer et al., 2018).

Table 3.1 Garden and gardeners' characteristics that were associated with ES in past studies

Scale	Factors associated with the supply or importance of ES studied	ES
Gardener	- income (and neighbourhood median income) - distance to travel time to the garden (place of residence) - motivation - education - time spent in gardens (da Silva et al., 2016; Gregory et al., 2016; Veen et al., 2015)	Provisioning service
Garden	- management type - presence of trees - garden size (Clarke and Jenerett, 2015; Cabral et al., 2017; Kurtz 2001; Gregory et al., 2016; Langemeyer et al., 2017; Speak et al., 2015)	
Garden	- tree presence - garden size - permeable surface area - lease term (Colding and Barthel, 2013; Cabral et al., 2017; Dennis and James, 2016a; Speak et al., 2015)	Regulating service
Gardener	- motivation, - age, migration, education - time spent in the garden - neighbourhood land cover of residence (Dunnett and Qasim, 1999; Egerer et al., 2018; Langemeyer et al., 2017; Veen et al., 2015)	Cultural service
Garden	- management type - tree presence - garden size - # of partnership groups - # of gardeners - # types of events/programs (management budget) - year of garden foundation (Bendt et al., 2013; Cabral et al., 2017; Dennis and James, 2016b; Kurtz 2001; Langemeyer et al., 2017; Rishbeth, 2004; Rogge et al., 2018; Speak et al., 2015; Veen et al., 2015)	

3.1.3 Research objectives and questions

A good understanding of how multiple ES interact and, more importantly, what factors affect these interactions, is essential for managing multifunctionality to minimize unwanted trade-offs and maximize desirable synergies (Bennett et al., 2009). In this chapter, I investigated two questions:

1) What are the patterns of trade-offs and synergies among provisioning and cultural ES that are perceived by gardeners in community gardens and food forests?

2) What characteristics of gardens and gardeners are associated with the trade-offs or synergies of the perceived ES?

To address these questions, I conducted a cross-sectional survey of 342 gardeners from 50 community gardens and food forests across the city of Vancouver, Canada to understand their experiences of food and cultural ES, as well as a series of interviews with 26 representatives who spoke for a total of 42 gardens and food forests, and land use mapping of the 50 sites to identify potential factors associated with ES.

3.2 Methods

3.2.1 Study area: Vancouver and its community gardens

The city of Vancouver, which lies on the southwest coast of Canada near the U.S. border, covers an approximate area of 114 km^2 and is home to over 630,000 people (Statistics Canada, 2016). The city has the second most expensive housing market in Canada (Kwan, 2019), and within the greater metropolitan area it has the highest food insecurity and lowest sense of community belonging among all municipalities (My Health My Community 2014). In 2010, the municipal government launched the Greenest City 2020 Action Plan to become the greenest city in the world (City of Vancouver, 2012), setting environmental sustainability goals such as: ensuring that residents have access to green space within a 5-minute walk; planting 150,000 trees (including fruit trees); and converting street rights-of-way to green spaces, including community gardens and orchards. The City also aimed to increase food assets including the number of community garden plots by 50% and the number of community orchards by 330% over 2010 levels in the city by 2020 while encouraging planting of fruit trees in community gardens (City of Vancouver, 2012). The Vancouver Food Strategy (2013) defines a community garden as "land managed by a non-profit society or a group of individuals, and used to grow plants and harvest food or ornamental crops" (City of Vancouver, 2013, p. 53). The detailed description is included in section *1.3 Vancouver as a case study.*

3.2.2 Online and in-person surveys

I conducted a cross-sectional survey of gardeners (Pinsonneault and Kraemer, 1993) to measure eleven key ES that gardeners perceive in public and private community gardens and food forests (hereinafter referred to collectively as "gardens") in Vancouver, and to identify the characteristics of gardeners and their gardening practices that could be associated with their perception or experience of ES from June to October 2019 (see the survey consent form in Appendix B.1, as well as the survey questionnaire in Appendix B.2**).** The survey questionnaire was tested it with gardeners at a community garden network meeting in March 2019, and then emailed to the 111 gardens that have public contact information in the City's community garden database (updated on November 2018) with a study invitation (Appendix B.3) explaining the purpose of the study and encouraging the contact person to distribute our online survey link to their garden members and volunteers over 18 years of age.

A total of 366 gardeners from 50 gardens across 17 neighborhoods in the city (i.e., 45% of the 111 gardens contacted) participated in the survey (Figure 3.1). I excluded 24 of the original 366 survey respondents who failed to answer the questions related to ES or were associated with more than one garden. Therefore, 342 samples were included in the analysis. A median of four participants (range=1-22) from each of 50 gardens participated. A non-probability sampling approach (Baker et al., 2013) was necessary because there was no prior information on community garden members (e.g., contact information, demographic characteristics). To increase the response rate and minimize unit non-response bias (Phillips et al., 2016), I employed both online and in-person surveys by visiting on average twice per garden, sent three study invitation reminders plus one reminder sent by the City of Vancouver and Parks Board staff to their contacts, translated the English survey into traditional and simplified Chinese (because of the large Chinese population in the city), and offered a chance to win a $50 gift certificate to a garden supply store or supermarket. Nevertheless, the survey results may not be inferential due to the non-probability sampling.

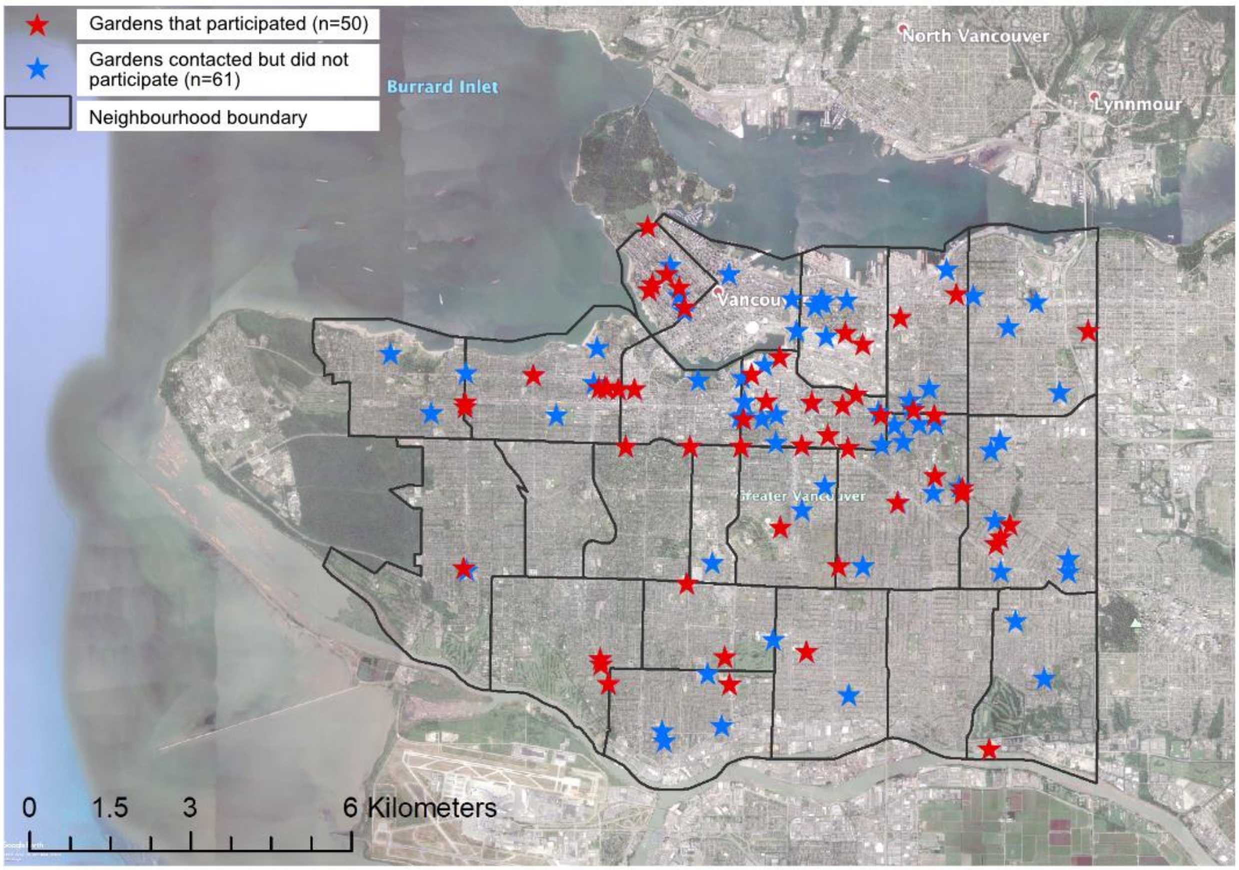


Figure 3.1 A map of participating gardens and non-participating gardens in Vancouver, Canada

3.2.3 ES variables

I selected a total of three provisioning and eight cultural ES that are found to be relevant to gardeners in Vancouver (Table 3.2) based on the past surveys that identified gardeners' motivations and perceived benefits (e.g., Bwika, 2011; Lowcock, 2014; Seto, 2011), relevant local policies (e.g., Local Food Action Plan, 2013; Vancouver Food

Strategy, 2013) and a local health survey (https://www.myhealthmycommunity.org). I also engaged in informal conversations with gardeners and staff of both the City of Vancouver and the Vancouver Board of Parks and Recreation.

The Millennium Ecosystem Assessment (MEA, 2005) categorized food-related services as provisioning ES and culture-related services such as recreation, education, and spirituality as cultural ES. I followed the MEA's categorization of food and cultural ES because many previous quantitative assessments of ES in community gardens and urban green space adopted the MEA's categorization, and using this categorization would allow for results that can be easily compared to the patterns of trade-offs and synergies that are found in other studies that use the MEA categorization and concept of ES. Keeping this limitation in mind, the cultural ES that I studied in this and following chapters should be understood as "ecosystems' contribution to the nonmaterial benefits (e.g., capabilities and experiences) that arise from human-ecosystem relationships" (Chan et al. 2011, p. 206).

Different values toward nature exist, including intrinsic, relational and instrumental (Lliso et al., 2022). Nature's Contributions to People (NCP) refer to "all the contributions, both positive and negative, of living nature (diversity of organisms, ecosystems, and their associated ecological and evolutionary processes) to people's quality of life (Díaz et al., 2018, p. 270). NPs is an umbrella concept intended to embody different values and highlight the role of culture in the production of ES (Díaz et al., 2018). The practice of growing food may be deeply rooted in cultural identities and people's values toward nature and may not always be just about material benefits. Through the lens of NCP, culture is not isolated to one category but rather permeates across different NCP and influences both material and non-material contributions of nature to people. Many cultural ES in the MEA framework are referred to as non-material NCP—"nature's effects on subjective or psychological aspects underpinning people's quality of life, both individually and collectively" (Díaz et al., 2018, p. 271). This approach may be more appropriate for understanding ES in the context of community gardening. Yet, unpacking how different values or worldviews influence different NCP and perceived trade-offs and synergies alone deserves in-depth analysis of the different ways of quantifying and interpreting, which is out of the scope of my research.

Table 3.2 Summary of indicators for the perceived supply of ES assessed in this study, including variables, units, and related references. A detailed description of the variables and relevant literature is included in Appendix B.4. The 4-point Likert scale categories used in the survey were "strongly disagree", "somewhat disagree", "somewhat agree", and "strongly agree" except for the sense of belonging variable scale which were "very weak", "somewhat weak", "somewhat strong", and "very strong."

ES category	ES indicator	Variable	Unit	Reference
Provisioning	Perceived importance of community garden as food source	Level of agreement with: "My community garden is an important source for food to myself or my family."	4-point Likert scale	Camps-Calvet et al. (2016)
	Variety of garden crops	Number of different garden crops that were harvested over the past seven days	# of plants harvested (0-7)	Algert et al. (2014)
	Subsistence level of garden crops	Sum of: estimated percentage of the amount of each garden crop that came from the garden to the total amount of each crop consumed by the household over the past seven days	% (0 – 700)	Jones et al. (2014)
Cultural	Social cohesion (Garden acquaintances)	Number of fellow gardeners that participants know by both name and their contact information (garden acquaintances)	# of persons	Veen et al. (2015)

		Number of fellow gardeners that participants can ask for help outside their community garden (reciprocity)	# of persons	
	Place attachment	Level of agreement with: “I feel like the community garden is part of me.”	4-point Likert scale	Vaske and Korbin (2001)
	Sense of belonging	Level of agreement with: “How would you describe your sense of belonging to your garden community?”	4-point Likert scale	My Health My Community (2014)
	Learning	Number of topics learnt through community gardening (from a pre-defined list of learning topics, with an option to report additional topics)	# of learning topics (0-7)	Colding and Barthel (2013)
		Perceived importance of community garden as a learning source. Level of agreement with: “My community garden is an important source for me to acquire knowledge and skills.”	4-point Likert scale	Camps-Calvet et al. (2016)
	Aesthetics	Level of agreement with: “My community garden is beautiful and aesthetically pleasing.”	4-point Likert scale	Bwika (2011)
	Connectedness to nature	Level of agreement with: “When I spend time in my community garden, I feel a deep feeling of love toward nature.”	4-point Likert scale	Kals et al. 1999; Mayer and Frantz 2004

In doing surveys, the best practice is to use multiple items to measure a latent, multi-dimensional psychological concept such as connection to nature or place attachment. My survey questionnaire has different sets of questions about community gardens, to gauge gardeners' perceptions of 11 different services, their gardening practices, as well as of socio-economic characteristics. When the initial survey questionnaire, which had multiple items for ES concepts, was presented to gardeners at a community garden networking meeting and in personal meetings, gardeners expressed concern that the survey questionnaire was too long and some questions were repetitive, and that many busy gardeners would not be able to complete the survey. As an exploratory study, I decided it would be best to include a good number of ES that are valued by gardeners and to involve as many gardeners as possible in the study. I thus used single items to measure connectedness to nature and place attachment in the final survey questionnaire. For place attachment, Vaske and Kobrin (2001) operationalized place attachment using two concepts: (a) place dependence (i.e., a functional attachment) and (b) place identity (i.e., an emotional attachment). I adapted one of the items of the place identity scale used by Vaske and Kobrin because its factor loading was the greatest among all place identity items studied, and gardeners did not oppose the wording of the adapted question about place attachment during the meeting with gardeners. However, this approach is less reliable and rigorous than the use of the multi-item scales, which presents limitations to interpret and conclude gardener's experience of place attachment and connectedness to nature.

3.2.4 Social characteristics of gardens

To investigate the social characteristics of the 50 gardens, I interviewed 26 garden representatives (e.g., coordinators, board members, chairs or presidents, managers) in person, six representatives via email, and four representatives by phone, who together spoke for a total of 42 gardens, from June 2019 to October 2019. The in-person and phone interviews were audio-recorded and fully transcribed, except for one which was recorded by note-taking; the average length of the interviews was 38.5 minutes. For the eight gardens whose representatives did not respond to our interview invitation, I collected as much data as possible through garden visits, analysis of survey responses and websites when available. Interviews and data collection followed the Ethics Protocol (No. H19-01480) approved by the Research Ethics Board of the University of British Columbia (consistent with Canada's Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans).

During the interviews, I asked about garden characteristics such as the number of individual plots, existence of communal space for growing food and of fruit trees, and whether there were mandatory volunteer hours or work parties (Figure 3.2). I later categorised gardens into three management types: individual (all plots assigned to individual gardeners with no communal growing space), collective (entire garden is communally managed), or mixed (combination of individual plots and communal space) (Drake and Lawson, 2015). See Appendix B.5 for the interview questions and consent form for interviewees.

Figure 3.2 Photos of the participating gardens and food forests in Vancouver, Canada

3.2.5 Biophysical characteristics of the gardens

I assessed the biophysical characteristics of the 50 gardens, including physical surface area, tree canopy cover and different land uses. My research assistant and I brought printed orthophotos of the gardens (resolution of 7.5 cm, taken from April to July 2015; https://opendata.vancouver.ca/explore/dataset/orthophoto-imagery-2015/information/) with us during our garden visits in 2019, and we compared the orthophotos against our observations and conversations with interview participants by taking field notes. Then, we mapped land uses in all gardens—individual plot areas, communal spaces for growing food, infrastructure, trails and recreational areas—by manually digitizing the orthophotos in ArcGIS (Figure 3.3). We asked gardeners during the site visits and interviews to confirm the land uses in the gardens. In addition, we mapped the tree canopy cover of each garden by digitizing the orthophotos and calculated the proportion of the tree canopy that covered the total surface area of each garden. I then compared the delineated canopy cover area (based on the orthophotos in 2015) against the tree canopy cover as measured during our garden visits in 2019 by following the i-Tree Eco Field Manual (USDA, 2017). Tree canopy covers of the sites from the orthophotos and field measurements were highly correlated (Pearson's correlation coefficient=0.97, $p < 0.01$).

Garden surface area, average plot size, communal space (%), and canopy cover were included in the analysis of gardens and gardener characteristics associated with ES. I chose tree canopy cover as one of the important garden factors to examine, as trees were perceived as a limiting factor for vegetable production but also provided shade for gardeners during the hot day time, and were perceived to improve aesthetics of garden spaces in other studies (Kurtz, 2001; Speak et al., 2015). Moreover, garden surface area or size of plot area was positively associated with area for growing food, which was used as a proxy for provisioning ES of community gardens (Speak et al., 2015; Dennis and James, 2016a). Past studies (e.g., Kurtz, 2001; Langemeyer et al., 2018) suggested that garden surface area in combination with management type was associated with a certain set of food and cultural ES (as discussed in Chapter 1 and introduction in Chapter 3). In addition, Speak et al., (2015) used communal space where gardeners could interact with another as a proxy for cultural ES such as social cohesion. In this chapter, instead of using land uses (e.g., recreation area, plots) as a proxy for provision and cultural ES, I asked gardeners about their perception and experience of food and cultural ES through the survey in order to identify associations between perceived supply of ES and biophysical and social characteristics of gardens.

Figure 3.3 Land use mapping of four gardens and food forests in Vancouver, Canada

3.2.6 Analyses of ES associations

To understand the general patterns of ES associations, I performed Kendall *Tau-b* correlation tests between all pairs of the eleven ES variables using the *cor.test* function, and created heatmaps using the corrplot package in R (version 1.4.1103). I tested the robustness of the Kendall results by comparing them to Spearman correlations tests; results were similar thus I chose Kendall as more appropriate for small samples with large numbers of ties (Bishara and Hittner, 2015; Petrovic et al., 2019).

To examine the interactions between ES in greater depth, I fitted generalized mixed-effects regression models using the package glmmTMB v. 1.0.2.1 (Magnusson et al., 2020) in R. To avoid multi-collinearity among ES, I used Kendall Tau-b correlation coefficients to select 7 of the 11 ES that were uncorrelated and conceptually different. I recoded the 4-point Likert scale to binary categories (disagree vs agree) and excluded surveys with missing values and gardens with <3 surveys, which left a sample of 258 cases. Next, I fitted a full model for each ES as a response variable with the six other ES as fixed-effect variables and gardens as a random effect variable. I performed backward stepwise model selections, using the *stepAIC* function from the package

MASS v. 7.3-53.1 (Ripley et al., 2021) and selected two models with the lowest Akaike information criterion (AIC) and Bayesian information criterion (BIC). Then I selected a best-fit model for each ES, using the likelihood-ratio test. Finally, I tested for overall uniformity of and dispersion of the residuals by using the simulateResiduals function in the package DHARMa v.0.3.3 (Hartig, 2020).

To assess the associations between garden/gardener characteristics and ES, I ran generalized mixed-effects regression models for each ES with all explanatory variables—the biophysical and social garden characteristics, sociodemographic characteristics of gardeners, and gardening practices. The biophysical and social garden characteristics studied were management type, tree canopy cover, garden surface area, average plot size, communal space area (%), and existence of mandatory volunteer hours or work parties. Sociodemographic characteristics of gardeners were income, ethnicity, and age. Gardening practice characteristics of gardeners studied were volunteer hours and membership year of individual gardeners. I chose the best-fit models by following the previous backward stepwise elimination and identified factors associated with ES that were statistically significant ($p < 0.05$). I kept outliers after confirming that results with and without outliers were similar. Finally, following Bennett et al. (2009), I categorized the ES associations as positive or negative and unidirectional or bidirectional. For example, when the association was bidirectional, both services were associated with another (Figures 3.4.5, 3.4.6.) A unidirectional association indicates an one-directional association (e.g., Figures 3.4.3, 3.4.4). Associations among ES could be trade-offs (arrow in grey), synergies (arrow in black), or no-effect relationships (no arrow). The associations between garden or gardener factors and perceived ES were categorized as positive or negative, and as “independent” (i.e., factors associated with one ES in the ES pair) or “shared” (i.e., factors with both ES in the ES pair). Only statistically significant associations (p <0.05) were interpreted in the following sections.

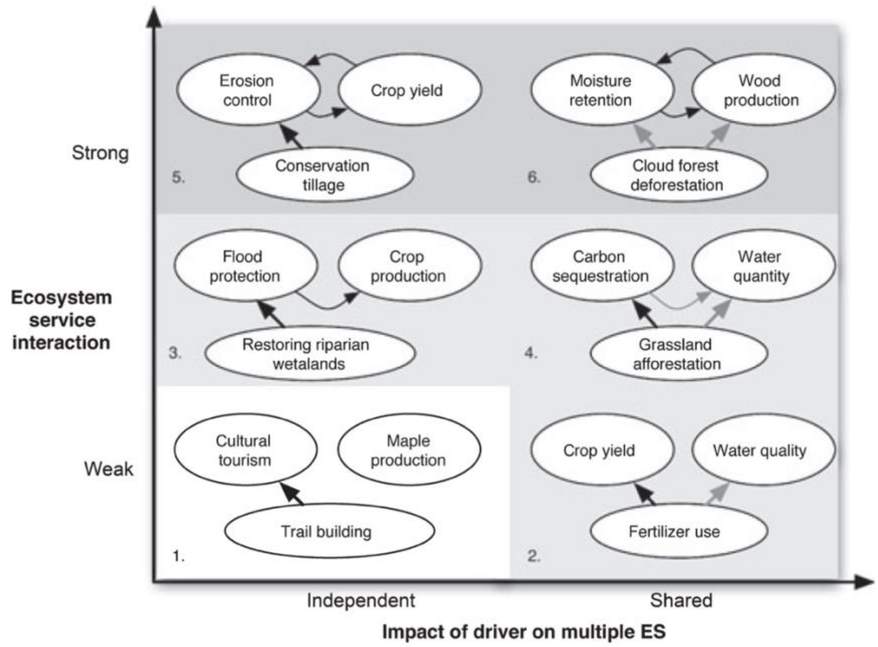


Figure 3.4 Categorization of types of associations between ES and between drivers and ES suggested by Bennett et al. (2009)

3.3 Results

3.3.1 Characteristics of gardeners, gardening practices, and gardens

The majority of the survey participants were well-educated, middle-aged, Caucasian, female and held Canadian citizenship. Household income levels varied (Table 3.3). On average, most participants had been garden members for 5.3 years (range= 0-41), spent 4.4 hours/week in their garden, and volunteered for their garden 5.8 hours/month. Motivations for community gardening varied and included: enjoying nature (34.9%); learning (15 %); growing organic, fresh food, herbs or flowers (13.3%); reducing grocery budgets (10.2%); meeting neighbors (7.9%); and others (e.g., contribution to sustainability). Participating gardens, on average, were 0.16 ha, with 47.6 individual plots each measuring 6.2 m^2. Mean tree canopy was 29.5% but highly variable (0-64.3 %). The majority of the gardens had mixed management, mandatory volunteer hours or participation in work parties, and were planted with fruit trees (see Appendix B.6).

Table 3.3 Socio-economic characteristics of survey participants. Only some (*) of the socio-economic characteristics —age, household income, and ethnicity — were included in the analysis to identify factors associated with ES.

Category	Frequency	%
Total participants	342	
Gender		
Female	240	70.2%
Male	86	25.1%
Prefer not to answer	9	2.6%
NA	7	2.0%
***Age** (median =49, mean =49.6, SD=14.1, range=22–- 82)		
18-39	106	31.0%
40-64	160	46.8%
65	66	19.3%
NA	10	2.9%
Education		
Below high school	3	0.9%
High school	20	5.9%
Certificate or diploma	67	19.6%
Bachelor's or higher	251	73.4%
NA	1	0.3%
***Household income**		
under $40,000	71	20.8%
$40,000 to $79,999	109	31.9%
$80,000 to $119,999	74	21.6%
$120,000 and above	55	16.1%
NA	33	9.6%
Immigration		
Canadian citizen	298	87.1%
Permanent resident	29	8.5%
Work or study permit	10	2.9%
Prefer not to answer	2	0.6%
NA	3	0.9%
***Ethnicity** (multiple choices)		
Aboriginal	8	2.2%
Caucasian	244	68.3%
Others (e.g., Chinese, Japanese, Hispanic, etc.)	92	25.8%
NA	13	3.6%
Food security		
We always had enough of the kinds of food we wanted to eat.	298	87.1%
We had enough to eat, but not always the kind of food we wanted.	42	12.3%
Sometimes or often, we did not have enough to eat.	1	0.3%

NA	1	0.3%
Sense of belonging		
Very weak	15	4.4%
Somewhat weak	76	22.2%
Somewhat strong	175	51.2%
Very strong	73	21.3%
NA	3	0.9%

3.3.2 Gardeners perceived multiple ES

Most respondents reported multiple ES through community gardening in Vancouver (Table 3.4). Seventy-three percent said their gardens were an important source of food. Gardeners harvested on average 4.7 different crops (e.g., broccoli, kale, tomatoes, beets) over the seven-day survey period, accounting for 48.5% of the total household consumption of those crops. Almost all gardeners said their gardens are aesthetically beautiful and felt a deep connection to nature in their gardens. Over 88% of the respondents felt place attachment and said that their gardens were an importance source for learning topics such as gardening, local ecological conditions, social organization and participation, cultural food and practices, and local politics and social issues. Gardeners knew on average 7.7 fellow garden members (See Appendix B.7 for a visual representation of Table 3.4).

Table 3.4 Summary of ES reported by the survey participants

ES variables (Number of responses)	Strongly agree (%)	Somewhat agree (%)	Somewhat disagree (%)	Strongly disagree (%)	Mean (S.D.), range
Perceived importance level as a food source (n=341)	35.1	37.7	14.6	11.1	
Subsistence level of garden crops (%) (n=286)					339.4 (±202), 0-700
Variety of garden crops (n=312)					4.7 (±2.1),0-7
Reciprocity (n=325)					2.8 (±3.9),0-30

Garden acquaintances (n=330)					7.7 (±7.5), 0-80
Sense of belonging (n=340)	25.4	50	20.5	3.5	
Perceived importance as a learning source (n=342)	48.8	40.1	6.7	4.4	
Variety of learning topics (n=342)					3.1 (±1.6), 0-7
Aesthetic (n=342)	75.1	21.1	2.3	1.5	
Connectedness to nature (n=341)	67.5	28.4	1.5	2.3	
Place attachment (n=341)	47.7	41.8	6.1	4.1	

3.3.3 Most provisioning and cultural ES were positively correlated

Both Kendall *Tau-b* correlation tests and mixed-effect regression analyses showed dominant positive associations between and among ES. Out of 55 pairwise correlations between all pairs of the eleven ES tested by Kendall *Tau-b*, all of the 44 correlations that were statistically significant ($p < 0.05$) were positive (see blue cells in Figure 3.5). This was the case both among food-related ES, among cultural ES and between food-related and cultural ES. Mixed-effect regression analyses, which estimated associations among the seven selected ES, yielded similar results. Out of eleven associations that were statistically significant ($p < 0.05$), ten were positive (see Appendix B.8 for the detailed results from the regression analyses among the seven ES). Most positive and bidirectional associations were found among cultural ES in addition to one positive, bidirectional association between the social cohesion variable (i.e., number of garden acquaintances) and the subsistence level of garden crops. The only trade-off that we found was between the aesthetics and the subsistence level of garden crops.

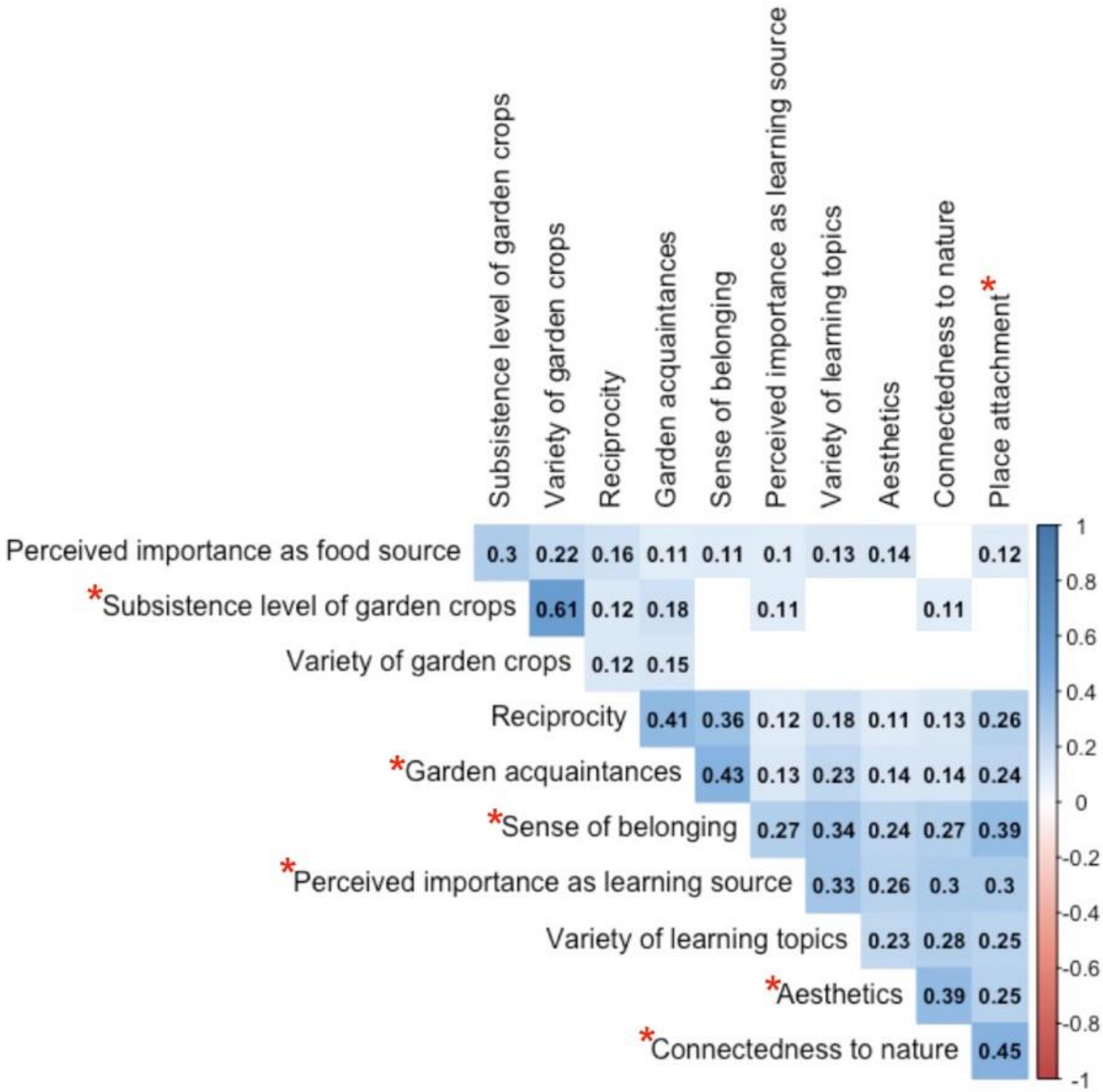


Figure 3.5 A heatmap of Kendall Tau-b correlation coefficients for all pairs of the eleven ES variables. Blue cells indicate synergies (positive correlations); red cells (of which there are none) would indicate trade-offs (negative correlations). A blank cell infers statistical insignificance (*p*>0.05). Out of 55 pairwise correlations tested, 44 correlations (i.e., 80%) were statistically significant (*p*<0.05), and all of them were positive. *ES variables were included in subsequent regression analysis.

3.3.4 Three variables explain synergies among ES

Three key variables—tree canopy cover, volunteer hours and mixed management (Figure 3.6)— explained the synergies between ES. Higher tree canopy cover was associated with place attachment and higher aesthetic value of gardens (Figure 3.6.c). Volunteer hours was positively associated with place attachment (Figure 3.6.d), sense of belonging (Figure 3.6.e) and the number of garden acquaintances. Mixed management was associated with a higher number of both garden acquaintances and subsistence level of garden crops, whereas individual management had fewer acquaintances and collective management had lower subsistence levels (Figure 3.6.f, 3.6.g, 3.6.h). Interestingly, the size of a community garden and of its individual plots were not significant factors for any ES (Table 3.5).

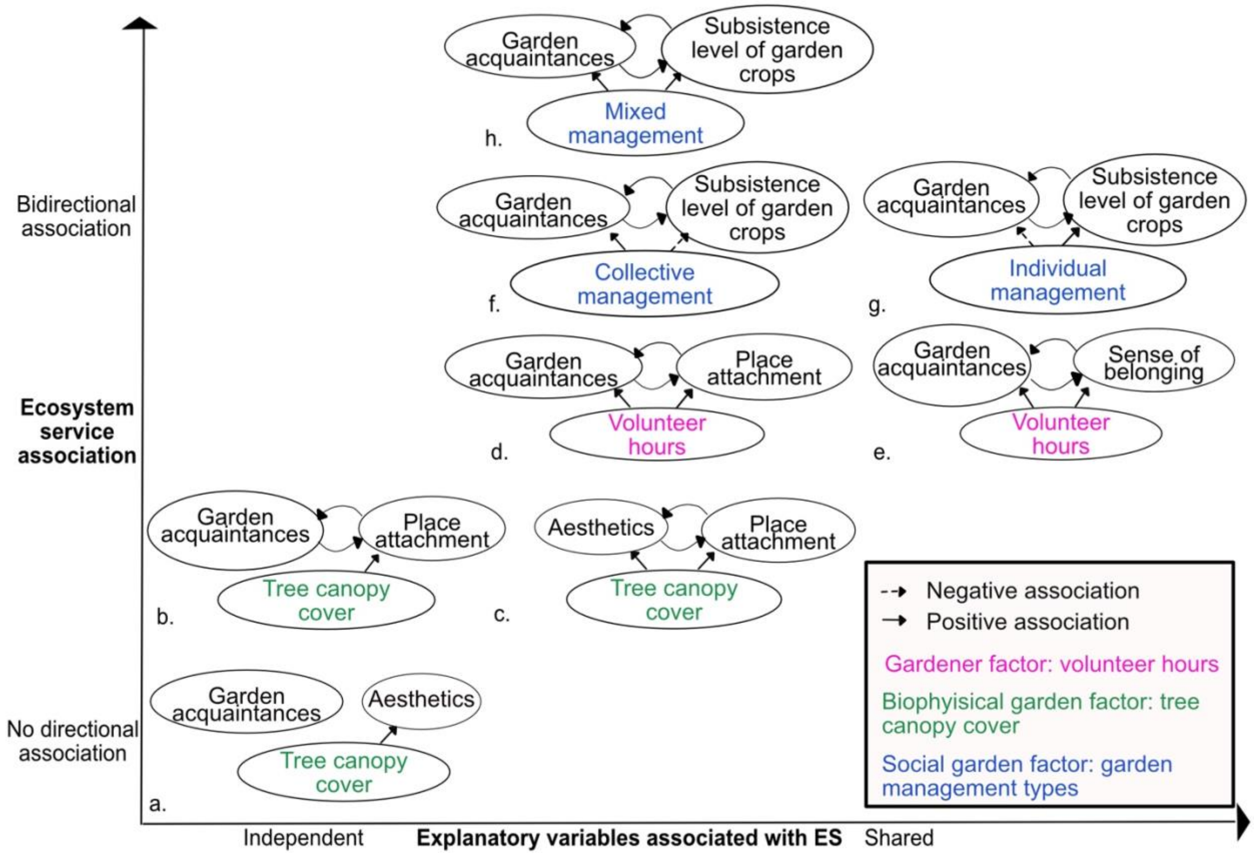


Figure 3.6 Associations among garden and gardener factors and ES, as found in community gardens in Vancouver (diagram adapted from Bennett et al., 2009). The gardener factor is colour-coded in pink. Garden factors are colour-coded in green (biophysical) and blue (social). A dashed arrow infers to a negative

association and a black arrow infers to a positive association. ES associations in this figure are either bidirectional (i.e., two ES are associated with another) or non-directional (i.e., two ES are not associated). Garden (i.e., tree canopy cover, management types) or gardener (i.e., volunteer hours) factors are either associated with one service in each pair (i.e., “independent” factor) or with both ES in each pair (i.e., “shared” factor).

All associations shown in Figure 3.6 were statistically significant. In (a), the number of garden acquaintances and the aesthetics had no positive or negative association (See Appendix B.8 for the regression analysis results). Also, tree canopy cover was positively associated with the aesthetics but had no association with garden acquaintances (See Table 3.5). In other words, the number of garden acquaintances and the aesthetics did not have a statistically significant association and tree canopy percent was positively associated with aesthetics only. In (b), there was a bidirectional association between ES and an independent factor of one ES, showing that the number of garden acquaintances and sense of place attachment had a positive bidirectional association, and tree canopy percent was positively associated with place attachment only. Figures from (c) to (h) show the cases in which ES had bidirectional associations and a shared factor for both ES. In (c), for example, the aesthetics and place attachment had a positive, bidirectional association, and tree canopy percent was positively associated with both ES.

Table 3.5 Summary of response (ES) and explanatory (garden and gardener factors) variables used in the stepwise mixed-effected regression analysis

<table>
<tr><th>Response variable</th><th>Explanatory variable</th><th>Marginal R-squared</th><th>Estimate</th><th>Std. Error</th><th>z value</th><th>Pr(>|z|)</th><th>Model distribution</th></tr>
<tr><td rowspan="2">Aesthetics</td><td>Intercept</td><td rowspan="2">0.35</td><td>2.10</td><td>0.49</td><td>4.26</td><td>0.00</td><td rowspan="2">Binomial</td></tr>
<tr><td>Tree canopy percent</td><td>0.09</td><td>0.04</td><td>2.10</td><td>0.04</td></tr>
<tr><td></td><td>Intercept</td><td>0.21</td><td>2.25</td><td>0.48</td><td>4.71</td><td>0.00</td><td>Binomial</td></tr>
</table>

Connectedness to nature	Tree canopy percent		6.64	3.68	1.80	0.07	
Number of garden acquaintances	Intercept	0.38	0.25	0.30	0.85	0.40	Negative binomial distribution
	Membership year		0.06	0.01	4.65	0.00	
	Volunteer hours		0.03	0.01	2.54	0.01	
	Age		0.01	0.00	1.71	0.09	
	Identity (Others)		-0.22	0.12	-1.77	0.08	
	Identity (Aboriginal)		-0.40	0.41	-0.99	0.32	
	Tree canopy percent		0.92	0.65	1.40	0.16	
	Mean plot size		-0.01	0.01	-1.41	0.16	
	Collective management		1.84	0.44	4.22	0.00	
	Mixed management		1.74	0.35	5.01	0.00	
	Communal space percent		-1.02	0.55	-1.85	0.06	
	Garden size		0.00	0.00	0.86	0.39	
	Existence of mandatory work party or volunteer hours		-0.60	0.29	-2.07	0.04	
Perceived importance as a learning source	Intercept	NA	2.01	0.23	8.73	0.00	Binomial
	None		NA	NA	NA	NA	
Place attachment	Intercept	0.39	0.80	0.39	2.08	0.04	Binomial
	Volunteer hours		0.19	0.09	2.13	0.03	

	Tree canopy percent		0.05	0.02	2.14	0.03	
Sense of belonging	Intercept	0.49	0.31	0.24	1.26	0.21	Binomial
	Volunteer hours		0.28	0.07	3.81	0.00	
Subsistence level of garden crops	Intercept	0.05	1.76	0.50	3.51	0.00	Gaussian
	Individual management		1.37	0.67	2.05	0.04	
	Mixed management		1.71	0.52	3.29	0.00	

3.3.5 Management type moderated social cohesion and food production

Participants from gardens with mixed management reported a higher subsistence level of garden crops than participants from collectively managed gardens. Participants from gardens with mixed management reported a higher number of garden acquaintances compared to participants from individually managed gardens. Nevertheless, only 5% of the variance in the subsistence level was explained by the best-fit model, which indicates the minimal explanatory power of garden management. In addition, the number of garden acquaintances was associated with other factors such as volunteer hours, the number of membership years, gardener’s age, and the existence of mandatory work parties or volunteer hours (Table 3.5).

3.3.6 Both garden and gardening characteristics explained place attachment

Place attachment was positively associated with tree canopy cover and volunteer hours (Table 3.5). Place attachment also had bidirectional, positive associations with two other ES—the number of garden acquaintances and the aesthetics. The number of garden acquaintances was associated with explanatory variables such as management type and gardening practices (e.g., membership year, volunteer hours), while aesthetics was associated with tree canopy cover. These results showed that an interplay among the biophysical characteristics, social characteristics, and gardening practices was likely to play a role in people's experience of place attachment.

3.4 Discussion

3.4.1 Gardens are small, multifunctional green spaces

This chapter demonstrates that urban food production systems such as community gardens and food forests can be multifunctional, providing important food sources, as well as encouraging informal social networking, social support or learning and adding to the aesthetics of neighborhoods. They also provide city dwellers with an opportunity to feel connected to nature. More importantly, these ES tend to synergise rather than trade-off with one another, particularly among cultural ES. These findings are in line with previous research that found that community gardens play an important role as multifunctional green spaces that provide access to nature in compact cities (Bonow and Normark, 2018; Pourias et al., 2016) and reinforce social relationships, using food production by bringing together diverse groups of people, stimulating shared learning experience for gardening, culinary and cultural knowledge, creating stronger bonds within the garden community (Semeraro et al., 2021).

My study results suggest that some gardeners could benefit from both food production and social cohesion through community gardening, in contrast to other studies that indicate general trade-offs between these two values in community gardens and allotment gardens (Kurtz, 2001; Langemeyer et al., 2018). This finding may be explained by the fact that my study participants are predominantly from mixed-management gardens. Mixed management provides gardeners with both individual plots for growing their own food, which motivates regular garden visits to attend to their plot (e.g., watering), and communal space in which gardeners can interact with one another, and grow and share additional crops (Veen et al., 2015). Other factors that I did not examine may also play a role, such as gardening experiences (Lee and Matarrita-Cascante, 2019), length of the membership year (Veen et al., 2015), motivations (da Silva et al., 2016), garden bed design and soil management practices

(Gregory et al., 2016), land tenure (Albrecht and Wiek, 2021), and vandalism or theft (Egerer and Fairbairn, 2018; Hou and Grohmann, 2018).

This chapter also shows that the size of gardens may not be as critical a factor for both food and cultural ES as other studies have suggested (Kurtz, 2001; Langemeyer et al., 2018). Instead, factors such as the proportion of tree canopy cover, management type and volunteer hours may play a more important role in enabling multifunctionality in Vancouver. Fortunately, these factors can be more easily manipulated in established gardens than changing the physical garden size or planting an overly-large green space for food production at the cost of other infrastructure in highly urbanized areas with limited space.

It is important to note that most of my study participants shared similar socio-demographic characteristics in terms of gender (primarily women), education level (bachelor or higher), and ethnicity (Caucasian), although income levels were more variable. It would thus be appropriate to interpret the findings in that light. My participants' sociodemographic characteristics were very similar to those of past survey participants from community gardens in Vancouver, who were also female, Caucasian, Canadian-born and had high educational background (Seto, 2011). Such socio-demographic description of the survey participants was somewhat different from the descriptions of dominant community garden users in Barcelona and New York, who were characterized as elderly, low-middle income, or immigrant (e.g., Camps-Calvet et al., 2016; Gregory et al., 2016). Policy makers, green space managers, and involved organizations in Vancouver would need to examine whether urban food production systems like community gardens are benefiting people who are food-insecure, or new immigrants, or with fewer opportunities to regularly connect with nature (Lowcock, 2014; Wong and Hallsworth, 2016).

My survey participants may not represent the overall socio-economic characteristics of community garden users in Vancouver. Moreover, this study was not able to identify how gardeners with different socio-demographic backgrounds experience ES trade-offs and synergies differently. Statistically, the study results cannot be used to infer the perceptions or experiences of the whole population of community gardeners in Vancouver due to my non-random sampling method and lack of full information on the community gardeners in the city.

3.4.2 Nature and people co-create multifunctionality

Place attachment are the emotional and functional bonds that a person develops with a particular physical and social setting (Gross and Brown, 2008). Amongst the cultural ES studied, the positive associations between place attachment and two other cultural ES—aesthetics and social cohesion—paint a picture of how the environmental space and people's practices within it co-create multiple ES in urban food production systems. For example, trees enhance the aesthetic value of green spaces, filter noise and provide shade during the summer, motivating people to visit, linger and connect to nature (Rostami et al., 2015). In particular, fruit trees planted in a communal space can enhance the beauty with colourful fruits and flowers while providing fruit that people can share (Colinas et al., 2019; Speak et al., 2022). At the same time, a communal space where gardeners collectively contribute to maintenance encourages informal social networks and support through interactions with other people (Langemeyer et al., 2018). Such combination of beautiful, treed spaces to connect with nature, fruits and other tree crops to grow and share, and interactions with other people through regular maintenance or informal social events could together help to build place attachment to the gardens (Walhowe, 2022). This interpretation is aligned with that when intentionally designed, urban green spaces can influence how people interact with nature and with other people, and that trees are an important design element in urban green spaces to bring people together ('O'Rourke and Baldwin, 2016). Therefore, community gardens provide space for urban residents to reconnect with nature that they aspire to (re)create in a social environment through social interaction and collaboration (Semeraro et al., 2021; Walhowe, 2022).

This study followed the MEA categorization and did not consider connectedness to nature and place attachment as relational values. Gardener's sense of love for nature should not be interpreted? as a pure product of gardens (Jax et al., 2018). The concept of connectedness to nature is used for understanding "how individuals personally identify with the natural environment and the relationships they form with nature" (Sato et al., 2021, p. 1). Most community gardeners who participated in my study reported a sense of love toward nature when they are in community gardens. Such a sense of love may well be an antecedent to participating in the first place, and community gardens may provide a place for people to express or take an action on their relational values toward nature in the urban environment. My study did not examine how their motivations changed before and after community gardening, and therefore it is unknown whether and how community gardens have influenced people's values toward nature and their relationships with nature, for example instrumental values being changed to non-instrumental, reciprocal values or "practice of care" (Jax et al., 2018, p.23). Instead, my study results show diverse motivations for community gardening in Vancouver including enjoying nature, which was most frequently mentioned by gardeners, and other motivations such as learning, growing healthy food, reducing grocery budgets, and even contributing to sustainability. Moreover, many gardeners related with multiple motivations. These diverse motivations indicate that a range of values toward nature exist in community gardens and might be reflected in the multiple benefits that I observed through this study.

In community gardens, the importance of social and natural functions cannot be separated from their multifunctionality (Prados and Ramos, 2020). This chapter illustrates examples of urban green spaces where cultural ES are "co-produced and co-created outcomes of peoples' interaction with ecosystems" rather than "products of nature" (Fish et al., 2016, p. 209). Cultural ES, and in particular connectedness to nature and place attachment, should be understood in the context of the environmental spaces and cultural practices that arise from human-nature relationships (Chan et al., 2012; Díaz, 2018; Fish et al., 2016). While there is room for the MEA framework in policy and scientific discourse for community gardens and urban green spaces such as an assessment of demand and supply of certain ES (e.g. Kroll et al., 2012), future ES researchers should make efforts to embody different human-nature relationships beyond utilitarian values and explore different ways of understanding and assessing nature’s contributions to people, in particular non-material contributions, through relational values (Chan et al., 2011; Chan et al., 2018; Dickinson and Hobbs, 2017; Ono et al., 2021).

3.4.3 Practical considerations for planting trees and adopting mixed management

Although high tree canopy cover and mixed management may facilitate multifunctional gardens, there are caveats to consider. Trees, especially large trees, can be difficult to maintain for gardeners with limited resources and equipment and require expertise that may not be readily available. Also for trees to start bearing fruit or to grow large enough to provide shades or other ES, gardens require larger space than gardens without trees. While garden size was not a significant factor for achieving food and cultural services, gardens that participated in my study were larger than the average size of all gardens that I contacted in Vancouver.

For social factors such as volunteer hours and mixed management to successfully be implemented, garden coordinators and management teams require skills, capacity, and time to recruit and coordinate volunteers and activities, and to manage both individual plots and communal space. Not all garden users and volunteers have time to contribute to the maintenance of the overall site. In fact, case studies show that encouraging people to work together and interact with another is one of the important benefits of community gardens and at the same time keeping people involved in communal work is one of the biggest challenges for community projects (Bonow and Normark, 2018; Drake and Lawson, 2015). As a result, a careful assessment of garden’s capacity as well as of gardener’s motivations will be needed in order to determine which type of management will be appropriate to the community and extent of resources and time required to successfully implement the design and management of choice (Langemeyer et a., 2018). I suggest that urban planning policies should encourage civic organizations to tailor their design and management to fit micro-scale circumstances and different needs of users (Walhowe, 2022).

Chapter 4: Different multifunctionality of urban food production systems in Vancouver, Canada

4.1 Introduction

Urban food production systems, such as community gardens and food forests, offer an opportunity to enhance multiple ES (Semeraro et al., 2021). These services include not only provisioning ES (e.g., vegetables, fruits) and cultural ES (e.g., social cohesion, connectedness to nature, learning, aesthetic value) as shown in the previous chapter but also regulating ES (e.g., stormwater runoff control, carbon sequestration, provision of shade during hot day time) (e.g., Edmondson et al., 2014; Gittleman et al., 2017; Schafer et al., 2019; Semeraro et al., 2021; Speak et al., 2015). Despite the growing body of evidence on different ES of the urban food systems, current research is lacking a comprehensive assessment of synergies and trade-offs among provisioning, cultural and regulating ES, which is essential for minimizing unwanted ES trade-offs (Pinto et al., 2022). In practice, neither trade-offs nor synergies between food production and other ES are adequately taken into consideration in green space planning (Haase and Wolff, 2022).

A common approach to examining associations of multiple ES is identifying ES bundles (i.e., suites of ES that appear together repeatedly) (Raudsepp-Hearne et al., 2010). To my knowledge, only one study (Langemeyer et al., 2018) has identified the bundles of regulating, cultural and provisioning ES in different types of community gardens, based on gardener surveys. This study in Barcelona, Spain, detected two ES bundles: one with a higher value for place attachment and social cohesion in small, collectively-managed gardens, and the other with a higher value for recreation, biophilia, and food production in large, plot-oriented gardens. These two bundles were associated with different benefits and values in similar social and environmental settings, rather than being analysed as spatial/biophysical bundles of ES that co-vary in their production across landscapes that have been commonly analyzed (Klain et al., 2014). Similar positive associations were observed in gardens in Minneapolis, USA, between food production and opportunities for people to connect to nature on their own terms, and between socializing and sense of community, based on participant observation and interviews with gardeners (Kurtz, 2001). These case studies suggest that people can perceive or experience different sets of ES across community gardens.

Multifunctionality is the capacity of green infrastructure or green space to deliver multiple functions, services and benefits simultaneously. It aims at “combining different functions and services, thus using limited space more effectively” (Hansen and Pauleit, 2014, p.518). To unpack the multifunctionality of urban food production systems, I examined community gardens and food forests in Vancouver to answer two questions:
1) What ecosystem service bundles exist across community gardens and food forests in Vancouver?
2) What biophysical and social factors are associated with the different bundles of ES?
In this chapter I employed ES bundle analysis, which captures the patterns of trade-offs and synergies among provisioning, cultural and regulating ES rather than just between pairs of provisioning and cultural ES as was done in the previous chapter.

In the previous chapter, I discussed limitations of the MAE framework in embodying relational values toward nature and conceptualizing culture and non-material NCP. Although I categorized connectedness to nature and place attachment as cultural ES, this chapter does not claim these values should be understood as “products of nature”. Similar to Langemeyer et al. (2018)’s approach, ES bundles in this chapter are intended for describing baskets of ES that are associated with different values and benefits in similar social and biophysical settings of community gardens in Vancouver. For data collection, I used mixed methods, namely by conducting a cross-sectional survey of gardeners, structured interviews with garden representatives, and i-Tree Eco analysis of trees and land use assessment of the garden sites.

4.2. Material and methods

4.2.1 Study area, Vancouver

Vancouver currently has 2,065 hectares (ha) of canopy cover which is estimated to sequester 24,000 metric tonnes of CO_2 and remove 186 metric tonnes of air pollutants each year (City of Vancouver, 2018). The 111 community gardens contacted for Chapters 3 and 4 cover an approximate area of 10.6 ha. Detailed description of the city and community gardens are included in Chapters 2 and 3.

4.2.2 Data collection: Cross-sectional survey, structured-interviews, land use mapping, and tree inventory

Surveying is a common method for collecting people's perceptions or experience of ES and motivations for community gardening. In surveying, the unit of analysis can be the individual, group, organization, community, or multiple of these, as long as the unit(s) chosen is clearly defined and appropriate for the research questions and hypotheses (Pinsonneault and Kraemer, 1993). Varied units of data collection and of data analysis are used in community garden surveys. For example, the individual gardener can be a unit of both data collection and analysis. Some studies have examined the relationships between perceived ES and benefits and socio-economic status of gardeners by using the individual gardener as a unit of data collection and of analysis (e.g., Camps-Calvet et al., 2016; van den Berg et al., 2010). Another approach is for the individual gardener to be a unit of data collection with garden as the unit of analysis. In this case, individual responses may be cautiously averaged or aggregated for each garden for subsequent statistical analysis (Pinsonneault and Kraemer, 1993). Langemeyer et al. (2017) analysed associations among multiple ES at a garden level by collecting the values of ES in a Liker-scale ranking reported by individual gardeners through participant surveys and averaging the ranking values collected from the gardeners for each garden. Egerer et al. (2018) investigated relationships between well-being benefits of gardens and the neighbourhood's social and biophysical conditions by counting the number of benefits mentioned by each gardener and aggregating the counts of all gardeners sampled from each garden. Other studies used a different method for data collection. For example, Dennis and James (2016a, 2016b) assessed biophysical characteristics of different small green spaces including community and allotment gardens and orchards as well as total volunteer hours and a total number of social events of each site to estimate provision of ES and trade-offs. In this case, individual gardens are the unit of data collection and of data analysis.

For this chapter I investigated the patterns of trade-offs and synergies among a total of ten ES—one provisioning, six cultural, and three regulating— and four biophysical and social characteristics in 31 community gardens and food forests (hereafter gardens) in Vancouver (Table 4.1). For provisioning and cultural ES, I used the gardener survey data as the unit of data collection, and then aggregated the survey responses by garden. A detailed description of the survey method is provided in Chapter 3. As discussed in the previous chapter, a main limitation with this method is that these participants were not selected randomly and the number of garden responses per garden is small, and thus experiences and perceptions should not be interpreted as full characterizations of the gardens or the supply of ES by gardens. In addition, as ES values are aggregated from individual gardeners' perceptions or experience of ES, ES bundles should be interpreted as baskets of ES linked to perceived benefits and values that are "person-specific and shaped by social and environmental contexts" (Klain et al., 2014, p. 317).

Table 4. 1 Summary of eleven ES variables assessed in this study, including variables, units, and related references (modified from Chapter 3). A detailed description of the provisioning and cultural ES variables and relevant literature is included in Chapter 3 and Appendix B.3.

ES category	ES indicator	Variable	Unit	Reference
Provisioning	Subsistence level of garden crops	Sum of estimated percentage of each crop consumed by the household over the past	% (0 – 700)	Jones et al. (2014)

		seven days that came from the garden		
Cultural	Social cohesion (garden acquaintances)	Number of fellow gardeners that participants know by both name and their contact information	# of people	Veen et al. (2015)
	Place attachment	Level of agreement with: "I feel like the community garden is part of me."	4-point Likert scale	Vaske and Korbin (2001)
	Sense of belonging	Level of agreement with: "How would you describe your sense of belonging to your garden community?"	4-point Likert scale	My Health My Communit y (2014)
	Learning	Perceived importance of community garden as a learning source. Level of agreement with: "My community garden is an important source for me to acquire knowledge and skills."	4-point Likert scale	Camps-Calvet et al. (2016)
	Aesthetics	Level of agreement with: "My community garden is beautiful and aesthetically pleasing."	4-point Likert scale	Bwika (2011)
	Connectedness to nature	Level of agreement with: "When I spend time in my community garden, I feel a deep feeling of love toward nature."	4-point Likert scale	Kals et al. (1999); Mayer and Frantz (2004)
Tree-related regulating	Stormwater runoff control	Stormwater intercepted by (leaf area of) woody plants annually	Cubic meters/year	USDA Forest Service (2017b)
	Air pollutants removal	Air pollutants removed by (leaf area of) woody plants annually	Kilograms/y ear	

	Annual carbon sequestration	Carbon (C) sequestrated by (biomass) of woody plants annually	Metric tonnes/ year	

For regulating ES, I used the tree inventory data collected in gardens, and therefore gardens are the unit of data collection. I employed the i-Tree Eco urban forest and ES assessment tool (USDA Forest Service, 2018a) for this chapter to estimate three regulating ES provided by trees and shrubs in the gardens. i-Tree Eco is a sample or inventory-based model developed by the USDA Forest Service that helps urban forests managers in calculating the composition and structure of urban forests and to estimate various regulating ES of urban trees. The model uses pollution, weather, and other location-specific information (USDA Forest Service, 2016). It has been widely adopted for estimating the values of urban forests and trees by both researchers and urban forestry managers that can be found in itreetool.org (e.g., Andrew and Slater, 2014; Treeconomics London, 2015). These regulating ES include annual carbon sequestration (tonnes/year), removal of air pollutants (e.g., NO_2, SO_2, O_3, CO, PM2.5; in kg/year), and avoided stormwater run-off (m^3/year). I measured the properties of 1,445 trees and shrubs whose diameter at breast height was at least 2.54 cm, including total tree height, live crown height, diameter at breast height, crown base height, crown width, missing crown area, crown light exposure, and land use, following the i-Tree Eco Field Manual v.6 (USDA Forest Service, 2018a). I chose this method instead of asking gardeners' perceptions of the regulating ES because regulating services can be "homogenously perceived" by gardeners even though the land cover patterns of the sites varied considerably (Langemeyer et al., 2018). All fieldwork and data collection took place from June to November 2019.

There are important limitations with the use of i-Tree Eco. One major limitation is that i-Tree Eco only estimates the regulating ES provided by woody plants, primarily trees, and consequently this study does not include the regulating ES provided by soils and other land covers and vegetation types in community gardens (McHale et al. 2018). The other major limitation is that this approach does not measure other benefits of trees for garden users such as cooling effects or provision of shade during summertime under which people rest or interact with other gardeners and family in community gardens. Further limitations related to the use of i-Tree Eco is discussed in *5.3.1. Limitations*.

4.2.3. Data analysis

4.2.3.1 ES bundle assessment: Multivariate Regression Tree

Initially, 366 gardeners from 50 gardens across 17 neighborhoods in the city (i.e., 45% of the 111 gardens contacted) participated in the survey. From these, I included gardens in the analysis if at least two gardeners from the garden reported all provisioning and cultural ES; consequently, I analyzed 312 survey responses from 31 gardens. Since the provisioning and cultural ES values were measured at the level of the individual gardeners, I obtained the ES values for each garden by calculating the mean values of the gardeners' responses. For the cultural ES values reported on a 4-point Likert scale, I recoded the 4-point scale values to binary values (i.e., 0 = strongly disagree or somewhat disagree; 1 = strongly agree or somewhat agree), and then calculated the mean values for each service by garden. The regulating ES values for each garden were estimated using the i-Tree Eco model (USDA Forest Service, 2018b; www.itreetools.org), which is widely used for estimating the values of urban forests and trees by both researchers and urban forestry managers (Andrew and Slater, 2014). The estimated regulating ES values were subsequently normalized by dividing by their respective garden surface area (Dennis and James, 2016a, 2016b). As the measurement units of the ES values differed, I standardized each of the ten ES values to range from 0 to 1 to compare them more easily (Ndong et al., 2021).

I used a multivariate regression tree (MRT) to explore different bundles of provisioning, regulating, and cultural ES that were associated with similar biophysical and social garden characteristics (Legendre and Gauthier, 2014). MRT is a machine-learning technique which "can be used to analyze complex ecological data, and especially to explore, describe, and predict relationships between multispecies data and environmental characteristics" (De'ath, 2002, p. 1105). MRT has been used for identifying bundles that are associated with similar ES and socioeconomic and biophysical characteristics (e.g., Lamy et al., 2016; Renard et al., 2016; Ndong et al., 2021). This method has a few advantages such as its ability to identify non-linear effects between response and explanatory variables (Borcard et al., 2018), threshold effects of explanatory variables on ES trade-offs and synergies (Ndong et al., 2021), and interactions between explanatory variables, which is a difficult task for other common approaches such as redundancy analysis and canonical correspondence analysis (De'ath, 2002). In this chapter, MRT was used as an exploratory approach to describe sets of the ten ES that are associated with similar garden characteristics.

I fitted MRT models with all ten ES values as response variables and the five garden characteristics as explanatory variables, using *mvpart* function from the R package *mvpart* (Therneau et al., 2014). The explanatory variables included: garden surface area, tree canopy cover, management type, volunteer hours and communal space for growing food (%). For the response variables, I included all ten ES values that were averaged and standardized from 0 (minimum value) to 1 (maximum value) at the garden level in the model. The MRT model split the gardens into bundles based on garden characteristics (i.e., explanatory variables) and each final bundle represents a group of gardens that provide a similar basket (i.e., bundle) of ES (i.e., response variables) under similar garden characteristics. With the ES and garden variables, I first identified the optimal regression tree size (number of splits =3) where a 10-fold cross-validation error was the lowest, by plotting the curves of error and tree size (See Appendix C.1 for detailed results). Then, I ran MRT again with the same dataset, by using the *mvpart* (xv='min', xval=10) function and a 10-fold cross validation and selected the regression tree model that had three splits with the minimum cross-validated error (Ndong et al., 2021) (See Appendix C.2). After the model yielded the bundles with similar garden characteristics, I identified which community gardens belonged to each bundle, averaged the values of each service for each bundle, and visualized differences across ES within each bundle. Last, I compared the ES values of each bundle to the averaged values of all four bundles in order to visualize the relative levels of ES between the bundles (Lamy et al., 2016).

Due to the small sample size and non-random sampling, the MRT analysis is exploratory and not intended to predict ES patterns or represent the whole population of community gardens in the city. In addition, there is a risk that the MRT selected is over-fitted and its accuracy is over-inflated as I used the small sample size and a cross-validation procedure instead of block cross-validation (Roberts et al., 2017)

4.2.3.2 Analysis of interviews for each ES bundle: Natural language processing

To complement the ES bundles with gardeners' narratives, I transcribed and analyzed the 26 interviews with garden representatives who spoke for a total of the 30 gardens and garden benefits. One garden did not participate in the interview. I analyzed the interview transcripts using Word2Vec, a natural language processing method (Mikolov et al., 2013a) that "converts the meanings of words into vectors in a multidimensional space using deep learning" (Lee and Kim, 2021, p. 4). Word2Vec allows for analysis of semantic associations between word vectors—a "centre word" (i.e., a word of interest that I choose) and a "context word" (i.e., neighboring word that a model yields given the centre word)—based on the arrangement and co-occurrence of words in the same sentence throughout the corpus (Banks et al., 2018). Cosine similarity (i.e., cosine of the angle) between word vectors is used for assessing the semantic similarity between words, and the cosine similarity value between word vectors that is close to 1 implies that two words have high semantic similarity (Mikolov et al., 2013a; Rozado, 2019). This method was recently used by Kim and Son (2021) to complement cultural ES bundles in an urban park with park visitors' perceptions and knowledge about the park, based on narratives collected from blog posts. The authors noted the Word2Vec model allowed for "abundant interpretations of people's perceptions and activities" in the park (p.1).

I first read all 26 interview transcripts to have a general understanding of the benefits of each ES bundle that were described by the garden representatives. Then I created a text corpus for each bundle by aggregating the interview transcriptions according to the bundle types, as derived from the previous MRT model. Then, I excluded personal and garden names as well as words that appear too frequently (such as a, the, we, she, in, etc.), and broke the text corpora up into words (i.e., tokenization), using the natural language processing tool (NLTK) package (Bird et al., 2009) in Python. I used the *gensim* package (Rehurek and Sojka, 2010) to generate the word embeddings of the corpus vocabulary, and then trained the models with different hyperparameters (Gennaro et al., 2021). The optimized model with the lowest loss among the trained models had the following hyperparameters (Mikolov et al., 2013b): training method = Skip-gram model, minimum word count to be included in the model = 2, window size = 5, number of vector dimensions: 10, number of negative samples = 20, number of epochs = 20001, random down-sampling threshold for frequent words = 1e-5, initial learning rate= 0.025, minimum learning rate= 0.0001). Finally, I analyzed context words for the centre word "garden" whose cosine similarity value was 0.7 or above throughout the corpus of each bundle. Last, I re-read the original transcripts to understand how the garden representatives used the context words of "garden" when they were describing their gardens.

4.3. Results

4.3.1 Garden characteristics

The 31 gardens covered a total surface area of 6.5 ha and had a mean area of 0.21 ha (min.: 0.02, max.: 1.56), which was larger than the mean surface area of the 111 gardens in the city (mean: 0.09, total: 10.09). The majority of the gardens (n=21, 67.7%) had mixed management with both individual plots and communal space for growing food, followed by individual (n=6, 19.4%) and collective management (n=4, 12.9%). The gardens dedicated a mean of 9.7% (min.: 0%, max.: 68.2%) of their total surface area to communal space for growing food. Gardeners volunteered on average 5.5 hours per month towards overall garden maintenance (min.: 0.5, max.: 15.5). The number of trees and shrubs significantly varied across the gardens (min.: 0, max.: 531, mean: 46.8, S.D.:121.6) and was skewed due to two gardens that had 531 and 436 woody plants, respectively. We identified 98 genera and 151 species of trees and shrubs across all gardens; the most abundant genera by the number of individual trees of the same genus were apple (*Malus spp.),* cherry *(Prunus spp*.), and cottonwood (*Populus spp*.).

4.3.2 ES descriptions

The community gardens were associated with multiple ES, and in particular cultural ES. Over 96% of the gardeners felt connected to nature in their garden (connectedness to nature) and found that their garden was beautiful (aesthetic) (Table 4.2). Almost 90% felt their garden was part of themselves (place attachment) and an important source for learning about local nature, gardening, and social and political issues. On the other hand, the regulating ES values were widely variable across the gardens.

Table 4.2 Summary of ES values prior to standardization for the MRT analysis, to provide an overview of the ES provided by the 31 gardens

ES	Agree	Disagree	Mean (S.D.); Range
Subsistence level of garden crops (%)			339.1 (203.6); 0-700
Number of garden acquaintances (n)			7.65 (8.34); 0-80
Sense of belonging (%)	76	23.4	
Place attachment (%)	89.1	10.9	
Learning source (%)	88.5	11.5	
Connected to nature (%)	96.2	3.53	
Aesthetic (%)	96.2	3.85	
*Annual carbon sequestration (metric tonnes)			0.16 (0.42); 0-1.91
*Annual avoided rainwater runoff (cubic meters)			16.62 (42.64); 0-212
*Annual air pollutants removal (kilograms)			3.3 (8.95); 0-43.78

4.3.3 Four ES bundles were identified, based on their characteristics and ES

The optimal MRT model with the lowest cross-validation error yielded four ES bundles with similar biophysical and social characteristics (Figure 4.1.a). Each bundle was associated with all ten ES to varying degrees (Figure 4.1.b), and all bundles were associated with at least two ES whose values were above average, including at least one cultural ES. No bundle had all ten services above average, although Bundle 4 came close (Figure 4.1.c). Important explanatory factors for the ES bundles were the proportion of tree canopy cover (>= 35.9%), management type (i.e., individual versus collective, mixed), and garden size (>= 0.05 ha).

Bundle 1 was characterized by plot-oriented, individual garden management. It was associated with above-average values of two cultural ES—place attachment and connectedness to nature—and sequestered slightly more carbon than average. This bundle had low levels of sense of belonging and garden acquaintances. None of the gardens in this bundle had communal space for growing food, and gardeners mostly attended to their own plots. This bundle also had the lowest mean volunteer hours of all four bundles (Table 4.3). This type of individual-focused management was not found in other bundles. In the Word2Vec model, the centre word “garden” was associated with context words such as individual, fun, private, and business (Table 4.4 and see Appendix C.3 for the full list of context words). Most gardens in this bundle were temporary community gardens, managed by a private company on behalf of property development companies. They were planted on vacant private lots that were temporarily used for food production by neighbors while the lots awaited redevelopment. An interviewee shared his view on community gardening in temporary settings:

> *“Community gardening is a recreational activity and must be scoped that way, and most people don't enjoy recreational activity forever, so…[our] projects are temporary. I think we beautify the spaces in the community and we create a place for a lot of neighbors to come together and meet and just overall create a physical place to connect with.”*

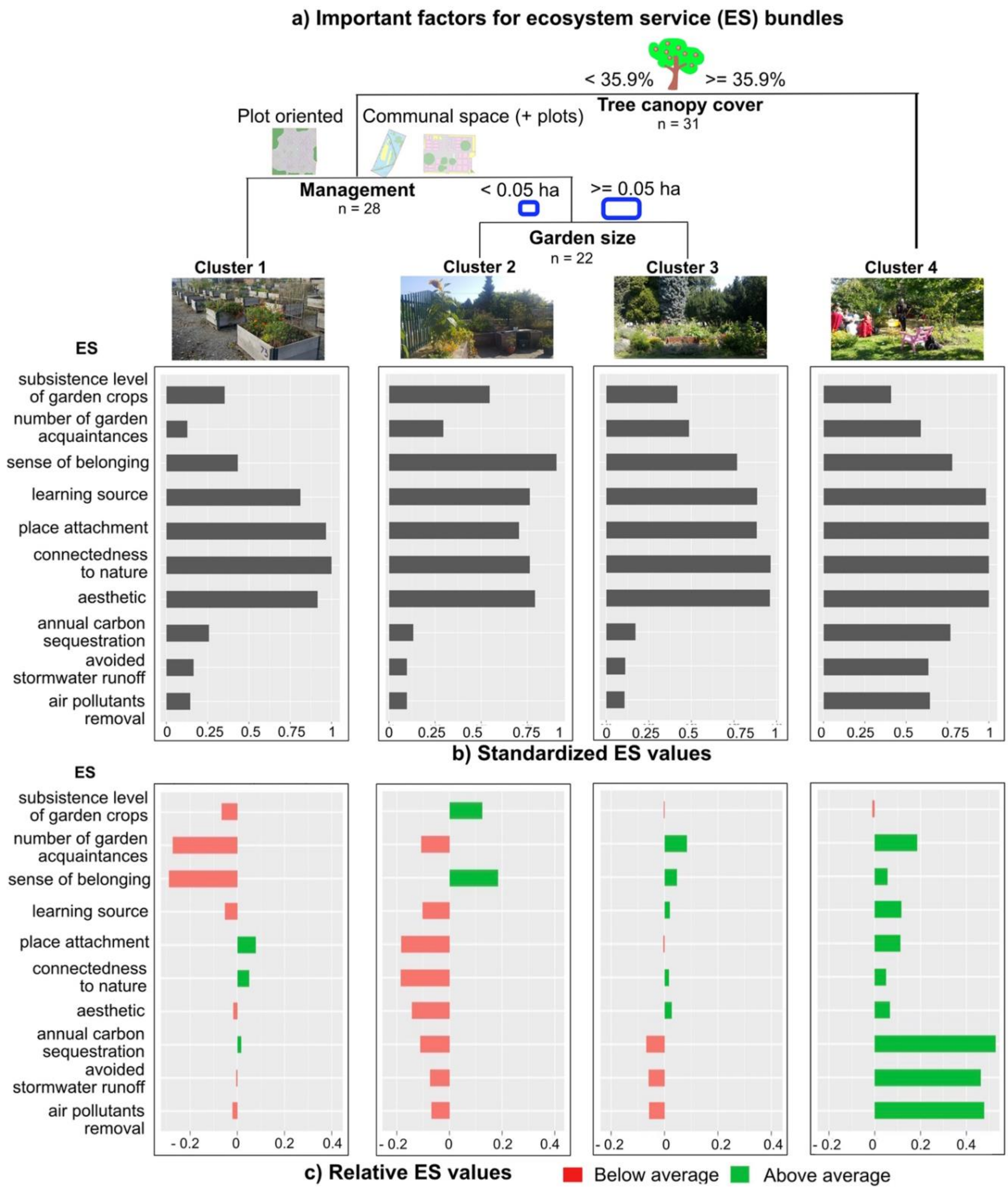


Figure 4.1 Multivariate regression tree (MRT) analysis of ten ES and biophysical and social characteristics of community gardens and food forests in Vancouver

showing: a) important characteristics associated with the ES bundles; b) standardized ES values (ranging from 0 to 1) for each bundle; and c) relative standardized ES values of each bundle to the average ES values of all bundles. The model error: 0.585, 10-fold cross-validated (CV) error: 0.796, standard error (SE): 0.144 (See Appendix C.2 for detailed MRT results).

Table 4.3 Summary of the biophysical and social characteristics of each bundle. Among these, tree canopy cover, management type and garden size were identified as defining characteristics of the gardens. Other variables are included in the table to provide additional information.

Characteristics	Bundle 1 mean (min., max.) n = 6	Bundle 2 mean (min., max.) n = 4	Bundle 3 mean (min., max.) n = 18	Bundle 4 mean (min., max.) n = 3
Tree canopy cover (%)	15.34 (0, 33.92)	2.6 (0, 8.16)	15.03 (0, 30.77)	49.9 (37.8, 64.3)
Management type	individual	collective and mixed	mixed and collective	mixed
Garden size (ha)	0.19 (0.11, 0.38)	0.036 (0.02, 0.05)	0.14 (0.05, 0.49)	0.9 (0.06, 1.56)
Volunteer hours per month	2.56 (0.5, 9)	7.46 (2, 14)	5.4 (1.85, 11.5)	10.6 (5.6, 15.5)
Communal space for growing food (%)	0 (0, 0)	21 (2.3, 46.6)	21.86 (2.13, 58.61)	44.26 (18.88, 68.16)

Bundle 2 was the only bundle associated with above-average provisioning ES (i.e., higher level of subsistence garden crops). Sense of belonging was high and above average, while the number of garden acquaintances and all other cultural and regulating ES were below average. The gardens in this bundle were characterized by the lowest tree canopy cover and smallest surface area. Half of the gardens were in collective management, and the other half in mixed management. Despite the smallest mean garden size, the gardeners in this bundle volunteered more hours to the overall maintenance of the gardens than gardeners in Bundle 1 and Bundle 3. The gardens in

this bundle were associated with context words such as sharing, enjoy, waitlist, and work party. One of the interviewees mentioned that collective management allowed other residents to access the gardens, garden crops, and opportunities to meet neighbors through volunteering, sharing harvests, and attending workshops without having to wait to get a plot and thus they enjoyed direct access to community gardening. Another garden representative expressed their perspective about food production in their garden:

> *"It's a small garden. This isn't gonna feed the city and it's not gonna feed the community. So, what we aim to do is to have demonstrations so that on a small scale, people can learn about gardening, about growing food, about where their food comes from and about other cultures that are in the community."*

Bundle 3 was associated with slightly above-average, diverse cultural ES values (except place attachment) and slightly below-average regulating and provisioning ES values. In some sense, Bundle 3 showed a good all-round mix of ES, with most ES around average values. Gardens in this bundle were largely characterized by a mean tree canopy cover of 15%, which was lower than Bundle 4, by mixed garden management including both individual plots and communal space for growing food, and by a mean garden size of 0.14 ha, which was larger than that of Bundle 2. More than half the gardens included in the study belonged to this bundle.

The gardens in this bundle were described by garden representatives with context words such as knowledge, children, peaceful, friendship, biodiversity, and teach, which showed diverse values of the gardens perceived by gardeners. One interviewee shared his own experience that was not captured by the MRT or the text analysis:

> *"…I think it's real clear that this [garden] gives them a peaceful place to sit down and have lunch or picnic or play guitar and meet with people. Very frequently when we are having a work party and people who walk by on the Greenway and say 'thank you'. That happens all the time. 'Thank you for giving this to us. This is so wonderful.' I think it goes to the greater community as far as Kitsilano."*

And he explained how such a reaction affects him:

> *"I'm contributing to something that's greater than me. I feel like I'm making the community I live in a nicer place to be in. People that are in my community to come by, whether they thank me or not, just to see them sitting here and talking and smiling brings me joy. Again as an immigrant here, who has no roots, it makes me feel like I have roots."*

Another interviewee described how neighbours enjoyed the garden as well:

> *"Because we have this large apartment building, we have a lot of people from that area that come here to enjoy the garden and just walk through and they don't necessarily want the garden plot. They just bring their kids and show what is happening throughout the seasons. I really enjoyed that that part of it. Just because it's next to a children's playground, there are always lots of children."*

Bundle 4 was the most multifunctional basket, with all cultural and regulating ES values that were not only above average but also higher than those of other bundles (except sense of belonging) (Figure 4.1.c). In particular, the regulating ES values of woody plants in this bundle were much higher than average while the cultural ES were just above average. The provisioning ES was below average. This multifunctionality was largely explained by high tree canopy cover (>= 35.9%). This bundle had the largest mean surface area of the gardens and communal space for growing food (%) as well as the highest mean volunteer hours of all bundles (Table 4.3).

In the Word2Vec model, the centre word "garden" in this bundle was associated with context words such as wedding and tour that indicate public uses of the gardens beyond their garden members. For example, one interviewee described the public use of their garden: "Sometimes people use the garden for something like weddings, because aesthetically it pleases them, and they want it as part of their life. So, is that an event? Yes, that's a community event.” Another garden representative described shared learning in their garden: “Any gardener that wants to learn about a particular area, more experienced gardeners can show them how to do certain thing. We have a gardener who has done some tree pruning so he can help with the dormant pruning and also show other gardeners.”

Table 4.4 Examples of important context words of gardens for each ES bundle. The full list of context words is included in Appendix C.3.

Bundle 1 ‘context word’ (cosine similarity value)	Bundle 2 ‘context word’ (cosine similarity value)	Bundle 3 ‘context word’ (cosine similarity value)	Bundle 4 ‘context word’ (cosine similarity value)
'bed' (0.90)	'sharing' (0.89)	'grow’ (0.89)	'company' (0.85)
'allocating' (0.81)	'enjoy’ (0.79)	'teach' (0.88)	'bed’ (0.80)
'fee' (0.79)	'growing' (0.77)	'play' (0.85)	'communal' (0.79)
'private' (0.77)	'meeting' (0.76)	'children’ (0.83)	'accessible’ (0.79)
‘client’ (0.73)	'everybody' (0.76)	'knowledge' (0.79)	‘wedding' (0.78)
'business' (0.72)	'workparty' (0.75)	'peaceful' (0.78)	'ecology’ (0.77)
'individual' (0.70)	'waitlist' (0.75)	'meet’ (0.76)	'tour’ (0.75)
'food' (0.70)	'learn’ (0.74)	'share’ (0.75)	'mixed’ (0.73)
'fun’ (0.70)	'volunteer' (0.71)	'friendship' (0.74)	'education' (0.70)
	'care' (0.70)	'biodiversity' (0.70)	

4.4 Discussion

4.4.1 Multifunctional food forests

The results highlight that a suite of provisioning, cultural and regulating ES can be found in community gardens and food forests (Artmann and Sartison, 2018). More importantly, they have different sets of services and benefits that can be taken into consideration in order to achieve specific goals of each project. A large food forest with high tree canopy cover (e.g., over 35 % tree canopy cover in Bundle 4) and mixed management can be associated with higher regulating and more diverse cultural ES than smaller gardens with a low tree canopy cover or gardens with individual management in Vancouver. However, such food forests require a large space for growing trees and non-tree crops (e.g., vegetables), ongoing maintenance (with greater labor/volunteer hours), as well as knowledge of trees and resources to manage the large space, in order to maximize multiple regulating and cultural ES and minimize a potential trade-off between regulating ES and provisioning ES (Speak et al., 2015; Cabral et al., 2017).

In addition to these biophysical and managerial conditions observed in Vancouver, Albrecht and Wiek (2021) point out that high development pressure and land prices in compact cities often make it hard for communities to secure long-term lease agreements. As a result, community projects are often given a short-term lease contract, which is a major challenge for food forest projects because food forests require high start-up costs and labour hours in the first 2 to 3 years of the implementation and take several years before they establish. Inevitably, there can be several years of a gap between the initial stage of a project where most of the funds and labour time (for site preparation, planting of trees, etc.) are spent as well as community's excitement for a food forest project is likely to be highest, and the medium or mature stage of the project (at least after five years) where people can start harvesting food crops and experience multiple benefits that food forests can provide. As a result, implementing food forest projects can be more challenging than allotments or temporary community gardens in cities with high land demand.

4.4.2 Small, collectively-managed gardens are better for promoting sense of belonging and food-sharing

This study also shows that small gardens have an important role to play in areas with very limited space. Small gardens that are collectively-managed (i.e., where gardeners maintain the whole garden together without having individual plots) can maximize space for gardeners and non-member volunteers to share food and to interact with one another. In addition, these gardens allow residents to participate in community gardening with less or no time on a waiting list in comparison to gardens with individual management (e.g., allotment gardens) or mixed management that have a limited number of individual plots available for residents. However, such small gardens may not be best at providing regulating ES, as trees planted in these gardens are likely to be smaller in biomass and canopy cover than trees in large food forests, for example, and gardeners may not want to plant large trees in small gardens to maximize area for growing vegetables (Speak et al., 2015). Such small, collectively managed gardens offer valuable design and management considerations for promoting a sense of belonging and food-sharing among residents in underutilized spaces in residential areas (Spilková and Vágner, 2016).

In the previous chapter, the number of garden acquaintances and sense of belonging were strongly positively associated while in this chapter their association was rather weak. I speculate possible explanations for this observation: 1) the number of small and collectively-managed gardens that participated in the study was low, and this weak association might be unique to the few gardens included; 2) the gardens could have a large flow of participants that come and go, and the participants do not always work with a large number of the same people; 3) the small surface area may limit the number of participants who can work at the same time; and 4) yet, they can build friendships with a small pool of volunteers. Further research with a larger sample size will be needed to unpack relationships between sense of belonging and number of garden acquaintances.

4.4.3 Comparing ES patterns in Vancouver to other cities

The overall patterns of trade-offs and synergies among cultural ES that I found are similar to patterns in other cities, but with some exceptions. For example, allotment gardens provide space for urban residents to regularly connect with nature but may lack in social interactions and social cohesion while small, collectively-managed gardens can better promote social interactions (Langemeyer et al., 2018; Veen et al., 2015). In Vancouver, although gardeners may feel a sense of belonging through social interactions in small, collectively-managed gardens, this may not necessarily mean that gardeners and volunteers are acquainted with a large number of other garden members or volunteers. Interestingly, social cohesion and sense of belonging can also be promoted in large gardens with mixed management, which has not been discussed in previous studies that assessed ES in community gardens (e.g., Dennis and James, 2016a, 2016b; Langemeyer et al., 2018). Trade-offs between food production and regulating ES (Speak et al., 2015) and between food production social cohesion (Kurtz, 2001) found in other studies are not evident across the studied gardens in Vancouver.

It is difficult to pinpoint why Vancouver exhibits some different patterns of ES associations from other cities. Previous studies do not provide the quantitative values for “large” vs “small” gardens, which makes it difficult to compare the ES trade-offs and synergies associated with garden size to those in Vancouver (e.g., Kurtz, 2001; Langemeyer at al., 2018). Two European studies (Langemeyer at al., 2018; Veen et al., 2015) only examined ES patterns in individually-managed and collectively-managed gardens and did not discuss gardens with mixed management, a garden type commonly found in Vancouver. In addition, the small sample size in this study makes it difficult to discern whether some patterns are unique to a few gardeners who participated in the research or are general characteristics of the gardens.

4.4.4. Community gardens where people can design and care for nature

Bearing in mind the limitations of the MEA framework for understanding cultural ES, the study findings suggest that community gardens and food forests provide space and opportunities for people to feel connected to nature and place attachment. Such urban food production systems can provide residents with an opportunity not only to interact with nature in cities (Church, 2018) but also to design and care for small green spaces in their neighborhoods (Chisholm, 2008). These relational values expressed or cultivated through community gardening, and human-nature interactions can serve as a gateway for increasing public awareness of the importance of urban green spaces in urban areas and for encouraging environmental stewardship (Andersson et al., 2015; Langemeyer et al., 2018; Sarabi et al., 2019; Torres et al., 2017). The implications of the study findings for policy and practice as well as the study limitations are further discussed in *Chapter 5.*

Chapter 5: Conclusions

5.1. Key messages

Urban food production systems are flourishing in many cities across the world in an attempt to serve the different needs of urban communities (City of Vancouver, 2012; FAO, 2016; McLain et al., 2012; Osaka et al., 2021). My dissertation by no means suggests that multifunctionality is the magic wand for solving important societal challenges in different cities and neighborhoods. Rather it unpacks the multifunctionality of community gardens and food forests in Vancouver, Canada through the lens of ES trade-offs, synergies and bundles with hope to inform strategic design and management in green spaces. My study yields two key integrated insights: 1) community gardens and food forests are multifunctional and can support different sets of services and benefits at the same time, and 2) their multifunctionality is associated with a combination of both biophysical and social conditions in these systems. In order to meet the different needs of communities in relation to urban green spaces, it is important to strategically manage both environmental and social factors in green spaces associated with different sets of multiple services and benefits.

5.1.1 First insight: Community gardens and urban food forests are multifunctional in different ways

The concept of 'urban food forestry' is currently interpreted in both broad and narrow ways in the scientific literature. The broad interpretation is simply that food trees are planted in urban landscapes, and such an interpretation of urban food forestry encompasses a range of urban food production systems involving trees. Examples of these systems that are discussed in the scientific literature range from fruit or nut trees on streets, to orchards, vegetable gardens with a few fruit trees, and multistorey, polycultural food forests. The more complex these systems are in their vegetative composition and structure, the more synergies may be created as well as more trade-offs between benefits. For example, fruit trees and shrubs planted along the boundaries of urban farms could function as buffers protecting crops from winds and as producing tree crops. On the other hand, home gardeners may value the aesthetic effects and regulating services of trees (e.g., cooling) in their gardens but can be concerned about shading, which could be a limiting factor for their vegetable production.

Four different bundles of ES can be found across community gardens and food forests in Vancouver. The first type appears to be a plot-oriented system planted with trees that provides urban residents with an opportunity to regularly connect with nature and feel a sense of attachment to their neighborhood. The second type could be a small, collectively-managed system planted with limited tree canopy cover which takes advantages of small but multiple spaces for growing and sharing food and for facilitating regular volunteer opportunities that can promote a sense of belonging. The third type may be a medium sized, mixed management system planted with some tree canopy cover that is associated with multiple benefits such as connectedness to nature, social cohesion and aesthetics. The fourth type can be characterized as a large food forest that provides a significantly higher value of regulating ES as well as more diverse cultural ES than other types.

Both the scoping review and the empirical data that I collected in Vancouver suggest that community gardens and food forests can be multifunctional. In community gardens and food forests in Vancouver, gardeners experience a range of cultural ES. More importantly, a greater number of synergies between ES than trade-offs can be achieved including between food production and social cohesion, in contrast to other studies that find trade-offs between these two services. Moreover, these systems can serve different sets of goals even though they are primarily considered a type of food asset or food production system. Therefore, different types of such systems can be considered and distributed across an urban landscape to ensure that the city's green space as a whole provides a wide variety of services and meet different needs (Hansen et al., 2019; Langemeyer et al., 2018).

5.1.2 Second insight: Multifunctionality is shaped by the combination of biophysical and social characteristics

The three main chapters underscore that both biophysical and social factors are important for understanding ES trade-offs and synergies and multifunctionality. For example, the biophysical (e.g., tree canopy cover) and social factors (e.g., mixed management, volunteer hours) may explain the synergies between cultural ES while moderating a potential trade-off between food production and social cohesion. A promising finding is that the size may not be as critical a factor for providing cultural ES as other studies have suggested (Kurtz, 2001; Langemeyer et al., 2018). Instead, factors such as tree canopy cover, mixed management, and volunteer hours play a more important role in maximizing synergies between the cultural ES. This study also shows that in very limited spaces, small gardens with collective management can contribute to food production and sense of belonging by maximizing space for gardeners and volunteers to grow and share food and to interact with another.

When including regulating services in ES assessments, the surface area of urban food production systems can become an important factor for maximizing the number of ES provided while moderating trade-offs. In Vancouver, the combination of large surface area, large tree canopy cover and mixed management is associated with more synergies between regulating and cultural ES and fewer trade-offs between provisioning and other ES. Still, both pairwise comparison between food and cultural ES, and a bundle analysis of food, cultural and regulating ES, indicate that tree canopy cover and management types are important considerations for designing and managing community-based food production systems for multifunctionality. Finally, achieving multifunctionality requires adequate space, resources, capacity and knowledge for materializing desired garden design and management.

5.2 Study contributions and implications for policy and practice

5.2.1 Empirical contributions

This dissertation contributes empirical data that describe the multifunctionality of urban food production systems – a topic which has not often been studied to date. Chapter 2 is the first scoping review of the scientific literature on urban food forestry since the first usage of the term "urban food forestry" in the literature in 2013. It sheds light on the inconsistent conceptualizations of urban food forestry that include a wide range of vegetation structures and functions, and it identifies opportunities for future research to advance the practice. Chapter 3 and Chapter 4 address one of the gaps identified in Chapter 2, which was the lack of empirical examples on ES trade-offs and synergies and potential enabling factors that are associated with ES trade-offs and synergies in such systems. By assessing provisioning, cultural, and regulating ES in community gardens and food forests in Vancouver, this dissertation scrutinizes the patterns of trade-offs and synergies between (e.g., pairwise comparison in Chapter 3) and among different ES (e.g., bundle analysis in Chapter 4) in the urban food production systems. The dissertation provides a small-scale but comprehensive assessment of multifunctionality of green spaces and their associations with both biophysical (e.g., % tree canopy cover, surface area) and social characteristics (e.g., individual, mixed and collective management types), both quantitatively (e.g., multivariate regression analysis of ES) and qualitatively (e.g., analysis of gardeners' perceptions).

The primary strength of this dissertation lies in its use of a mixed-methods approach. The approach combines a cross-sectional survey of over 366 gardeners and volunteers from 50 gardens, structured interviews of 26 gardeners that represented a total of 42 gardens, an inventory of 1,445 trees, and mapping of land use in 50 sites. The dissertation examines three ES categories—provisioning, cultural and regulating ES—together and the associations among them rather than within just one ES category. I measured the provisioning and cultural ES values based on people's perceptions and experiences of provisioning and cultural ES (e.g., proportion of crops harvested to total consumption of the crops, sense of belonging, number of gardeners participants known by name and contact information) rather than a proxy that makes crude estimations of provisioning and cultural ES (e.g., different land uses). At the same time, I estimated the regulating ES based on tree measurements rather than asking people's perceptions as these have been shown to be unreliable (Langemeyer et al., 2018). Finally, my qualitative assessment of the interview data contextualizes the quantitative analysis of the ES associations with people's narratives.

5.2.2 Implications for policies and practice

Based on the results, I highlight five key implications for policies and practice. First, city policies should consider community gardens and food forests as green spaces that can contribute to different aspects of people's quality of life—they are not simply food assets (e.g., Greenest City Action Plan, 2012; Healthy City Strategy, 2014). In addition to growing food, community gardeners and volunteers feel connected to nature and a sense of belonging, build friendship and support networks with neighbors who they may not meet otherwise, and learn about a range of topics such as local ecology, political and social issues in the city as well as about other cultural foods and practices in these green spaces. Broadening the relevance of community gardens and food forests to issues beyond food insecurity in the city may attract more participants and civic groups, and provide more opportunities for incorporating different disciplinaries such as health, urban green infrastructure and urban forestry into such projects and practices (Langemeyer et al., 2018; Thiesen et al., 2022).

Second, city authorities should have a better understanding of who is benefiting from and interested in using these gardens, so as to meet the 2030 Sustainable Development target (under Goal 11) to provide "universal access" to public green spaces for all urban residents, especially vulnerable groups (UN, 2015). In my survey, more than 70% of the participants were female, and many gardeners bring their children to their community gardens. Only 20% of the participants reported their annual income as under $40,000 (low-income level) in comparison to 36% of the population in the city (MHMC, 2014). Most community gardens in Vancouver allocate plots on a "first come, first served" basis, and the gardens and the City do not have a system in place to collect socio-economic information of gardeners to understand garden users and their motivations for community gardening. Further understanding of demand for different types of gardens and current and potential supply of gardens will be valuable for evidence-based planning and management of green spaces in the city. Without such knowledge, it is difficult to know whether the gardens provide inclusive access to vulnerable groups in the community and whether city authorities can improve food insecurity by increasing the number of community garden plots for growing food.

Third, city staff, park managers, and community groups should be aware that multifunctionality does not come easily, especially without proper design and management. For large food forests to provide substantially greater regulating ES and diverse cultural ES without compromising food production, large spaces and tree canopy cover are required, as well as effective mixed management that provides an opportunity for people to work alone and with others, and resources, coordination, and knowledge to support garden management and maintenance. Many gardens and food forests on public lands are volunteer-based, and they often lack resources, knowledge and/or labor to manage and maintain the spaces (and trees) and the community. In addition securing a long-term lease contract for a large piece of land can be challenging in a city with increasing land development pressure and land price. It is important that city staff and local communities consider these potential challenges for creating and managing large food forests.

Fourth, the advantages and disadvantages of different design and management approaches must be taken into consideration. People from different socio-demographic backgrounds can value different sets of ES and have different capacities to participate in community gardening (da Silva et al., 2016). Large gardens under individual management might be better at providing space for people to connect to nature on their own terms while small gardens under collective management can maximize space for food sharing and social interaction. Depending on who will be participating in the gardens, having space for solitude while connecting with nature might be more valuable than social interaction. Meanwhile, mixed management, which is the most common management approach in Vancouver, seems to moderate the trade-offs that are associated with either collective or individual management. Yet it is important to recognize that not all community gardens can have the adequate capacity to recruit and coordinate gardeners and volunteers for attending to communal space. And not all gardeners have time available for volunteering in the gardens due to their work schedule or other constraints, and thus volunteer requirements could create a barrier for some people who need access to a plot for growing their own food but do not have time to commit to required volunteer hours.

Last, it may be necessary to prioritize the most important goals of community gardens and food forests to best-fit local contexts while minimizing unwanted trade-offs. A recent systematic review of Pinto et al. (2022) highlights that current scientific understanding of community gardens has built based on studies from Northern America and Europe. In these regions gardeners are often found to value both cultural and provisioning ES and even favour social, health and educational benefits of urban agriculture in some cases (Dona et al., 2021; Newell et al., 2022). Our current knowledge of community gardens is largely limited in developing countries, particularly in Africa and Asia in which community gardening may play a more essential role in delivering the provisioning ES (e.g., food) and prioritize food security and poverty alleviation to meet eminent local needs over other ES (Pinto et al., 2022). At the same time, recent case studies in Palestine (Raddad, 2022) and Sri Lanka (Dona et al., 2022) indicate the importance of integrating urban agriculture into green space management in order to support cities to become more resilient and to increase the multifunctional use of green spaces such as food security and health. Therefore, governments and community groups should identify the important needs of local people before deciding the right type of a food production system.

5.3 Limitations and opportunities for future research

5.3.1 Limitations

This dissertation has several limitations. Chapter 2 classifies the food production systems based entirely on the descriptions of the vegetation composition and functional attributes as provided in the studied articles. As a result, the actual examples in the articles may have different vegetation structures and functions from how they were described in the literature and hence interpreted and classified in this study. Often, the presence (or absence) of shrubs and purposes of trees in the studied systems were not explicitly mentioned. This study also has limitations due to the inclusion and exclusion criteria for document selection. First, we excluded literature on tropical homegardens (e.g., Akinnifesi et al., 2010; East and Dawes, 2009; Thaman, 1987) and tropical urban food forests (e.g., Nero et al., 2018) as we were interested in urban food forestry emerging in temperate climates where the practice has not been a common means of food production (Park et al., 2018). I was not aware of peer-reviewed scholarly articles on urban food forests in Australia or New Zealand at the time of the scoping review and I thus chose to focus on Europe and Northern American cities as emerging “habitats” for urban food forestry, so Australia and New Zealand were excluded in the search query. As permaculture is popular in this region, these two countries could have shed a valuable insight into the use of food trees in urban areas and urban food forests and should be included in future studies. Second, European literature whose study location was in rural areas or unspecified was excluded (e.g., Smith et al., 2017). A forest garden that was designed as a healing garden in a city in Denmark had positive effects of nature-based therapy (Sidenius et al., 2017) but was not included in this chapter because the article’s abstract did not include keywords such as town, city, or urban. Third, during the analysis of the documents, I discovered three concepts that were not included in our search query but closely related to urban food practices that involve trees: agricultural parks (e.g., Masson et al., 2013), urban foraging (e.g., Hurley and Emery, 2018), and multifunctional buffers (Wortman and Lovell, 2013). Lastly, the study only considered work published in English.

Chapter 3 uses non-random sampling due to lack of public information on the demograhics of garderners in community gardens. The results of the study therefore cannot be generalized. Correlation coefficients and regression methods to identify ES associations that I used in this chapter are known to have a higher probability of finding no-effect relationships and a lower probability of finding trade-offs than other descriptive or multivariate methods (Lee and Lautenbach, 2016). The use of the correlation coefficient and regression methods might thus have affected the lower number of trade-offs found in the analysis. In addition, the participants shared similar socio-demographic characteristics such as gender (women), education level (bachelor or higher), and ethnicity (Caucasian). I was not able to examine how participants from different socio-demographic backgrounds may experience ES differently.

The concept of ES and the MEA categorization have been dominantly used as a conceptual framework for understanding trade-offs and synergies, and multifunctionality in urban landscapes. My survey results suggest that gardeners are motivated by different values (e.g., contributing to sustainability, reducing grocery bills, etc.). They perceive or experience a variety of non-material benefits that could be associated with people's relational values such as connectedness to nature, place attachment, which go beyond utilitarian values. In hindsight, this study could have been an interesting example where the concept of NCP could be tested or operationalized to understand multifunctionality of the socio-ecological systems in cities by embodying different values and cultures across different benefits (Díaz et al., 2018; Ono et al., 2021).

Chapter 4 requires conservative interpretation of the ES bundles. First, the small sample size of 31 gardens could have caused overfitting of the regression tree model, and the non-random sampling method limits the analysis to exploratory interpretation. Second, the provisioning and cultural ES values perceived by gardeners were aggregated by garden, and the gardeners' perception or experience by no means represents the perceptions or experience of the whole population of community gardeners in Vancouver. Last, I used cross-validations to choose the best regression tree to describe ES bundles as a measure of the model's forecast performance (De'ath, 2002; Lamy et al., 2016). However, a cross-validation procedure is known to yield an over-estimation of model performance because of dependency of training and testing subset used in modeling. Gregr et al. (2019) suggest using block cross-validation (Roberts et al., 2017), which allows for restoring independence in samples by dividing observations into independent samples. I suggest that the four functional types found in this chapter be used as a heuristic, exploratory tool for urban planners, park managers and local community groups to discuss different design and management considerations for urban food production systems and consider the potential implications of these considerations on the provision of ES, rather than as a recipe for a successful garden project.

Regulating ES in community gardens could be measured differently. The process of tree inventory (and subsequently i-TREE ECO) was expensive, labour-intensive, and time-consuming. Moreover, it did not show how gardeners benefit from land covers such as open or lawn versus treed space for important regulating ES for such as rainwater run-off effects or cooling effects (e.g., through shading during hot summer days). These services, in particular cooling effects including shading, could have been easily perceived and experienced by gardeners and therefore I could have collected such regulating ES data at the gardener's level through my survey. Although being important benefits of urban green spaces (City of Vancouver, 2012, 2014; City of Vancouver and Vancouver Park Board, 2018; Park et al., 2019), carbon sequestration of trees may be more relevant to or of interest in large parks and urban or peri-urban forests than small community gardens that account for only a fraction of the land surface area and have smaller capacity to accommodate large trees and woody plants in the city. McHale et al. (2014) cautioned that many ES assessments, in particular of carbon sequestration of trees, are guided by "narrow, overly technical, and systematically biased agenda" (p. 121) while ignoring other ES that may not be perceived or measured as.

If I could assess regulating ES again, I would assess ES such as cooling effects and shade that are easily perceived by and affect gardener's experience in the sites through my gardener surveys. I would also assess other regulating ES that may not be easily perceived by gardeners using methods such as i-Tree Canopy and/or analysis of land covers (e.g., impervious, grass, forested, or areas for perennial vs annual plants), which could have been less labor-intensive and time-consuming than using the i-TREE Eco method. This approach could have allowed me to include more diverse perspectives on regulating ES beyond those that focus on trees.

From the series of conversations with garden representatives, I became aware of different models of community gardening beyond the ones that are usually discussed. One model presented an innovative way to engage volunteers, building residents, and people who use a Neighbourhood House—non-profit local organisations that provide social, educational and recreational activities for their communities. The Neighbourhood House would make an agreement with residential buildings with underutilized land so that neighbourhood volunteers and building residents access to plots in this area to grow crops or flowers. The crops are donated to a neighbourhood kitchen project, to be accessed by people with lower income, or to an educational project where people showcase or learn how to cook or make essential oils. Such models of community gardening were not included in Chapters 3 and 4 due to low participation of volunteers in the study. Qualitative analysis of different models of community gardening through interviews could be useful for illustrating a variety of community garden projects that are not often discussed in ES assessment.

5.3.2 Opportunities for future research

A key area for future research is establishing a common understanding of what constitutes urban food forestry across the scientific and grey literature and public policies. I suggest that future research compare the different uses of the term “urban food forestry” in both the grey literature and public policies and plans in combination with consulting with urban planners, park managers and urban food forestry practitioners. Case studies on the biological composition and functions of different urban food forests can contribute empirical evidence that can help to improve the scientific understanding of emerging urban food forestry and of their benefits, as well as to advance the novel practice to addressing both environmental and societal challenges in cities (Clark et al., 2013; Rohwer and Marris, 2016; Albrecht and Wiek, 2022). Moreover, I did not find any review of urban food forestry in other regions such as tropical climate regions or the global south, which can help advance sharing of knowledge and finding consensus on the concept of urban food forestry.

Another key area for future research is understanding how people from different socio-demographic backgrounds experience or perceive urban food production systems of different garden design and management. It is critical to identify ways in which ES trade-offs and synergies affect different aspects of well-being of beneficiary groups (Reyers et al., 2013) from the lens of instrumental values (Lliso et al., 2022). A synergy from one perspective could be a trade-off from another, and ES assessments could cover or uncover a trade-off or synergy based on which ES are valued and from whose perspective (Daw et al., 2015). There is also a need for research that is embedded in relational values and that assess how ES trade-offs and synergies cultivate or negatively affect people's relationships with nature or with people through nature (Lliso et al., 2022). Such future research could focus urban food systems in low-income countries that experience high vulnerability to urban food insecurity, or Asian or African cities where fewer case studies have been conducted in comparison to North American or European cities (Pinto et al., 2022). Similar case studies in different cities could help to compare sets of multiple ES of community gardens and food forests and factors that are associated with multifunctionality.

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Appendices

Appendix A

Appendix A.1 Search query used for each database and detail description of document selection

Documents were selected in a three-phase process according to the inclusion and exclusion criteria (Table 1). Phase 1 started with the keyword search on 12 January 2018 in the Web of Science Core Collection, Scopus and Agricultural & Environmental Science Database (AESD), using the search strings shown below. I imported all selected documents into the reference management software Mendeley and deleted duplicate articles. In Phase 2, two researchers (Park and Morritz) screened the titles and abstracts of the first 500 articles together to develop a common understanding of the inclusion and exclusion criteria (of Phase 2) and to select papers based on these criteria for Phase 3. In Phase 3, we reviewed full texts of the articles to select candidate articles to be coded; then all authors of this study reviewed the biological description of systems studied in the candidate articles and finalised the list of the articles to be coded. In this process, articles that mention trees were present in only some of their studied sites or practices were excluded. We reported the results of each phase using the Prisma 2009 Flow Diagram (Moher et al., 2009).

1. Web of Science Core Collection

TOPIC: (“alley crop*” or agroforest* or allotment* or “backyard garden*” or “community garden*” or “domestic garden*” or “edible forest*” or “edible garden*” or "edible green infrastructure" or "edible urban greening" or “edible landscap*” or "edible urban forest*" or farm* or “forest farm*” or “food forest*" or “food tree*” or “fruit tree*” or "forest garden*" or "forestry food production" or homegarden* or "home garden*" or “improved fallow” or “nut tree*” or "permaculture garden*" or orchard* or “school garden*” or “riparian buffer” or silvopasture or ”tree garden*” or “windbreak*”) AND TOPIC: (urban or city or cities or town) NOT TOPIC: (Argentina or Brazil or Chile or Colombia or "Costa Rica" or Cuba or "Dominican Republic" or Ecuador or "El Salvador" or "French Guiana"

or Guadeloupe or Guatemala or Haiti or Honduras or Martinique or Mexico or Nicaragua or Panama or Paraguay or Peru or "Puerto Rico" or "Saint Barthelemy" or Afghanistan or Armenia or Azerbaijan or Bahrain or Bangladesh or Bhutan or Brunei or Myanmar or Cambodia or China or India or Indonesia or Iran or Iraq or Israel or Japan or Jordan or Kazakhstan or "North Korea" or "South Korea" or Kuwait or Kyrgyzstan or Laos or Lebanon or Malaysia or Maldives or Mongolia or Nepal or Oman or Pakistan or Philippines or Qatar or "Saudi Arabia" or Singapore or "Sri Lanka" or Syria or Taiwan or Tajikistan or Thailand or "Timor-Leste" or Turkmenistan or "United Arab Emirates" or Uzbekistan or Vietnam or Yemen or Nigeria or Ethiopia or Egypt or Congo or "South Africa" or Tanzania or Kenya or Sudan or Algeria or Uganda or Morocco or Mozambique or Ghana or Angola or Madagascar or Cameroon or Niger or "Burkina Faso" or Mali or Malawi or Zambia or Somalia or Senegal or Chad or Zimbabwe or "South Sudanor Rwanda" or Tunisia or Guinea or Benin or Burundi or Togo or Eritrea or "Sierra Leone" or Libya or "Central African Republic" or Liberia or Mauritania or Namibia or Botswana or Gambia or "Equatorial Guinea" or Lesotho or Gabon or "Guinea-Bissau" or Mauritius or Swaziland or Djibouti or Réunion or Comoros or "Cape Verde" or "Western Sahara" or Mayotte or "São Tomé and Príncipe" or Seychelles or "Saint Helena, Ascension and Tristan da Cunha" or Australia or "New Zealand")
Refined by: DOCUMENT TYPES: (ARTICLE OR REVIEW) AND LANGUAGES: (ENGLISH)
Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI Timespan=All yearsfr

2. Scopus
TITLE-ABS-KEY (town OR urban OR city OR cities) AND TITLE-ABS-KEY ("alley crop*" OR agroforest* OR allotment* OR "backyard garden*" OR "community garden*" OR "domestic garden" OR "edible forest*" OR "edible garden*" OR "edible green infrastructure" OR "edible urban greening" OR "edible landscap*" OR "edible urban forest*" OR farm* OR "forest farm*" OR "food forest*" OR "food tree*" OR "fruit tree*" OR "forest garden*" OR "forestry food production" OR homegarden* OR "home garden*" OR "improved fallow" OR "nut tree*" OR

"permaculture garden*" OR orchard* OR "school garden*" OR "riparian buffer" OR silvopasture OR "tree garden*" OR "windbreak") AND NOT TITLE-ABS-KEY (argentina OR brazil OR chile OR colombia OR "Costa Rica" OR cuba OR "Dominican Republic" OR ecuador OR "El Salvador" OR "French Guiana" OR guadeloupe OR guatemala OR haiti OR honduras OR martinique OR mexico OR nicaragua OR panama OR paraguay OR peru OR "Puerto Rico" OR "Saint Barthelemy" OR afghanistan OR armenia OR azerbaijan OR bahrain OR bangladesh OR bhutan OR brunei OR myanmar OR cambodia OR china OR india OR indonesia OR iran OR iraq OR israel OR japan OR jordan OR kazakhstan OR "North Korea" OR "South Korea" OR kuwait OR kyrgyzstan OR laos OR lebanon OR malaysia OR maldives OR mongolia OR nepal OR oman OR pakistan OR philippines OR qatar OR "Saudi Arabia" OR singapore OR "Sri Lanka" OR syria OR taiwan OR tajikistan OR thailand OR "Timor-Leste" OR turkmenistan OR "United Arab Emirates" OR uzbekistan OR vietnam OR yemen OR nigeria OR ethiopia OR egypt OR congo OR "South Africa" OR tanzania OR kenya OR sudan OR algeria OR uganda OR morocco OR mozambique OR ghana OR angola OR madagascar OR cameroon OR niger OR "Burkina Faso" OR mali OR malawi OR zambia OR somalia OR senegal OR chad OR zimbabwe OR "South Sudanor Rwanda" OR tunisia OR guinea OR benin OR burundi OR togo OR eritrea OR "Sierra Leone" OR libya OR "Central African Republic" OR liberia OR mauritania OR namibia OR botswana OR gambia OR "Equatorial Guinea" OR lesotho OR gabon OR "Guinea-Bissau" OR mauritius OR swaziland OR djibouti OR réunion OR comoros OR "Cape Verde" OR "Western Sahara" OR mayotte OR "São Tomé and Príncipe" OR seychelles OR "Saint Helena, Ascension and Tristan da Cunha" OR australia OR "New Zealand") AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (LANGUAGE , "English"))

3. Agricultural and Environmental Sciences Database (AESD)

((TI,AB,SU("alley crop*" OR agroforest* OR allotment* OR "backyard garden*" OR "community garden*" OR "domestic garden*" OR "edible forest*" OR "edible garden*"

OR "edible green infrastructure" OR "edible urban greening" OR "edible landscap*" OR "edible urban forest*" OR farm* OR "forest farm*") AND ti,ab,su(urban OR city OR cities OR town)) AND peer(yes) AND (loc.exact("United States US" OR "USA" OR "Canada" OR "Europe" OR "US" OR "Ethiopia" OR "Italy" OR "British Isles" OR "United States" OR "France" OR "Netherlands" OR "Germany" OR "California" OR "Spain" OR "Sweden" OR "British Columbia Canada" OR "Ontario Canada" OR "Poland" OR "United Kingdom UK" OR "USA, New York, New York City" OR "British Isles, England" OR "MED, Italy" OR "MED" OR "North America" OR "New York" OR "New York City New York" OR "USA, California" OR "Greece" OR "ANW, USA, New York, New York City" OR "Denmark" OR "ANE, Europe" OR "Canada, Ontario" OR "Russia" OR "British Isles, England, Greater London, London" OR "Belgium" OR "British Isles, Scotland" OR "Canada, Quebec" OR "France, Paris" OR "Portugal" OR "Romania") AND at.exact("Article" OR "Review") AND stype.exact("Scholarly Journals") AND la.exact("ENG"))) OR ((TI,AB,SU("food tree*" OR "fruit tree*" OR "forest garden*" OR "forestry food production" OR "homegarden*" OR "home garden*" OR "improved fallow" OR "nut tree*" OR "permaculture garden*" OR orchard* OR "school garden*" OR "riparian buffer" OR silviculture OR "tree garden*" OR "windbreak") AND ti,ab,su(urban OR city OR cities OR town)) AND peer(yes) AND (loc.exact("United States US" OR "USA" OR "Europe" OR "Germany" OR "MED, Turkey" OR "Spain" OR "Canada" OR "France" OR "MED" OR "MED, Italy" OR "Turkey" OR "ANE, France" OR "British Columbia Canada" OR "Denmark" OR "North America" OR "Slovakia" OR "Sweden" OR "British Isles" OR "Chicago Illinois" OR "Estonia" OR "Germany, Berlin" OR "MED, Turkey, Anatolia, Izmir" OR "Poland" OR "Serbia" OR "USA, California" OR "USA, Florida" OR "USA, Maryland" OR "USA, North Carolina" OR "ANE, Europe" OR "ANE, Portugal" OR "ANW, USA, New York, New York City" OR "Austria" OR "Belgium" OR "British Isles, England, South Yorkshire, Sheffield" OR "Canada, British Columbia" OR "Croatia, Zagreb" OR "Europe, Mediterranean Region" OR "Finland" OR "France, Paris" OR "Greece" OR "INE, USA, Pacific Northwest" OR "Italy" OR "Latvia" OR "MED, Black Sea" OR "Netherlands" OR "New York" OR "New York City New York" OR "Norway" OR "Quebec Canada" OR "Romania" OR "Romania, Bucharest" OR "Rome Italy" OR "USA, Georgia" OR "USA, Illinois" OR "USA, Illinois, Chicago" OR "USA, Ohio" OR

"USA, Pennsylvania") AND at.exact("Article" OR "Review") AND stype.exact("Scholarly Journals") AND la.exact("ENG")))

Appendix A.2 Questions used to code and analyse documents in Chapter 2

1. Information of articles: authors; year of publication; study location; name of journal and methodology	
1.1. Authors	
1.2. Year of publication	
1.3. Study location	
1.4. Name of Journal	
1.5. Methods	Case study; Literature review; Remote sensing; Interviews; Participant survey; Field survey; Spatial analysis
2. Concepts: system(s) or practice(s) studied	
2.1. System(s) studied	Food forest; Forest garden; Community garden; Allotment (or allotment garden); Homegarden; Edible forest; Agroforestry system; Urban garden; Home garden; Riparian buffer; Edible landscape; Orchard
2.2. Practice(s) studied	Food forestry; Forest gardening; Urban food forestry; Home gardening; Agroforestry; Edible landscaping; Urban greening
3. Description of a system or a practice: nature of biological component; spatial configuration of trees; temporal configuration of trees and livestock/non-woody plants; socio-economic management level, location; scale	
3.1. Nature of biological component (trees-crops-livestock)	3.1.1 Planting of fruit and/or nut trees ("food trees") only: Monoculture orchard; Polyculture orchard; Street planting
	3.1.2 Agrisilviculture (crops and trees or crops and shrubs/trees): Food (or unspecified) trees and non-woody plants; Food (or unspecified) trees, shrub and non-woody plants
	3.1.3. Silvopastoral (pasture/animals and tree crops): Fruit or nut trees with livestock
	3.1.4. Agrosilvopastoral (crops, pasture/animals and trees): Food trees, non-woody crops, and livestock; Food trees, shrub, non-woody crops, and livestock
	3.1.5. Apticulture with trees
	3.1.6. Aquaculture with trees
3.2. Spatial configuration of trees	Alternative rows or alley cropping; Grouped; Isolated; Scattered (random mixture); Trees on boundary; Mixed dense; Unknown
3.3. Temporal configuration of trees and	Coincident; Concomitant; Sequential (separate); Unknown

livestock/non-woody plants	
3.4. Socio-economic management level	3.4.1. Level of technology input (etc. machinery) and infrastructure (e.g. facilities, trails)
	3.4.2. Intensities of use: Presence of individual plots
	3.4.3. Cost/benefit relations (e.g. commercial; subsistence; intermediate)
	3.4.4. Accessibility, tenure, or ownership (private versus public)
3.5. Location	Suburban; Urban; Peri-urban; Vacant lots; Streets; Urban parks; Private lands; Riparian; Agricultural lands; Household
3.6. Scale (size)	No predetermined code
4. Functions of trees and systems studied: ecosystem services; biodiversity; well-being and ecosystem disservices	
4.1. Ecosystem services	Provisioning: Food; Fresh water; Wood and fiber; Fuel
	Regulating: Carbon sequestration and storage; Climatic regulation (temperature control); Disease regulation; Flood regulation; Water purification
	Cultural: Aesthetic; Educational; Recreational; Spiritual
	Supporting: Nutrient cycling; Primary production; Soil formation
4.2. Biodiversity	No predetermined code
4.3. Well-being	Basic material for good life: Access to goods; Adequate livelihoods; Shelter; Sufficient nutritious food
	Good social relations: Ability to help others; Mutual respect; Social cohesion
	Health: Access to clean air and water; Feeling well (mental, psychological); Strength (Physical)
	Security: Personal safety; Secure resource access; Security from disasters
	Freedom of choice an action
4.4. Ecosystem disservices	No predetermined code

Appendix A.3. A list of 44 articles included in the review

Author	Year	Presence of food trees and vegetation structure)	Nature of biological components (trees, crops, livestock)		Practice	Study Location	Methods	Title	Name of Journal
Masson, V; Lion, Y; Peter, A; Pigeon, G; Buyck, J; Brun, E	2013	Food production system with unspecified trees (no mentioning of shrubs and food trees)	Trees and crops		Urban planning and agroforesty	France	Planning, Scenario planning	"Grand Paris" : regional landscape change to adapt city to climate warming	Climate Change
Larondellea, Neele; Strohbacha, Michael W	2016	Food trees only	Trees		Urban foraging and urban trees	Germany	Field survey	A murmur in the trees to note: Urban legacy effects on fruit trees in Berlin, Germany	Urban Forestry & Urban Greening
Davies, Z G; Fuller, R A; Loram, A; Irvine, K N; Sims, V; Gaston, K J	2009	Food trees only	Trees		Wildlife gardening	UK	Participant survey	A national scale inventory of resource provision for biodiversity within domestic gardens	Biological Conservation
La Rosa, Daniele; Barbarossa, Luca; Privitera, Riccardo; Martinico, Francesco	2014	Food production system with food trees	Trees and crops		Agroforestry and New Forms of Urban Agriculture	Italy	Spatial analysis	Agriculture and the city: A method for sustainable planning of new forms of agriculture in urban contexts	Land Use Policy
Majzlan, O; Holecova, M	1993	Food trees only	Trees		Unclear	Slovak	Field survey	Arthropodocoenoses of an orchard ecosystem in urban agglomerations	Ekologia-Bratislava
Meenar, M R	2017	Food trees only	Trees		Urban agriculture and community gardening	USA	Spatial analysis; Multicriteria analysis	Assessing the spatial connection between Urban agriculture and equity	Built Environment
Gray, L; Guzman, P; Glowa, K M; Drevno, A G	2014	Food production system with food trees	Trees and crops		Home gardening and urban agriculture	USA	Participant survey	Can home gardens scale up into movements for social change? The role of	Local Environment

									home gardens in providing food security and community change in San Jose, California	
Morán Alonso, N; Obeso Muñiz, Í; Hernández Aja, A; Fernández García, F; Moran Alonso, Nerea; Obeso Muniz, Icaro; Hernandez Aja, Agustin; Fernandez Garcia, Felipe	2017	Food trees only		Trees		Peri-urban agriculture	Spain	Spatial analysis; Multicriteria analysis	Challenges for the revitalisation of peri-urban agriculture in Spain: Territorial analysis of the Madrid and Oviedo metropolitan areas	Moravian Geographical Reports
Bendt, Pim; Barthel, Stephan; Colding, Johan	2013	Multistorey food production system with unspecified trees	Food production system with unspecifie d trees (no mentioning of shrubs and food trees)	Trees and crops		Community gardening (different from urban agriculture)	Germany	Interviews	Civic greening and environmental learning in public-access community gardens in Berlin	Landscape and Urban planning
Irvine, S; Johnson, L; Peters, K	1999	Multistorey food production system with unspecified trees		Trees and crops		Community gardening and urban agriculture	Canada	Literature review	Community gardens and sustainable land use planning: A case-study of the Alex Wilson Community Garden	Local Environment
Anderson, P G	2016	Food trees with other food production units		Trees and crops		Research	Canada	Unclear	Comparing nineteenth and twenty-first century ecological imaginaries at Ottawa's central experimental farm	Canadian Journal of Urban Research

Vig, K; Markó, V	2005	Food trees only		Trees		Unclear	Hungary	Field survey	Comparison of leaf beetle assemblages of deciduous trees canopies in Hungary (Coleoptera : Chrysomelidae)	Communications in agricultural and applied biological sciences
Sembratowicz, I; Rusinek, E; Ognik, K	2010	Food production system with food trees		Trees and crops		Unclear	Poland	Field survey	Contents of nitrates (III) and (V), lead and cadmium in select domestic fruits	Polish Journal of Environmental Studies
Giacche, Giulia; Paffarini, Chiara; Torquati, Biancamaria	2017	Food trees with other food production units		Trees and crops		Urban agriculture	Italy	Interviews; participant observation	Cultivating changes: Urban Agriculture as a tool for socio-spatial transformation	Future of Food- Journal on Food, Agriculture and Society
Poulsen, Melissa N	2017	Food trees with other food production units		Trees and crops		Civic (urban) agriculture	USA	Interviews; participant observation	Cultivating citizenship, equity, and social inclusion? Putting civic agriculture into practice through urban farming	Agriculture and Human Values
Komisar, J; Joe, Nasr; Gorgolewski, M	2009	Food trees with other food production units	Food trees with other food production units	Trees, crops and livestock		Urban agriculture	Canada	Unclear	Designing for food and agriculture: Recent explorations at Ryerson University	Open House International
Kobyleko, T; Nowak, B	2006	Food trees only		Trees		Unclear	Poland	Field survey	Detection and occurrence of Apple mosaic virus in hazelnut in south-east Poland	Journal of Plant Pathology
Kurtz, Hilda	2001	Multistorey food production system with food trees	Food production system with unspecifie d trees (no mentioning of shrubs	Trees and crops		Community gardening	USA	Interviews; Literature review	Differentiating multiple meanings of garden and community	Urban Geography

			and food trees)							
Shestakov, I E; Zinovyevna Eremchenko, O; Viktorovna Moskvina, N	2013	Food trees only		Trees		Unclear	Russia	Field survey	Ecological state of soils and technogenic superficial formations in perm city	World Applied Sciences Journal
Kortright, R; Wakefield, S	2011	Food production system with food trees		Trees and crops		Home gardening and urban agriculture	Canada	Interviews	Edible backyards: A qualitative study of household food growing and its contributions to food security	Agriculture and Human Values
Wortman, Sam E; Lovell, Sarah Taylor	2013	Multistorey food production system with food trees		Trees and crops		Urban agriculture	USA	Literature review	Environmental Challenges Threatening the Growth of Urban Agriculture in the United States	Journal of Environmental Quality
Rishbeth, C	2004	Multistorey food production system with unspecified trees		Trees and crops		Communtiy gardening	UK	Case study; Interviews	Ethno-cultural representation in the urban landscape	Journal of Urban Design
Güler, Y; Dikmen, F; Özdem, A	2015	Food trees only		Trees		Unclear	Turkey	Field survey	Evaluation of bee diversity within different sweet cherry orchards in the SultandaĞi reservoir (Turkey)	Journal of Apicultural Science
Tóth, A; Timpe, A	2017	Food trees only		Trees		Urban agriculture system (part of green infrastructure)	Germany; Ireland; Switzerla nd; Bulgaria	Spatial analysis	Exploring urban agriculture as a component of multifunctional green infrastructure: Application of figure-ground plans as a spatial analysis tool	Moravian Geographical Reports
Newman, L; Nixon, D	2014	Food trees with other food production units		Trees, crops and livestock		Permacultur e agriculture and peri-	Canada	Interviews	Farming in an agriburban ecovillage development: An	SAGE Open

					urban agriculture			approach to limiting agricultural/residential conflict	
Pirro, Chiara; Anguelovski, Isabelle	2017	Food trees with other food production units	Trees and crops		Peri-urban agriculture	Spain	Case study	Farming the urban fringes of Barcelona: Competing visions of nature and the contestation of a partial sustainability fix	Geoforum
Askerlund, Per; Almers, Ellen	2016	Multistorey food production system with food trees	Trees and crops		Agroforestry	Sweden	Interviews; Participant observation; Archival study	Forest gardens - new opportunities for urban children to understand and develop relationships with other organisms	Urban Forestry & Urban Greening
Gürel, S; Başar, H	2015	Food trees only	Trees		Unclear	Turkey	Field survey	Heavy metal status of pear trees grown in southeastern Marmara region of Turkey	Oxidation Communications
Knigge, LaDona	2009	Food trees only	Trees		Community gardening	USA	Case study	Intersections between public and private : community gardens , community service and geographies of care in the US City of Buffalo , NY	Geographica Helvetica
Hurley, P T; Emery, M R	2018	Food trees only	Trees		Urban foraging and green infrastructure (urban forest)	USA	Spatial analysis	Locating provisioning ecosystem services in urban forests: Forageable woody species in New York City, USA	Landscape and Urban Planning
Cubino, J P; Subirós, J V; Lozano, C B	2014	Food trees only	Trees		(Household) Gardening	Spain	Spatial analysis; Participant survey	Maintenance, modifications, and water use in private gardens of Alt Empordà, Spain	HortTechnology

Gürel, S; Başar, H	2014	Food trees only		Trees		Unclear	Turkey	Field survey	Metal Status of Olive Trees Grown in Southeastern Marmara Region of Turkey	Communications in Soil Science and Plant Analysis
Budetta, P; Santo, A	1994	Food trees only		Trees		Terracing (or unspecfied)	Italy	Geological survey	Morphostructural evolution and related kinematics of rockfalls in Campania (southern Italy): A case study	Engineering Geology
Lovell, S T	2010	Food trees only		Trees		Urban agriculture (part of green infrastructure)/also mentions urban homegardens (agroforestry) in developing countries	USA	Literature review	Multifunctional urban agriculture for sustainable land use planning in the United States	Sustainability
Ružičková, H; Halada, L	2005	Food trees only		Trees		Unclear	Slovak	Field survey	Orchard meadows of Banská Štiavnica town (central Slovakia)	Polish Botanical Studies
McLain, Rebecca; Poe, Melissa; Hurley, Patrick T.; Lecompte-Mastenbrook, Joyce; Emery, Marla R.	2012	Food trees only	Multistorey food production system with food trees	Trees	Trees and crops	Urban forest management and urban greening; agroforestry/ permaculture for the Beacon Food Forest	USA	Literature review; Interviews	Producing edible landscapes in Seattle's urban forest	Urban Forestry & Urban Greening

Goltsman, S; Kelly, L; McKay, S; Algara, P; Larry, W	2009	Food trees with other food production units		Trees and crops		Park management ?	USA	Planning, Scenario planning	Raising "free range kids": Creating neighborhood parks that promote environmental stewardship	Journal of Green Building
Foo, K; Martin, D; Wool, C; Polsky, C	2014	Food trees only		Trees		Community gardening	USA	Focus group discussion	Reprint of "The production of urban vacant land: Relational placemaking in Boston, MA neighborhoods"	Cities
Lange, E; Hehl-Lange, S; Brewer, M J	2008	Food trees only	Food production system with food trees	Trees	Trees and livestock	Urban-rural fringe griculture and (green space mangement)	Switzerland	3D Visualization Scenario	Scenario-visualization for the assessment of perceived green space qualities at the urban-rural fringe	Journal of Environmental Management
Barthel, Stephan; Folke, Carl; Colding, Johan	2010	Multistorey food production system with food trees		Trees and crops		Allotment gardening	Sweden	Participant survey; Field survey	Social-ecological memory in urban gardens--Retaining the capacity for management of ecosystem services	Global Environmental Change
Dickman, C R; Doncaster, C P	1987	Food trees only		Trees		Unclear	UK	Field survey	The ecology of small mammals in urban habitats. I. Populations in a patchy environment.	Journal of Animal Ecology
Williams, P A; Gordon, A M	1992	Food production system with food trees	Food production system with food trees	Trees and crops		Agroforestry	Canada; USA	Literature review	The potential of intercropping as an alternative land use system in temperate North America	Agroforestry System
Sorace, A	2001	Food trees with other food production units	Food trees only	Trees	Trees, crops and livestock	Urban agriculture	Italy	Field survey	Value to wildlife of urban-agricultural parks: A case study from Rome urban area	Environmental Management

Duryea, M L; Blakeslee, G M; Hubbard, W G; Vasquez, R A	1996	Food trees only	Trees		Unclear	USA	Participant survey	Wind and trees: A survey of homeowners after hurricane Andrew	Journal of Arboriculture

Appendix B

Appendix B.1 Survey consent form. Nature-based Solution: Multifunctional Community Gardens in Vancouver (H19-01480)

THE UNIVERSITY OF BRITISH COLUMBIA
Faculty of Forestry

Department of Forest Resources Management
Forest Sciences Centre
2045-2424 Main Mall
Vancouver BC Canada V6T 1Z4
Phone: 604-822-3482/Fax: 604.822.9106

Survey Consent Form for "Nature-based Solution: Multifunctional Community Gardens in Vancouver"

I. Research team
Principal Investigator:

Dr. Cecil C. Konijnendijk, Faculty of Forestry, University of British Columbia (UBC).

Co-Investigator(s):
Hyeone Park, Faculty of Forestry, UBC.

Dr. Jeanine Rhemtulla, Faculty of Forestry, UBC.

Research Assistant:
Yan Ting (Taelynn) Lam, Faculty of Forestry, UBC.

II. Sponsor
This project is funded by the Social Sciences and Humanities Research Council of Canada and by the University of British Columbia.

III. Purpose
Community gardens in Vancouver provide a wide range of benefits (e.g. food, art, social interaction, education, cooling effects, etc.). However, these benefits are insufficiently or incompletely recognized. The goal of this survey is to generate quantitative evidence of benefits provided by community gardens and to understand what factors influence how and who benefit from community gardening in Vancouver.

IV. Study procedures
You will participate in a survey, which will take approximately 15 minutes to complete and you will be asked about benefits that you are experiencing through community gardening and about yourself. You can choose either online (Qualtrics.com) or paper survey (in-person). For online survey, a weblink to a survey will be provided to you. For

in-person survey, a hard copy of the survey will be provided and be collected in-person or via mail.

V. Project outcomes
Possible research products will include: journal articles, posters, conference proceedings, report of the results in plain language, and an oral presentation in 2020. If you are interested in being contacted for the information about the oral presentation on the study results, please provide us with your contact details at the bottom of this form. Data from the project may also be re-analyzed at a later point if they connect with researchers' future projects.

VI. Potential benefits
There are no explicit benefits to you by taking part in this study. However, your participation will significantly contribute to understanding and communicating the range of benefits provided by the community gardens and informing garden polices and management in the city.

VII. Potential risks
There are no known physical, psychological and cultural risks in this study. You can withdraw your participation in the study or skip questions that make you feel uncomfortable.

VIII. Confidentiality
For paper survey: Your identity will be kept confidential. All surveys will be identified only by code number. You will not be identified by name. Hardcopies will be scanned and kept in a locked storage office room of the Faculty of Forestry of the University of British Columbia, and electronic files will be encrypted and kept on the hard drives of team members' computers – all of which are encrypted and password-protected. You will not be identified by name in any report of the completed study. Only research team members indicated in this consent form have access to the data.

For online survey: Your data will be collected through UBC-hosted version of Qualtrics, which is fully compliant with the BC Freedom of Information and Protection of Privacy Act (FIPPA). The survey data will be kept secure and is stored and backed up in Canada. Your confidentiality will be respected. If you have any questions regarding FIPPA legislation and online surveys please consult the Legal Counsel, Access and Privacy at the Office of the University Counsel access.and.privacy@ubc.ca). You will not be identified by name in any report of the completed study. If you would prefer not to complete the survey online, you may complete it in a hardcopy.

If you choose to share the online survey link or post the study information to the page, or "like" the page, or "follow" it in social media, you may be publicly identified with the study. However, we will not collect your name for any data collection form or publications derived from the study.

IX. Remuneration/Compensation

All participants who choose to provide their contact information, regardless of whether their survey is completed, will be able to enter the draw to win a $50 gift card for Hunters Garden Centre or Safeway. We encourage you to complete the questionnaire in order for us to accurately analyze your data.

X. Contact for information about the study
If you have any questions about the study or survey participation, please contact Hyeone Park.

XI. Contact for concerns or complaints about the study
If you have any concerns or complaints about your rights as a research participant and/or your experiences while participating in this study, contact the Research Participant Complaint Line in the UBC Office of Research Ethics at 604-822-8598 or if long distance e-mail RSIL@ors.ubc.ca or call toll free 1-877-822-8598.

XII. Consent
Your participation in this study is entirely voluntary and you may refuse to participate or withdraw from the study at any time. As your data is confidential, we cannot withdraw your data after you submit your data. By completing this questionnaire, you are consenting to participate in this study.

Appendix B.2 Survey consent form. Nature-based Solution: Multifunctional Community Gardens in Vancouver (H19-01480)

Section A	**Community Garden** This section asks about a community garden in which you are currently involved.

1. Name of your community garden:

2. What is your role in the garden?

a) garden member b) volunteer c) board member d) coordinator e) others (please specify:

3. If you are a garden member, how long have you been a member?

4. Do you have a plot in the garden?

a) yes, individual plot b) yes, shared plot c) no, I don't have a plot

5. How many hours per week do you usually spend in your community garden during a growing season?

6. What is your primary reason for community gardening (please choose one)?

a) reducing grocery budgets b) meeting neighbors c) enjoying nature

d) learning

f) physical exercise g) others (please specify:

7. How do you usually travel to your community garden? and how many minutes does it take for you to get the garden from your home? e.g. walking (15)

Section B	**Garden Crops.** This section asks about your garden crops in the past seven days.

1. Please write the seven most important plants that you harvested from the garden (including plot and/or communal space) **in the past seven days** with a plant name, type of garden products harvested and estimate a percentage of each item to your total household consumption of each item.

Plant name	Types of use (vegetable, fruit, ornamental, wood products, fiber, dye, herbs, medicinal plants, etc.)	Estimated proportion of each item to the total consumption of the item

2. How many people are in your household?

a) 1 (myself) b) 2 c) 3 d) 4 e) 5 f) more than 5

3. Please indicate to what extent you agree or disagree with a statement: "My community garden is an important food source for myself or for my family."

a) strongly disagree b) somewhat disagree c) somewhat agree

d) strongly agree e) I don't know

Section C	**Cultural benefits.** This section asks how you experience cultural benefits through community gardening.

1. How many fellow gardeners in your garden do you know by name and their contact information?

2. How many fellow gardeners can you ask for help OUTSIDE your community garden?

3. How would you describe your sense of belonging within the garden community? (e.g. feeling or the experience of being valued, needed or important by other gardeners)

a) very weak b) somewhat weak c) somewhat strong d) very strong

4. Do you learn any of the following through your participation in your community garden (check all that apply).

a) gardening and local ecological conditions b) social organization and participation

c) local politics and ways to participate in political decisions
d) social entrepreneurship
e) other cultural food and practices
f) nutrition and diet
g) others (please specify):

*Please indicate to what extent you agree or disagree with each statement.

	Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree
5. My community garden is important source for me to acquire knowledge and skills that I identified in the Question 4.	☐	☐	☐	☐
6. I feel like the community garden is part of me.	☐	☐	☐	☐
7. When I spend time in my community garden, I feel a deep feeling of love toward nature.	☐	☐	☐	☐
8. My community garden is beautiful and aesthetically pleasant.	☐	☐	☐	☐

9. If you think that your community garden is beautiful, which of the following contributes most to the beauty of your garden? Please check ONE answer.

(a) flowers and flower beds (b) trees (c) individual plots for growing food (d) animals, birds, pollinators (d) lawn and grass (e) fences, benches, and human-made structures (f) others (please specify):

Section D	**Community gardener.** This section asks about you in order for us to understand how different gardeners experience different benefits. All information is confidential and essential to analyse the information you have provided in the previous sections and to understand who is benefiting from community gardening.

1. What is your age?

2. What is your gender?

a) female b) male c) transgender d) prefer not to answer

3. Which of the following best describes your current status?

a) Canadian citizen b) permanent resident (landed immigrant) c) refugee claimant

d) work or study permit. e) I don't know f) prefer not to answer

3. Do you consider yourself to be (check all the apply):

a) aboriginal (i.e. First Nations, Métis or Inuit) b) White (European descent)
c) Chinese d) South Asian (e.g., East Indian, Pakistani, Sri Lankan, etc.)
e) Black (e.g., African or Caribbean) f) Filipino g) Latin American/Hispanic
h) Southeast Asian (e.g., Vietnamese, Cambodian, Malaysian, Laotian, etc.)
i) Arab j) West Asian (e.g., Iranian, Afghan, etc.) k) Korean l) Japanese
m) Other (please specify):

4. What is the highest level of education you have completed?

a) below high school b) high school c) certificate or diploma d) bachelor's or higher

5. Can you estimate your household income, before taxes and deductions, from all sources for the last calendar (tax) year? (Household refers to all family (related) members of your household, excluding roommates). If you live alone, please estimate your personal income.

a) under $40,000 b) $40,000 to $79,999 c) $80,000 to $119,999 d) $120,000 and above

6. Do you experience physical constraints to access to your garden (e.g. walking)?

a) yes (if possible, please specify): b) no c) I prefer not to answer

7. How would you describe your sense of belonging to your local community in general (not limited to your garden)?

a) very weak b) somewhat weak c) somewhat strong d) very strong

8. Which of the following statements best describes the food eaten in your household in the past 12 months?

a) we always had enough of the kinds of food we wanted to eat.

b) we had enough to eat, but not always the kind of food we wanted.

c) sometimes we did not have enough to eat.

d) often we did not have enough to eat.

9. On average, how many hours per month do you engage in communal work (e.g. work parties, watering, or weeding communal plots?

10. If you do communal work, why do you engage in communal work in your garden?

a) it is mandatory as a garden member

b) others (please specify):

11. What aspects of your garden discourage or prevent you from participating in communal work?

Please write your email address if you would like to participate in a draw for winning a $50 gift card of Hunters Garden Centre or of SAFEWAY:

☐ Please check the box if you wish to be informed of a focus-group discussion next year where the research will be giving an oral presentation on the study results and ask gardeners opinions. We will contact you with your email that you provide above.

Appendix B.3 Study invitation letter

THE UNIVERSITY OF BRITISH COLUMBIA
Faculty of Forestry

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2045-2424 Main Mall
Vancouver BC Canada V6T 1Z4
Phone: 604-822-3482/Fax: 604.822.9106

Nature-based Solution: Multifunctional Community Gardens in Vancouver

Invitation Letter

Dear [community garden] coordinator,

This email is to invite you and your community garden to participate in a study that aims to generate city-wide, quantitative evidence on diverse benefits of community gardens that are important for communities in Vancouver. The collected information will serve as a basis for understanding your garden and what factors influence how and who benefit from community gardening in the city.

Your fellow gardeners and you can participate in the study in three ways:

1. Online or in-person survey: All your garden members are invited to the survey. In the survey, we will ask about your garden, benefits of your garden, and yourself. It will take approximately 15 minutes to complete the questionnaire. You can choose either online by clicking this link (https://ubc.ca1.qualtrics.com/jfe/form/SV_9ZjgIPV4AJtS40R) or in-person survey. For online survey, a weblink to the survey will be provided to you. We encourage you to participate in the survey at least one week after you harvest your garden crops to answer the questions. For in-person survey, a hard copy of the survey will be provided and be collected in-person or via mail. The survey questionnaires are available in English and Chinese.

All information is confidential. Your response will not be identified by your name. All participants who choose to provide their contact information, regardless of whether their survey is completed, will be able to enter the draw to win a $50 gift card for Hunters Garden Centre or Safeway.

We encourage you to share the invitation letter for survey (attached) among your fellow gardeners so that your garden members can participate in the study. If you would like us to come to your garden to conduct the survey in person, please let us know when is a good time for you.

2. Interview: one of your garden coordinators, or board members are invited to the interview where we will ask about your garden. The interview will take approximately 20 minutes. You may choose to chat with us in person in your community garden, via phone, or via email. With your permission, the in-person or phone interview will be audio-recorded and then transcribed to accurately record your responses. If you would prefer the interview not to be audio-recorded, written notes alone will be taken, or you may choose to respond via email. All information is confidential.

Please refer to the attached consent form for the interview for more information, and please let us know when is a good time for you to participate in the interview.

3. Garden diary and survey: All your garden members are invited to record their garden diary and conduct the survey (the same survey above). You will choose in which month among July, August and September you wish to participate in the garden diary. For the month of your choice, you will record and take a photo of your garden harvests each time when you harvest from your community garden, which will take approximately 10 minutes to complete each time. You will be given a kitchen scale to weight your harvest and a garden diary form in either a hard copy or an electronic file (Microsoft word document). If your garden decides to participate and has a secured toolshed, we can leave a scale in the shed. At the end of the month, you will participate in a survey where you are asked about your garden, benefits that you experience through community gardening, and yourself. Your garden diary and survey responses will be analyzed together. All information is kept confidential.

After we receive and review your garden diary and photos, as a token of our appreciation to your time and participation, we will give you a $50 gift card to Hunters Garden Centre or of Safeway. The garden diary form is attached. We encourage you to share the consent form for the garden diary and the survey among your garden members.

If you have any questions about the study or survey participation, please contact Hyeone Park.

If you have any concerns or complaints about your rights as a research participant and/or your experiences while participating in this study, contact the Research Participant Complaint Line in the UBC Office of Research Ethics at 604-822-8598 or if long distance e-mail RSIL@ors.ubc.ca or call toll free 1-877-822-8598.

Thank you in advance for your participation.

Sincerely,
Dr. Cecil C. Konijnendijk, Faculty of Forestry, UBC
Dr. Jeanine Rhemtulla, Faculty of Forestry, UBC
Hyeone Park (PhD candidate), Faculty of Forestry, UBC
Yan Ting (Taelynn) Lam (research assistant), Faculty of Forestry, UBC

Appendix B.4 Description of eleven ES variables

Provisioning ES variables (summarized in Table 3.2)

In the scientific literature on community gardening, different measures are used for estimating provisioning ES, mainly production or consumption of fruit and vegetables harvested from gardens. These measures include but are not limited to: the weight of vegetables harvested from the garden and their potential cost savings during four months (Algert et al., 2014); proportion of vegetables and fruit produced from gardens to total vegetable and fruit consumption during a growing season (Breuste and Artmann, 2015); proportion of household vegetable consumption from garden during a growing season and during a winter (Gregory et al., 2016); ranking of a community garden as overall produce source (Gregory et al., 2016); weight of food item and gross and net values of food harvested over a seven month period (Smith and Harrington, 2014); frequency of vegetable and fruit intake per day among community gardeners and non-community gardeners (Alaimo et al., 2008); perception of consuming more fruits and vegetables because of their community gardening (Barnidge et al., 2013); or perceived importance of gardens for food production (Camps-Calvet et al., 2016). Outside the literature of community gardening, the relative extent of crop production on farms has been estimated by assessing the proportion of food consumed that came from a farmer's own farms to the total amount of each food item consumed by the farmer's household in the past seven days (Jones et al., 2014). In this dissertation, I assessed provisioning services in the following ways:

Variety of garden crops. Gardeners often grow a variety of crops which may indicate diversity of garden crops and of their use in their community gardens (Algert et al., 2014). The survey asked gardeners to recall the seven most important plants that they harvested from the garden in the past seven days and write the name of the seven most important plants that harvested from the garden in the past seven days. The number of different plants harvested indicate a degree of variety of garden crops, and the variety of garden crops harvested per gardener was calculated by tallying up the number of different plants that were reported by gardeners.

Subsistence level of garden crops. Gardeners were asked to recall the seven most important plants that they harvested from the garden **in the past seven days** and estimate the proportion of each item that came from the garden to the total amount of each item consumed by the household. The subsistence level of garden crops per gardener was calculated by summing the proportions of all items (from zero item to seven items) that were reported by each gardener.

Perceived importance of community garden as a food source. Gardeners described the importance of their community garden for ES including food production. This approach was used to analyse relative contributions of community gardens for different ES in Barcelona (Camps-Calvet et al., 2016; Langemeyer et al., 2018). Adapted from the survey of Camps-Calvet et al. (2016), the survey asked gardeners their level of agreement to the statement: "My community garden is an important source for food to myself or my family." Response categories include: (a) "strongly disagree", (b) "somewhat disagree", (c) "somewhat agree", (d) "strongly agree", and (e) "I don't know".

Cultural ES variables

Social cohesion. Social cohesion is broadly defined as the feeling and experience of being connected to each other in a society (Veen et al., 2015, p. 1273). Community gardens provide a gathering place for people with different lifestyles or cultural backgrounds (van der Jagt et al., 2017) and encourage informal networks and social support among neighbors (Armstrong, 2000; Speak et al., 2015). Veen et al. (2015) operationalize the concept of social cohesion to two elements in a community garden setting. One element is the existence of emotional bonds to other gardeners or social networks: for example, the degree to which people know other gardeners (i.e., **garden acquaintances**). The second element is the strength of the bond or social support: for example, whether people are willing to help each other beyond work at the garden (i.e., **reciprocity**). The survey asked: 1) the number of fellow gardeners that participants know by name and their contact information and 2) the number of fellow gardeners that participants can ask for help outside their community garden.

Sense of belonging. Sense of belonging is the experience “of being valued, needed or important” (Hagerty et al., 1996, p. 236) and is a vital element of social support systems and well-being of communities. The psychological sense of community construct shares many similarities with the concept of social cohesion in terms of feeling being part of a group, emotional connection to others, and expectation of needs being met by being in a group (Young et al., 2004). We modified a related survey question used in the local survey My Health My Community and asked: “How would you describe your sense of belonging to your garden community? (e.g., feeling or the experience of being valued, needed or important by gardeners)”. Response categories included: (a) “very weak”, (b) “somewhat weak”, (c) “somewhat strong”, (d) “very strong”, and (e) “prefer not to answer”.

Place attachment. Place attachment refers to emotional and functional bonds that a person develops with a particular physical and social setting (Gross and Brown, 2008). A person may develop feelings and memories about a place over time, and such emotional bonds bring a connection between the self and the place. A person may also depend on a place for meeting one’s social, psychological and/or physical needs and can develop functional bonds with that place (Sthapit et al., 2017). Studies suggest that place attachment may promote social cohesion in urban neighborhoods (Peters et al., 2010), and residents with strong attachment to their community also experience high levels of social cohesion (Brown et al., 2003). However, we did not assume place attachment is equivalent to social cohesion as it involves the emotional and functional bonds to a physical setting (i.e., garden) as well as a social setting (i.e., community). The survey asked the level of agreement to a statement regarding place attachment adapted from Vaske and Korbin (2001): “I feel like the community garden is part of me.” Response categories included: (a) “strongly disagree”, (b) “somewhat disagree”, (c) “somewhat agree”, (d) “strongly agree”, and (e) “prefer not to answer”.

Connectedness to nature. Connectedness to nature is the extent to which people feel or view that they are an integral part of nature (Schultz, 2001). It is measured by cognitive and emotional attitudes toward nature, and emotional affinity towards nature, in particular, is found to be a power predictor for "nature-protective willingness and behavioural decisions" (Kals et al., 1999, p. 195). Adapted from survey questionnaires used by Mayer and Frantz (2004) and Kals et al. (1999), the survey asked the level of agreement to the statement: 1) "When I spend time in my community garden, I feel a deep feeling of love toward nature". Response categories include: (a) "strongly disagree", (b) "somewhat disagree", (c) "somewhat agree", (d) "strongly agree", (e) "I don't know", and (f) "prefer not to answer".

Learning. Colding and Barthel (2013) identified four learning topics acquired through community gardening: (a) gardening and local ecological conditions; (b) social organization/integration and participation; (c) politics of neighborhoods and the city and ways to participate in political decisions; (d) entrepreneurship and business. In addition, (e) nutrition and diet (Diaz et al., 2017) and (f) other cultural food and practices (Park et al., 2018) can be learned through engaging in community gardening. The survey asked gardeners to indicate what they learned through community gardening among the six learning topics and gardeners were free to add a new learning topic (open-end question). Then, they indicated the level of agreement regarding **the perceived importance of community gardening for their learning source:** "My community garden is an important source for me to acquire knowledge and skills regarding the learning streams that I indicated in Question 4". Response categories included: (a) "strongly disagree", (b) "somewhat disagree", (c) "somewhat agree", (d) "strongly agree", (e) "I don't know", and (f) "prefer not to answer". The number of learning topics represents **the diversity of learning topic**s that gardeners learn through their community gardening and the level of agreement indicates the perceived importance of their garden for learning.

Aesthetics. Desire to create a beautiful green space in a neighborhood often motivates community gardening, and some community gardens are dedicated to growing ornamental plants (Bwika, 2011). The survey asked the level of agreement to the statement: "My community garden is beautiful and aesthetically pleasing". Response categories included: (a) "strongly disagree", (b) "somewhat disagree", (c) "somewhat agree”, (d) “strongly agree”, (e) “I don’t know”, and (f) “prefer not to answer”. In order to understand what elements in gardens are appreciated by gardeners, we asked: “If you think that your community garden is beautiful, which of the following contributes most to the beauty of your garden?” Response categories included: (a) “Flowers and flower beds”, (b) “Trees and fruit trees”, (c) “Individual plots for growing food”, (d) “Animals, birds, pollinators”, (d) “Lawn”, (e) “Fences, benches, and other human-made structures”, and (f) “Others (please specify:)”.

Appendix B.5 Interview consent form and questions

THE UNIVERSITY OF BRITISH COLUMBIA
Faculty of Forestry

Department of Forest Resources Management
Forest Sciences Centre
2045-2424 Main Mall
Vancouver BC Canada V6T 1Z4
Phone: 604-822-3482/Fax: 604.822.9106

Interview Consent Form for "Nature-based Solution: Multifunctional Community Gardens in Vancouver"

I. Research team
Principal Investigator: Dr. Cecil C. Konijnendijk, Faculty of Forestry, University of British Columbia (UBC).
Co-Investigator(s): Hyeone Park, Faculty of Forestry, UBC.
Dr. Jeanine Rhemtulla, Faculty of Forestry, UBC.
Research Assistant: Yan Ting (Taelynn) Lam, Faculty of Forestry, UBC.

II. Sponsor
This project is funded by the Social Sciences and Humanities Research Council of Canada and by the
University of British Columbia.

III. Purpose
Vancouver celebrates a diversity of community gardens. The goal of this interview is to shed light on how community gardens are managed and what affects different benefits that gardeners are experiencing in Vancouver.

IV. Study procedures
You will participate in an interview, which will take approximately 20 minutes to complete, where you will be asked about your community garden. You may choose to be interviewed in person in your community garden, via phone, or via email. With your permission, the in-person or phone interview will be audio-recorded and then transcribed to accurately record your responses. If you would prefer the interview not to be recorded, written notes alone will be taken, or you may choose to respond via email.

V. Project outcomes
Possible research products will include: journal articles, posters, conference proceedings, report of the results in plain language, and an oral presentation during a focus-group discussion with community gardeners in 2020. If you are interested in being contacted for the information about the oral presentation on the study results, please provide us with your contact details at the bottom of this form. Data from the project may also be re-analyzed at a later point if they connect with researchers' future projects.

VI. Potential benefits

There are no explicit benefits to you by taking part in this study. However, your participation will significantly contribute to better understanding different management approaches of community gardens in Vancouver which may influence the range of benefits the community gardeners are experiencing. The study results will be reported at the oral presentation during the focus-group discussion in 2020.

VII. Potential risks
There are no known physical, psychological and cultural risks in this study. You can withdraw your participation in the study or skip questions that make you feel uncomfortable.

VIII. Confidentiality
All hard copies of documents and recordings will be identified only by code number and kept in a locked filing cabinet in the lab of the co-investigator in the Faculty of Forestry. You will not be identified by name in the recording, the interview transcript, and any reports of this study. Electronic files will be encrypted and stored on the hard drives of team members' computers – all of which are encrypted and password-protected. Only research team members indicated in this consent form have access to the interview data.

If you choose to be interviewed in your garden, our conversation may be heard by others who are present in the garden during the interview and your confidentiality may not be protected. Also, if you choose to post the study information to the page, or "like" the page, or "follow" it in social media, you may be publicly identified with the study. However, we will not collect your name for any data collection form or publications derived from the study.

IX. Remuneration/Compensation
There is no compensation for your participation in the interview.

X. Contact for information about the study
If you have any questions about the study or participation, please contact Hyeone Park.

XI. Contact for concerns or complaints about the study
If you have any concerns or complaints about your rights as a research participant and/or your experiences while participating in this study, contact the Research Participant Complaint Line in the UBC Office of Research Ethics at 604-822-8598 or if long distance e-mail RSIL@ors.ubc.ca or call toll free 1-877-822-8598.

<u>XII. Consent</u>
Your participation in this study is entirely voluntary and you may refuse to participate or withdraw from the study at any time. As your data is confidential, we cannot withdraw your data at a later point after you submit your data. Your signature below indicates that you understand the study and consent to participate in this study.

Your name Your signature
Date

Please check off your preference.
(1) I agree that only notes can be taken of what I have to say. ☐
(2) I agree that an audio-recording can be made of what I have to say. ☐
(3) I agree that I respond to questions via email. ☐

Please provide your contact details (email or phone number) if you are interested in attending an oral presentation
on the results of this study : ____________________

Interview questions:

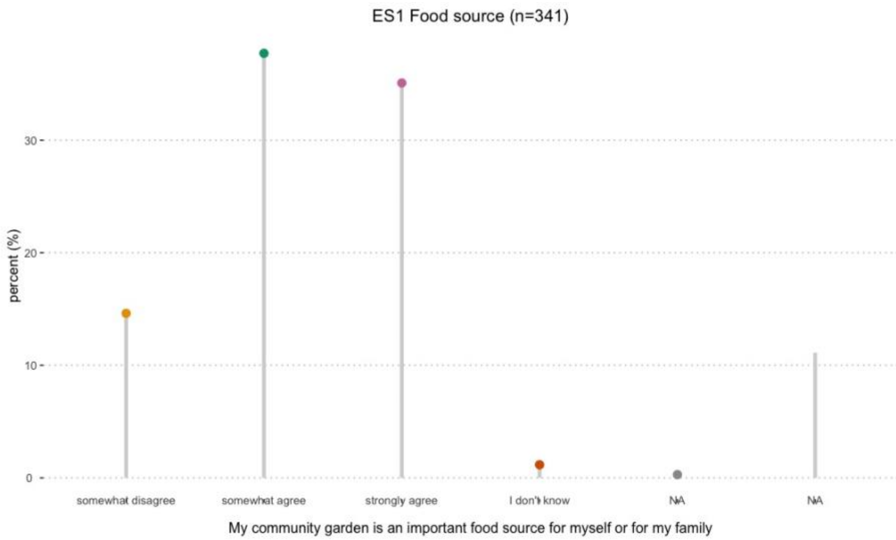
1. What is your role in the community garden? a) Coordinator, b) board member, c) manager, d) others
2. What is the size of your community garden?
3. How many members does your garden have?
4. How many individual plots are there in the garden?
5. How is the garden managed and maintained? How would you describe the type of garden management? (e.g. individual plot-oriented, shared plots-oriented, one communal plot or space-oriented, mixed, etc.)
6. Annual budget for management and maintenance?
7. What kind of events do you organize and how many events are there annually?
8. Do you have records of number of events, participants, or benefits of your garden? and can you share with us?
9. Do you have any policies or programmes to involve diversity of community members in your garden (e.g. age, abilities, and cultural backgrounds, etc.)? If there are, what are they?
10. What measures/polices are currently in place to engage garden members in communal work? What has worked and what hasn't?
11. How long is your land lease?
12. What benefits do you think your community garden/food forest provides?

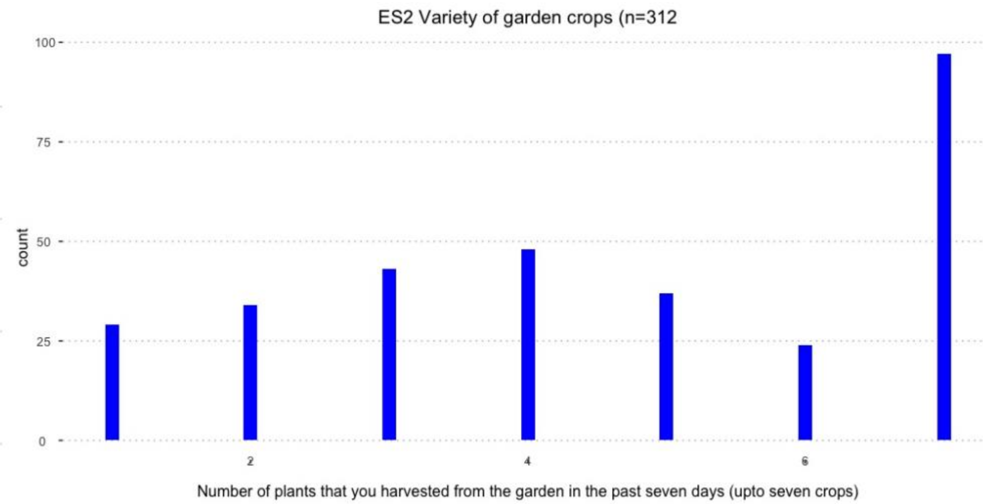
Appendix B.6 Biophysical and social characteristics of participating gardens.

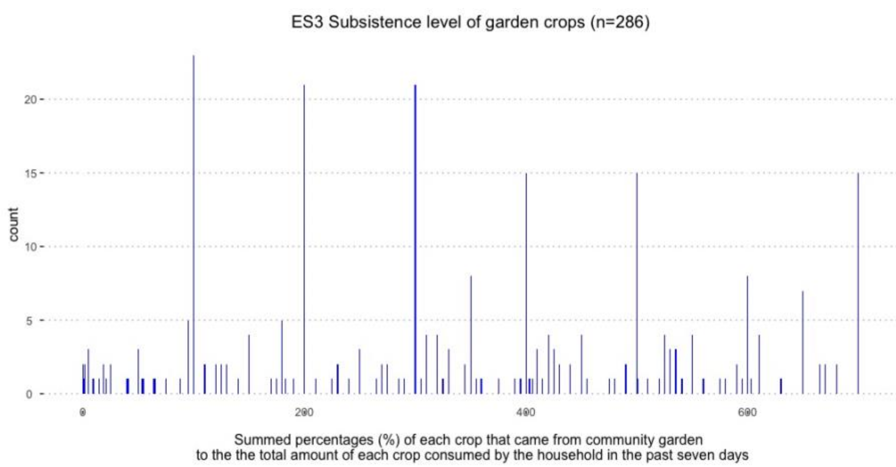
***Variables were included in the regression analysis.**

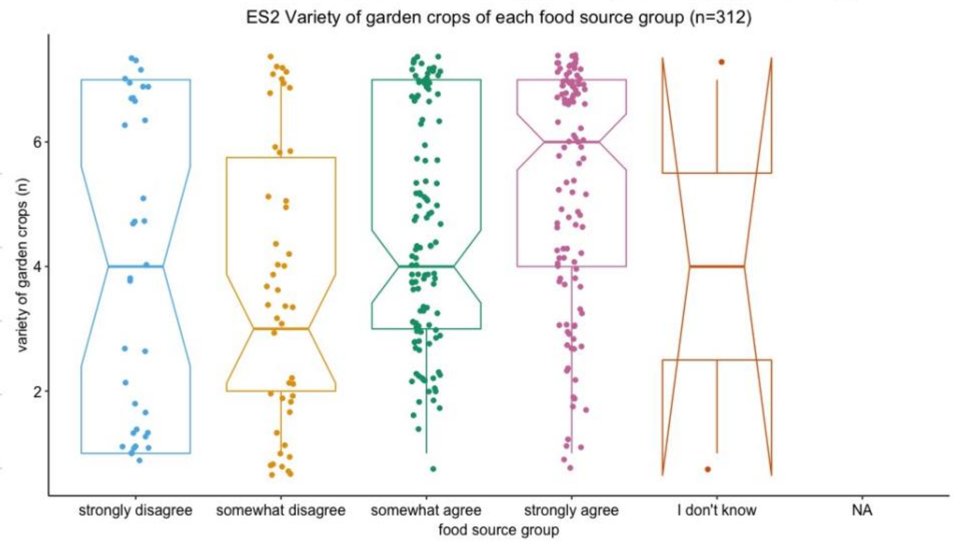
Explanatory variables	Total	Mean	S.D.	Min.	Max.	%
Biophysical						
*Garden area (ha)	8.0	0.16	0.3	0.007	1.6	
Individual plot area (m2)	16620.9	6.2	8.1	1.2	50.9	
Number of plots	2379	47.6	42.7	0	200	
*Tree canopy area (ha)	2.4	0.1	0.2	0.0	0.7	29.5
Land use						
*Total plot area (ha)	1.7	0.04	0.07	0.002	0.4	20.7
*Communal space (ha)	2.4	0.06	0.2	0.001	0.7	30.4
Recreation area (ha)	0.8	0.02	0.06	0.49	0.3	10.0
Infrastructure area (ha)	0.1	0.002	0.005	0.062	0.03	1.5
Trail (ha)	3.0	0.06	0.06	0.003	0.3	37.4
***Management type**						
Individual gardens (n)	11					22.0
Collective gardens (n)	11					22.0
Mixed gardens (n)	28					56.0
***Mandatory work party or volunteer hours required**						
Yes (n)	33					66.0
No (n)	13					26.0
NA (n)	4					8.0
Presence of fruit trees						
Yes (n)	31					62.0
No (n)	19					38.0

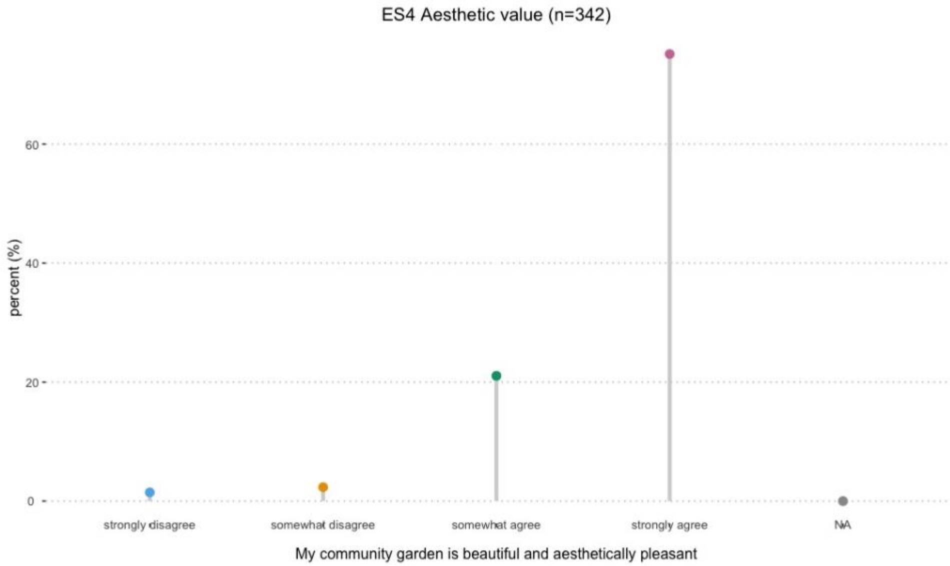
Appendix B.7 Visual representation of the ES perceived by gardeners.



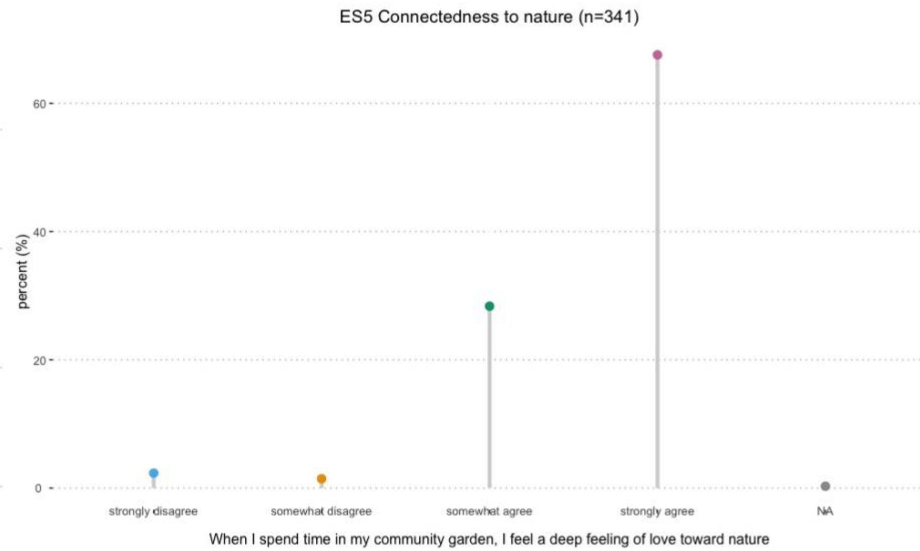




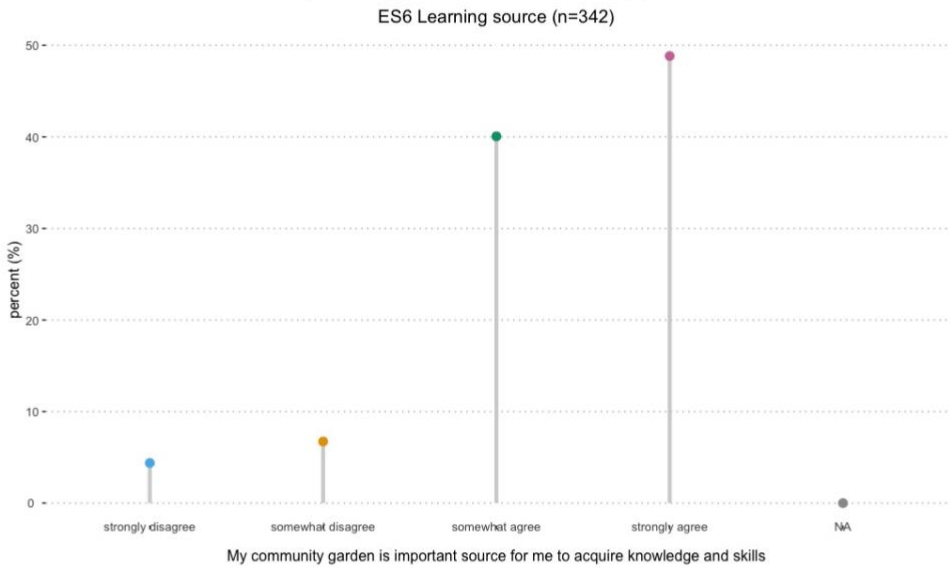




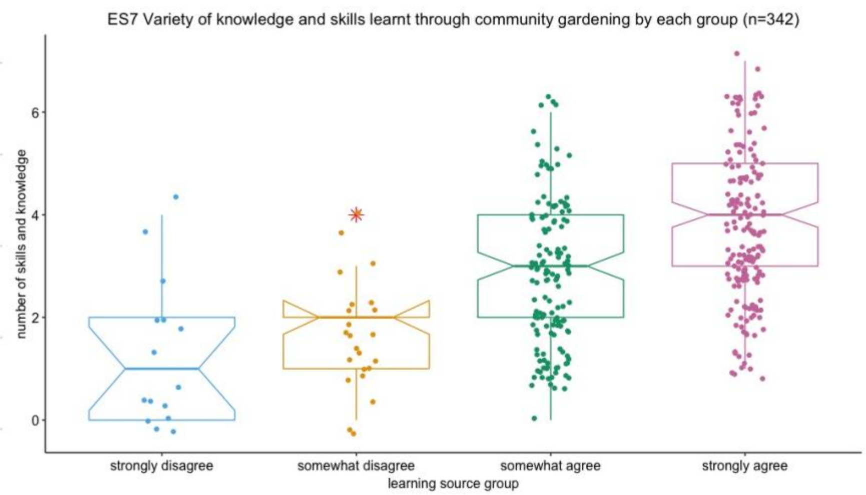
ES4 Aesthetic value (n=342)
percent (%)
60
40
20
0
strongly disagree
somewhat disagree
somewhat agree
strongly agree
NA
My community garden is beautiful and aesthetically pleasant



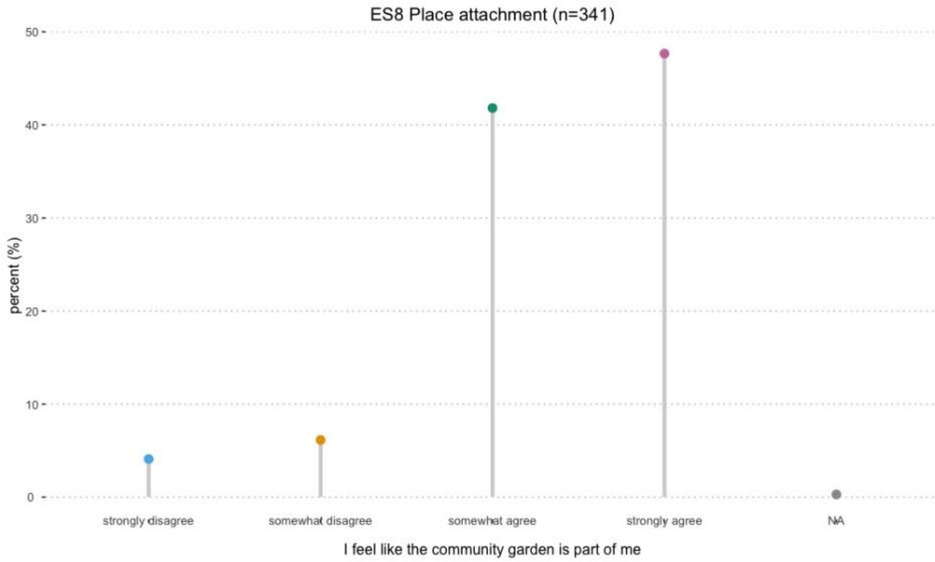
ES5 Connectedness to nature (n=341)
percent (%)
60
40
20
0
strongly disagree
somewhat disagree
somewhat agree
strongly agree
NA
When I spend time in my community garden, I feel a deep feeling of love toward nature

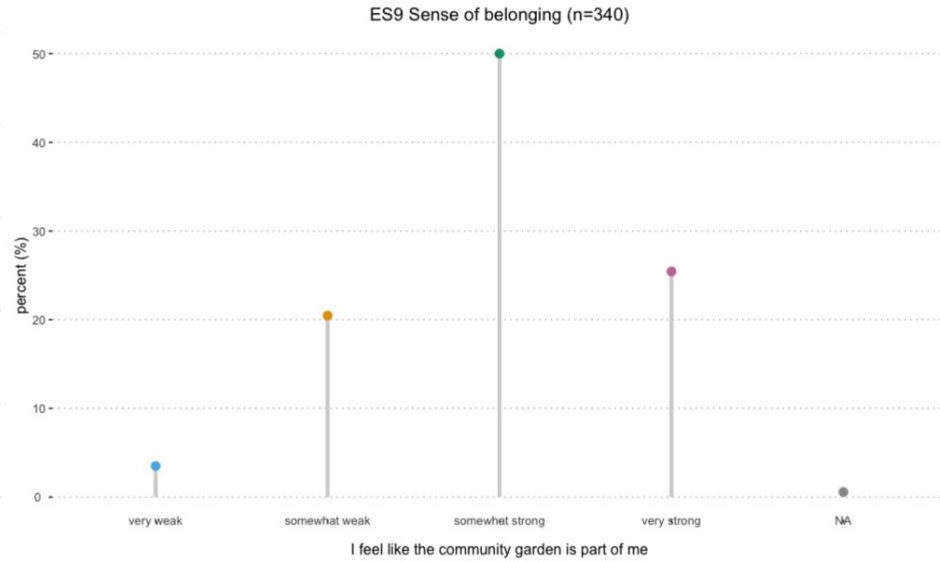


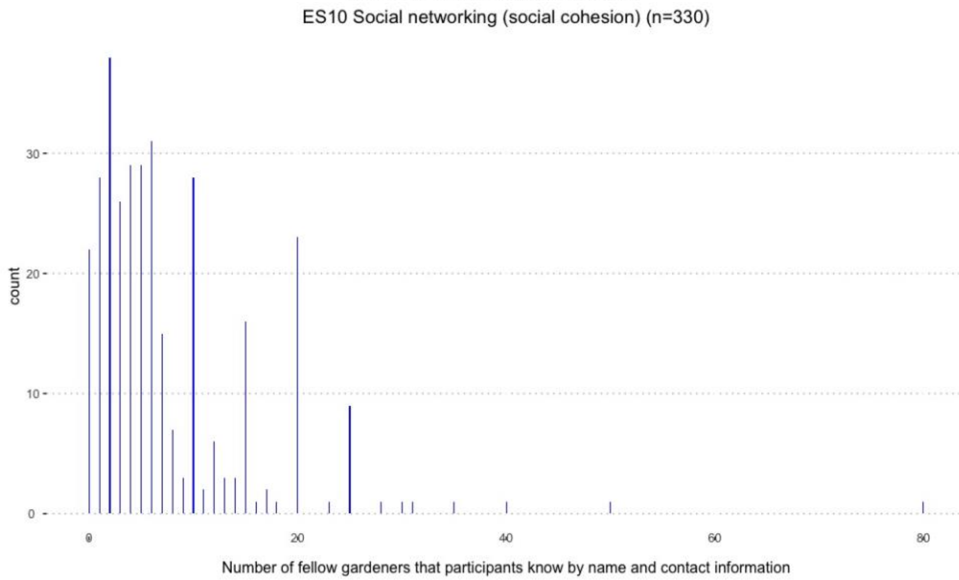
ES6 Learning source (n=342)
percent (%)
50
40
30
20
10
0
strongly disagree
somewhat disagree
somewhat agree
strongly agree
NA
My community garden is important source for me to acquire knowledge and skills

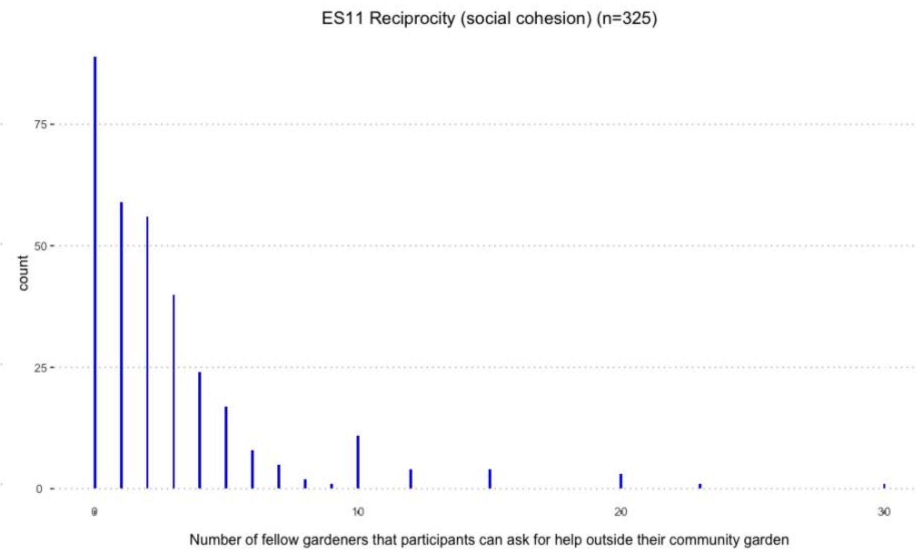


ES7 Variety of knowledge and skills learnt through community gardening by each group (n=342)
number of skills and knowledge
6
4
2
0
strongly disagree
somewhat disagree
somewhat agree
strongly agree
learning source group


ES8 Place attachment (n=341)
percent (%)
50
40
30
20
10
0
strongly disagree
somewhat disagree
somewhat agree
strongly agree
NA
I feel like the community garden is part of me


ES9 Sense of belonging (n=340)
percent (%)
50
40
30
20
10
0
very weak
somewhat weak
somewhat strong
very strong
NA
I feel like the community garden is part of me


ES10 Social networking (social cohesion) (n=330)
count
30
20
10
0
0
20
40
60
80
Number of fellow gardeners that participants know by name and contact information


ES11 Reciprocity (social cohesion) (n=325)
count
75
50
25
0
0
10
20
30
Number of fellow gardeners that participants can ask for help outside their community garden

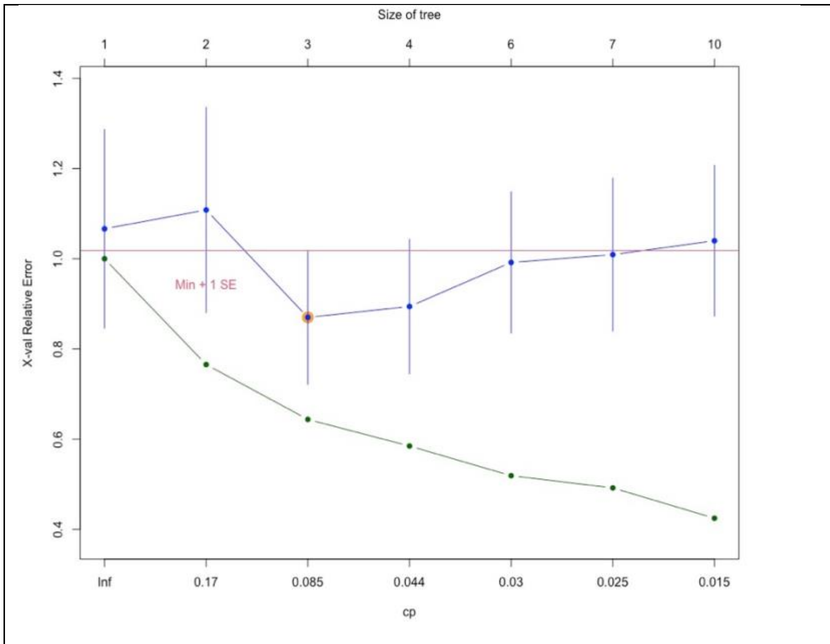
Appendix B.8 Mixed-effect regression analyses of ES associations

Dependent variable	Independent variable	Marginal R-squared	Esti-mate	Std. Error	z value	Pr(>|z|)	AIC	BIC	Log likely-hood	# of observa-tions	df.resid	Model
Aesthetic	Intercept	0.52	1.53	0.96	1.59	0.11	48.8	66.6	-19.4	258	253	glmmTMB(Aesthetic ~ Place attachment + Learning source + Subsistence level of garden crops + (1|garden), family = binomial(), data=survey)
	Place attachment agree		2.21	0.93	2.36	0.01						
	Learning source agree		4.0	1.18	3.40	0.00						
	Subsistence level of garden crops		-0.00	0.00	-2.08	0.03						
Connected-ness to nature	Intercept	0.42	-0.15	0.79	-0.19	0.84	47.6	61.8	-19.8	258	254	glmmTMB(Connectedness~ Place attachment + Learning source + (1|garden), family = binomial(), data=survey)
	Place attachment agree		2.71	1.38	1.95	0.05						
	Learning source agree		3.63	1.41	2.57	0.01						
Number of garden acquaintances	Intercept	0.25	1.27	0.35	3.64	0.00	1544.9	1573 .3	-764.5	258	250	glmmTMB(Number of garden acquaintances ~ Aesthetic + Place attachment + Connectedness + Sense of belonging + Subsistence level of garden crops + (1|garden), family = nbinom2(link = "log"), data=survey)
	Place attachment agree		0.82	0.23	3.54	0.00						
	Connectedness to nature agree		-0.59	0.34	-1.73	0.08						
	Sense of belonging strong		0.73	0.13	5.38	0.00						
	Subsistence level of garden crops		0.01	0.00	2.50	0.						
	Aesthetic agree		-0.33	0.32	-1.02	0.3						
Learning source	Intercept	0.4	-6.47	2.04	-3.16	0.00	136.6	157. 9	-62.3	258	252	glmmTMB(Learning source ~ Aesthetic + Place attachment + Connectedness + Sense of belonging + (1|garden), family = binomial(), data=survey)
	Aesthetic agree		3.76	1.41	2.66	0.00						
	Connectedness to nature agree		3.10	1.47	2.10	0.03						
	Sense of belonging strong		1.68	0.55	3.04	0.00						

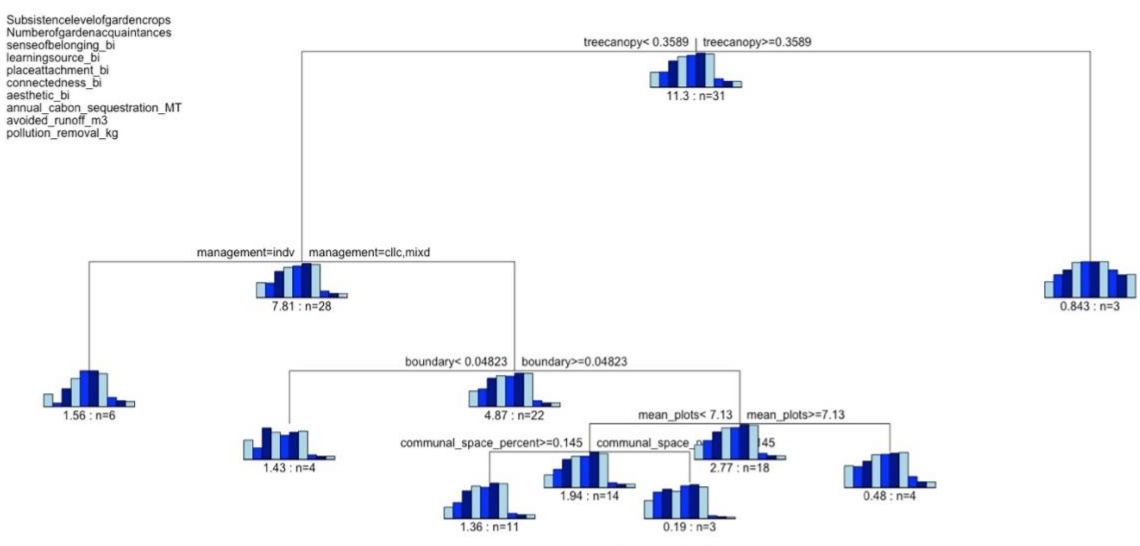
	Place attachment agree		1.57	0.72	2.17	0.02						
Place attachment	Intercept	0.62	-5.78	1.77	-3.26	0.00	127.1	148.5	-57.6	258	252	glmmTMB(Place attachment ~ Connectedness + Aesthetic + Learning source + Number of garden acquaintances + (1|garden), family = binomial(), data=survey)
	Connectedness to nature agree		3.95	1.32	2.99	0.00						
	Aesthetic agree		3.49	1.20	2.91	0.00						
	Number of garden acquaintances		0.25	0.08	3.00	0.00						
Subsistence level of garden crops	Intercept	0.04	392.49	64.27	6.10	0.00	3470.9	3495.7	-1728.4	258	251	glmmTMB(Subsistence level of garden crops ~ Number of garden acquaintances + Aesthetic + Learning source + Place attachment + (1|garden), family = gaussian(), data=survey)
	Number of garden acquaintances		3.375	1.49	2.25	0.02						
	Aesthetic agree		-179.79	75.27	-2.38	0.01						
	Learning source agree		49.65	44.37	1.11	0.26						
	Place attachment agree		52.32	46.27	1.13	0.25						
Sense of belonging	intercept	0.39	-1.20	0.49	-2.42	0.01	248.9	263.1	-120.5	258	254	glmmTMB(Sense of belonging ~ Learning source + Number of garden acquaintances + (1|garden), family = binomial(), data=survey)
	Learning source agree		1.73	0.48	3.60	0.00						
	Number of garden acquaintances		0.16	0.043	3.86	0.00						

Appendix C

Appendix C.1 Two MRT outputs with ten ES and five garden variables, as outputs of mvpart(xv=pick) function from the R package '*mvpart'*

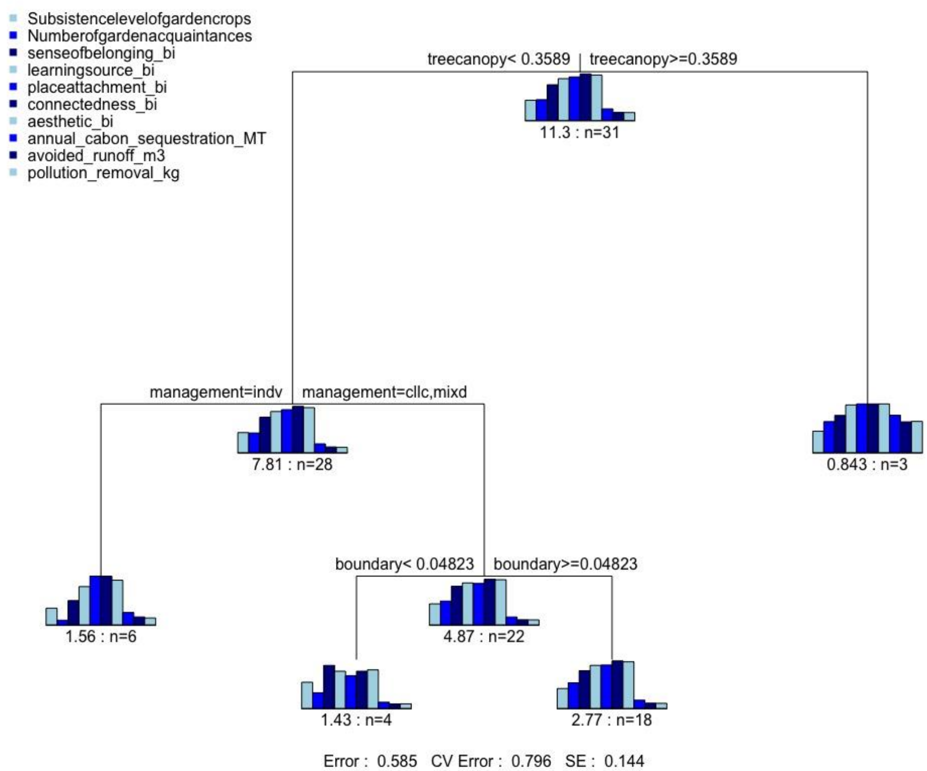


Blue line: cross-validated relative error
Green line: relative error
'cp' : complexity parameter to which the mvpart object will be trimmed
Orange dot: the smallest tree within one standard error of the cross-validated relative error



*the top figure: size of tree (i.e. number of splits) ; and
*the bottom figure: results of the regression tree

Appendix C.2 Results of the multivariate regression tree, as output by the R package mvpart (xv=min)



R code: mvpart(form = data.matrix(ES) ~ ., data = Driver, xv = "min", xval = 10, xvmult = 0, plot.add = TRUE, text.add = TRUE, which = 4, all.leaves = TRUE, prn = TRUE, keep.y = TRUE)

Summary of the results
n= 31
Variables actually used in tree construction:
[1] boundary management treecanopy

Root node error: 11.304/31 = 0.36466
n= 31

	CP	nsplit	rel error	xerror	xstd
1	0.234618	0	1.00000	1.07145	0.22311
2	0.121621	1	0.76538	1.05557	0.22512
3	0.058989	2	0.64376	0.91661	0.21930
4	0.027649	3	0.58477	0.79585	0.14365

Appendix C.3 Context words of the target word “garden” whose cosine similarity was 0.7 or above, for the four ES bundles.

	Bundle 1 (context word, cosine similarity)	Bundle 2 (context word, cosine similarity)	Bundle 3 (context word, cosine similarity)	Bundle 4 (context word, cosine similarity)
1	'bed' (0.90)	('sharing', 0.89)	('grow', 0.89)	('community', 0.89)
2	('community', 0.86)	('bring', 0.82)	('people', 0.88)	('company', 0.85)
3	('per', 0.85)	('take', 0.81)	('teach', 0.88)	('tell', 0.84)
4	('go', 0.85)	('offer', 0.81)	('together', 0.85)	('raised', 0.84)
5	('anybody', 0.84)	('far', 0.80)	('women', 0.85)	('want', 0.83)
6	('specific', 0.84)	('idea', 0.80)	('play', 0.85)	('space', 0.81)
7	('generally', 0.83)	('come', 0.80)	('interest', 0.85)	('mean', 0.80)
8	('open', 0.83)	('enjoy', 0.79)	('sometimes', 0.84)	('bed', 0.80)
9	('takes', 0.82)	('winter', 0.79)	('life', 0.83)	('two', 0.80)
10	('gardeners', 0.81)	('goes', 0.79)	('gives', 0.83)	('join', 0.80)
11	('allocating', 0.81)	('planted', 0.78)	('children', 0.83)	('see', 0.79)
12	('waive', 0.80)	('get', 0.78)	('clear', 0.82)	('interesting', 0.79)
13	('manage', 0.80)	('community', 0.78)	('place', 0.82)	('right', 0.79)
14	('online', 0.80)	('helped', 0.78)	('like', 0.82)	('communal', 0.79)
15	('software', 0.80)	('hasnt', 0.78)	('great', 0.81)	('accessible', 0.79)
16	('fee', 0.79)	('turn', 0.77)	('want', 0.81)	('come', 0.79)
17	('year', 0.78)	('gardeners', 0.77)	('guitar', 0.81)	('lose', 0.79)
18	('private', 0.77)	('growing', 0.77)	('others', 0.80)	('demand', 0.78)
19	('five', 0.77)	('whereas', 0.77)	('knowledge', 0.79)	('wedding', 0.78)
20	('allocated', 0.76)	('next', 0.76)	('bring', 0.79)	('thats', 0.78)
21	('organization', 0.75)	('meeting', 0.76)	('created', 0.79)	('nothing', 0.77)
22	('try', 0.74)	('people', 0.76)	('earth', 0.79)	('political', 0.77)
23	('signing', 0.74)	('everybody', 0.76)	('little', 0.79)	('ecology', 0.77)
24	('spaces', 0.74)	('general', 0.76)	('old', 0.78)	('take', 0.77)
25	('think', 0.73)	('workparty', 0.75)	('passing', 0.78)	('would', 0.77)
26	('like', 0.73)	('aspect', 0.75)	('theyre', 0.78)	('information', 0.77)
27	('client', 0.73)	('worked', 0.75)	('peaceful', 0.78)	('talk', 0.77)
28	('business', 0.72)	('waitlist', 0.75)	('suspect', 0.78)	('maybe', 0.77)

29	('things', 0.72)	('supposed', 0.75)	('come', 0.77)	('onethird', 0.77)
30	('high', 0.72)	('got', 0.74)	('lunch', 0.77)	('place', 0.76)
31	('could', 0.72)	('already', 0.74)	('required', 0.77)	('tour', 0.75)
32	('feedback', 0.71)	('theft', 0.74)	('mentioned', 0.77)	('works', 0.75)
33	('program', 0.71)	('way', 0.74)	('real', 0.77)	('theres', 0.75)
34	('part', 0.71)	('two', 0.74)	('things', 0.76)	('get', 0.74)
35	('years', 0.70)	('really', 0.74)	('rich', 0.76)	('years', 0.74)
36	('data', 0.70)	('great', 0.74)	('meet', 0.76)	('wants', 0.73)
37	('managing', 0.70)	('compost', 0.74)	('world', 0.76)	('mixed', 0.73)
38	('lands', 0.70)	('seem', 0.74)	('work', 0.76)	('ive', 0.73)
39	('doesnt', 0.70)	('learn', 0.74)	('oh', 0.75)	('particular', 0.73)
40	('involved', 0.70)	('thats', 0.73)	('key', 0.75)	('based', 0.73)
41	('complex', 0.70)	('year', 0.73)	('share', 0.75)	('compost', 0.72)
42	('individual', 0.70)	('like', 0.73)	('grown', 0.75)	('lots', 0.72)
43	('opportunity', 0.70)	('others', 0.73)	('guess', 0.75)	('could', 0.72)
44	('growing', 0.70)	('big', 0.73)	('helpful', 0.74)	('bring', 0.72)
45	('say', 0.70)	('interested', 0.72)	('whatever', 0.74)	('little', 0.72)
46	('build', 0.70)	('funds', 0.72)	('community', 0.74)	('people', 0.72)
47	('sometimes', 0.70)	('making', 0.72)	('encourage', 0.74)	('work', 0.72)
48	('food', 0.70)	('harvest', 0.72)	('nice', 0.74)	('talking', 0.72)
49	('land', 0.70)	('new', 0.72)	('looks', 0.74)	('terms', 0.71)
50	('amount', 0.70)	('last', 0.72)	('neighbors', 0.74)	('third', 0.71)
51	('fun', 0.70)	('even', 0.72)	('less', 0.74)	('us', 0.71)
52		('join', 0.71)	('friendhips', 0.74)	('constitution', 0.71)
53		('bed', 0.71)	('well', 0.74)	('plantings', 0.71)
54		('volunteer', 0.71)	('open', 0.73)	('past', 0.70)
55		('soil', 0.71)	('dont', 0.73)	('history', 0.70)
56		('whole', 0.71)	('probably', 0.73)	('weve', 0.70)
57		('bugs', 0.71)	('next', 0.73)	('money', 0.70)
58		('talking', 0.70)	('weekend', 0.73)	('worked', 0.70)
59		('extra', 0.70)	('hey', 0.73)	('still', 0.70)
60		('care', 0.70)	('brought', 0.73)	('drinks', 0.7)
61		('besides', 0.70)	('raised', 0.73)	('didnt', 0.70)
62		('plot', 0.70)	('space', 0.73)	('free', 0.70)
63		('share', 0.70)	('elders', 0.73)	('always', 0.70)
64		('time', 0.70)	('think', 0.73)	('big', 0.70)

65		('years', 0.70)	('skills', 0.73)	('raise', 0.70)
66		('ongoing', 0.70)	('enough', 0.73)	('make', 0.70)
67		('love', 0.70)	('majority', 0.73)	('especially', 0.70)
68		('collected', 0.70)	('tomatoes', 0.73)	('table', 0.70)
69		('started', 0.70)	('weed', 0.72)	('expansion', 0.70)
70		('endeavour', 0.70)	('alongside', 0.72)	('education', 0.70)
71		('grow', 0.70)	('us', 0.72)	('something', 0.70)
72			('walk', 0.72)	('asian', 0.70)
73			('member', 0.72)	('planned', 0.70)
74			('necessarily', 0.72)	
75			('necessary', 0.72)	
76			('beyond', 0.72)	
77			('enjoy', 0.71)	
78			('lot', 0.71)	
79			('quite', 0.71)	
80			('different', 0.71)	
81			('seen', 0.70)	
82			('found', 0.70)	
83			('sit', 0.70)	
84			('terms', 0.70)	
85			('biodiversity', 0.70)	
86			('dinner', 0.70)	
87			('illusion', 0.70)	
88			('something', 0.70)	
89			('site', 0.70)	
90			('theres', 0.70)	
91			('young', 0.70)	
92			('opportunity', 0.70)	
93			('working', 0.70)	
94			('thats', 0.70)	
95			('wouldve', 0.70)	
96			('interesting', 0.70)	
97			('call', 0.70)	
98			('still', 0.70)	
99			('raspberries', 0.70)	
100			('drink', 0.70)	
101			('far', 0.70)	
102			('food', 0.70)	
103			('benefit', 0.70)	

104	('silly', 0.70)
105	('live', 0.70)
106	('sets', 0.70)
107	('evening', 0.70)