Lots of Potential: Planning Urban Community Gardens

As Multifunctional Green Infrastructure

by

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ABSTRACT

Urban community gardens hold the potential to serve as a form of multifunctional green infrastructure to advance urban sustainability goals through the array of ecosystem services they afford. While a substantial body of literature has been produced that is dedicated to the study of these services (e.g., providing fresh produce, promoting socialization, and enhancing urban biodiversity), less attention has been paid to the strategic planning of urban community gardens, particularly in an expansive urban setting, and in the context of the co-benefit of mitigating extreme heat.

The research presented in this dissertation explores the potential of community gardens as a form of multifunctional green infrastructure and how these spaces can be planned in a manner that strives to be both systematic and transparent. It focuses on methods that can (1) be employed to identify vacant or open land plots for large metropolitan areas and (2) explores multicriteria decision analysis and (3) optimization approaches that assist in the selection of "green" spaces that serve as both provisioning (a source of fresh fruits and vegetables) and regulating (heat mitigation) services, among others. This exploration involves three individual studies on each of these themes, using the Phoenix metropolitan area as its analytical backdrop.

The major lessons from this piece are: (1) remotely sensed data can be effectively paired with cadastral data to identify thousands of vacant parcels for potential greening at a metropolitan scale; (2) a stakeholder-weighted multicriteria decision analysis for community garden planning can serve as an effective decision support tool, but participants' conceptualization of garden spaces resulted in social criteria being prioritized over physical-environmental factors, potentially influencing the provisioning of co-benefits; and (3) optimized urban community garden networks hold the potential to synergistically distribute co-benefits across a large metropolitan area in a manner that systematically prioritizes high-need neighborhoods. The methods examined are useful for all metropolises with a preponderance of open or vacant land seeking to advance urban sustainability goals through green infrastructure.

DEDICATION

I dedicate this dissertation to all of the educators in my life who have inspired me, from elementary to graduate school. Thank you for fostering intellectual curiosity and a love of learning that has made me the person that I am today.

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URBAN COMMUNITY GARDENS: MULTIFUNCTIONAL GREEN INFRASTRUCTURE FOR THE URBAN LAND SYSTEM

1.1 Introduction

Over 80 percent of the United States' population lives in urban areas (United Nations Population Division, 2018). This percentage is expected to continue to increase as that population increases in the coming decades, generating both infill within already developed parts of cities and inexorable (sub)urbanization of the hinterlands (Boone et al., 2014; Colby & Ortman, 2014; D'Amour et al., 2017). This growth raises myriad environmental and societal challenges—especially in the context of ongoing climate change and the frequently unprecedented impacts associated with it—as the resilience of current urban systems (e.g., food access and reified infrastructure) is tested and existing problems (e.g., extreme heat) are exacerbated (Hunt et al., 2017; Meerow, 2017; Romero-Lankao et al., 2017). These challenges to make cities more sustainable will be met, in part, through a critical reassessment of urban land use and planning practices (Campbell, 1996; Godschalk, 2004; Reenberg & Seto, 2014; Turner, 2016).

A potential mechanism to help mitigate social and environmental challenges and foster a more sustainable approach to urban development is through the use of green infrastructure. Green infrastructure, although variously defined, is generally considered to be a deliberate planning decision to either manage or integrate a variety of "greened" features (e.g., parkland, bioswales, green roofs, and stormwater retention ponds) into the urban landscape (Benedict & Mcmahon, 2001; Gill et al., 2007; Jerome, 2017; Lovell & Taylor, 2013). In many cases, these features are considered to be multifunctional and supply urban areas with an array of ecosystem or environmental services (Wu, 2013), including the four original categories applied to them: provisioning services, regulating services, cultural services, and supporting services (Carpenter et al., 2009).

It is in this same vein that urban agriculture, particularly in the form of urban community gardening, has become increasingly regarded as a form of multifunctional green infrastructure that holds the potential to promote urban sustainability goals through the array of ecosystem services it affords (Camps-Calvet et al., 2016; Lin et al., 2017; Newell et al., 2020; Russo et al., 2017). These services (also referred to as benefits or co-benefits) include locally-grown produce (Nicholls et al., 2020; Rosan & Pearsall, 2017; Russo et al., 2017; Turner, 2011), vegetative cooling (Ackerman et al., 2014; Okvat & Zautra, 2011; Zhang et al., 2017), spaces for outdoor recreation and community enrichment (Andreotta et al., 2019; Egli et al., 2016; Firth et al., 2011), and habitats for native flora and fauna (Cabral et al., 2017; Goddard et al., 2013; Paker et al., 2014).

The range of services notwithstanding, community gardens have thus far been championed largely for their provisioning and cultural services. Provisioning is linked to the role of community gardens to provide spaces to grow fresh and nutritious foods, resulting in the frequent siting of these gardens in neighborhoods designated as “food deserts”. Variously defined, food deserts are broadly considered to be neighborhoods in which access to affordable fresh, nutritious food options is limited (Dutko et al., 2012; Rhone et al., 2019; Walker et al., 2010). In addition to this provisioning, cultural services focus on community building, using gardens as locations for neighborhood engagement and the potential to build positive linkages from the interactions (Langegger, 2013; Petrovic et al., 2019).

While various benefits of urban community gardens have received extensive attention and other benefits are increasingly explored, at present the actual planning of urban community gardens across the country is not methodologically uniform nor necessarily systematic; rather, gardens are placed through a mixture of ad hoc methods or are treated as one-off projects (Eanes & Ventura, 2015; Saha & Eckelman, 2017). As a result, the identification process for a potential community garden location tends to lack the range of co-benefits considered. As such, these limitations may potentially overlook conditions that could improve or hinder the overall success of an urban community garden and which may reinforce certain urban inequities regarding neighborhood greening (Andersson et al., 2019; Heckert & Rosan, 2016; Meenar, 2017).

This dissertation examines urban community gardens as a form of multifunctional green infrastructure. It focuses on systematic methods that can (1) be employed to identify vacant or open land plots for large metropolitan areas and (2) explores multicriteria decision analysis and (3) optimization methods that assist in the selection of "green" spaces that serve as both provisioning (a source of fresh fruits and vegetables) and regulating (heat mitigation) services, among others. This exploration involves three research papers on each of these themes, using the Phoenix metropolitan area as its analytical backdrop. The methods examined, however, are useful for all metropolises with a preponderance of open or vacant land.

1.2 Background to the Research Problem

This research focuses on urban community gardens. These gardens increasingly are explored in terms of their multiple beneficial functions, both social and environmental, particularly concerning food contribution and nutritional health outcomes (Clinton et al., 2018; Lovell & Taylor, 2013; Russo et al., 2017). Regardless of these functions, community gardens are typically small-size plots or concentrations of cultivated plots on public or private property and are managed by members of a community (commonly hobbyists), sometimes with the support of non-profit organizations or government (Lin et al., 2017; Rosan & Pearsall, 2017). This research addresses such entities and does not include commercial agriculture within urban boundaries, commonly private enterprises undertaken on large plots of land, or household gardens, typically small in space, undertaken by individual households on their own home plots.

1.2.1 Land System Science, Urban Ecology, and Land System Architecture to Urban Planning

Scholarship related to the development and impact of urban form (primarily from an econometrics perspective) can be traced back to the early 1800s (Blanco, 2014; Fischer, 2011), with a focus on human relationships within the urban built environment itself, a subsequent interest emerging in the 1920s (Park et al., 1967). The incorporation of the ecological functions within an urban system is—by comparison—relatively nascent (Forman, 2014; Grimm et al., 2003; Hasse, 2014). The concept of urban ecology extends ecosystem services into the built environment (Grimm et al., 2003) and helped retool the conceptualization of the urban areas as highly complex, multiscale social-ecological/environmental systems (SESs) comprised of humans, natural processes, and the built environment which operate in the context of institutions, economics, social networks, and technology (Grimm et al., 2013; Haase et al., 2014; McPhearson et al., 2016). The application of urban ecology has, therefore, been highly varied and ranges in topics from urban biodiversity (Chollet et al., 2018; Hope et al., 2008) to urban biochemical cycling (Kaye et al., 2006; Lin et al., 2014) to the impact of the urban landscape on human health (Douglas, 2012; Pejchar et al., 2015). With its consideration of a variety of ecosystem services (i.e., those produced by both the environment and by humans operating in that space), urban ecology effectively provides the basis for green infrastructure, and how its integration into the urban landscape holds the potential to foster urban resilience and lead to more sustainable planning (Andersson et al., 2019).

Even within the interdisciplinary field of urban ecology, however, there remains a need for "…[a] *spatially explicit understanding of how urban structures that relate to functions are distributed across an urban extent* [that] *can enable planners and policymakers to better identify areas of vulnerability and spatially prioritize interventions…"* (McPhearson et al., 2016, p. 206). To facilitate a more nuanced understanding of the cumulative impacts of local or microscale land system processes and to facilitate the aforementioned spatially explicit understanding of form and function. It is in this vein that Land System Science (LSS) has entered the urban research domain.

LSS is the study of SESs (i.e., the dynamic, multiscale interplay between the human and environmental subsystems) concerning land use and land cover change across the earth's surface (Lambin & Meyfroidt, 2010; Turner et al., 2007; Turner, Lambin, et al., 2020). Through the use of remote sensing, GIS, and other analyses, LSS evaluates changes across these systems at multiple spatial and temporal scales, studying both the drivers of change and how those changes have the potential to diminish or increase environmental services, vulnerabilities, and resilience (Turner et al., 2021; Turner, Meyfroidt, et al., 2020). As such, by incorporating both the biogeophysical and the social/institutional drivers of land use and land cover change (Meyfroidt et al., 2018; Munroe & McSweeney, 2019), LSS has made substantial contributions to the study of far-reaching phenomena with global implications, such as environmental degradation and resource management (Chowdhury et al., 2017; Lambin & Meyfroidt, 2010; Munroe et al., 2019), urbanization and sustainable development (Brelsford et al., 2017; Seto et al., 2011, 2012), and agricultural change (Aspinall & Staiano, 2019; Hanaček & Rodríguez-Labajos, 2018; Heinimann et al., 2017). More recently, studies have begun to reexamine urban areas as a critical component of SESs (Hasse, 2014; Hersperger et al., 2018; Seto et al., 2017; Stokes & Seto, 2016) in two general ways, coarse- and fine-grain examinations. Coarse-grain studies tend to aggregate conditions at the city level or to treat urban areas as assemblages of classified pixels (e.g., Clinton et al., 2018; D’Amour et al., 2017; Ishtiaque et al., 2017; Khandelwal et al., 2017). Fine-grain studies, in contrast, have begun to examine the internal land system of cities, with a particular lens on the design or architecture of land covers and their impacts (Jenerette et al., 2016; Stuhlmacher et al., 2020; Wentz et al., 2016).

Land System Architecture (LSA) is part of LSS’s response. It seeks to provide a broader understanding of the multifaceted dimensions of SESs through the use of fine-grain spatial analyses that explore the impact of size, shape, composition, and configuration of land units on ecosystem service trade-offs and synergies (Turner, 2014, 2016). Because of this, LSA is apt to examine the intricacies of urban SESs. It and similar approaches variously labeled (e.g., urban morphology) have become increasingly applied to issues of urban sustainability, particularly the impacts of urban greening and how the characteristics and distribution of land features within heterogeneous urban and peri-urban regions can have wide-ranging impacts. The concept of LSA has arguably been most influential in advancing research concerning the urban heat island effect (Estoque et al., 2017; Galletti et al., 2019; Kamarianakis et al., 2019; Li et al., 2017; Zhang et al., 2017; Zhou et al., 2011) but has also been applied to topics such as the peri-urban water-energy nexus (Wentz et al., 2016) and the biodiversity implications urban land use and land cover change (Stuhlmacher et al., 2020). LSA is not just exclusive to fundamental assessments of urban challenges and impacts but can also be applied to inform sustainable urban planning interventions.

This dissertation research began from an LSS framing of LSA, informed by interests of urban ecology, on urban open spaces and their potential multifunctional uses. During the research process, however, the role of community gardens emerged, increasingly raising the role of provisioning and cultural services, expressed in ecosystem service terms, over other service roles, such as heat mitigating functions of green spaces. As such, the framing references of the original research problem merged with that on urban planning for sustainability, in which community gardens, their roles, and placements, have long been addressed.

Sustainable urban planning is not dissimilar, in principle, from the concepts of sustainability addressed as an assemblage of multiscale SESs applied in LSS and urban ecology. Indeed, the “Triple Bottom-Line” of economy, environment, and equity applied in planning is consistent with the sustainability link wherein the challenge is one concerning the flow of services and the actual configuration and composition of the urban landscape itself (Birch & Wachter, 2008; Wu, 2010). Multiple issues follow from these concepts that are variously accounted for in urban studies and planning, two of which are important for this dissertation.

The first is the multifunctionality of community gardens as green spaces that provide ecosystem services. As expanded on in the ensuing sub-sections, significant attention has been given to the provisioning and cultural services of urban community gardens (Petrovic et al., 2019; Rosan & Pearsall, 2017) and—to a lesser extent—regulating and supporting services, such as their ability to mitigate the extreme heat (Okvat & Zautra, 2011; Zhang et al., 2017). Relatively fewer studies have considered these co-benefits (particularly the environmentally-centered services) in a holistic sense As previously noted, urban community gardens can offer an array of ecosystem services that make them a boon for urban sustainability goals. However, the full suite of co-benefits needs to be recognized and factored into planning decisions if the multifunctional potential of community gardens is going to be realized.

The second issue involves the conflicts arising over the emphasis of the aforementioned functions and the spatial planning, or physical siting, of urban community gardens-green spaces. The utilization and location of urban land can prove to be contentious wherein conflicts arise between each of the components of the Triple Bottom Line and developing sustainable solutions (Campbell, 2016). Varying interests or objectives frequently compete with one another when decisions are made concerning where to site urban green infrastructure (Meerow, 2020; Pearsall et al., 2014).

Moreover, siting can be impeded by inadequate or inappropriate decision support tools, especially those that do not account for the synergies and tradeoffs—both social and environmental— that can affect siting, with implications for the ecosystem services gardens deliver. Decision support tools can help to ease these conflicts by revealing tradeoffs and synergies and providing a systemic approach for siting that promotes both equity and transparency. These tools, such as multicriteria decision analyses, have long been used to enhance the site selection process given an array of factors that contribute to the suitability or long-term viability of a given project and competing priorities are at play (Dobson, 1979; Malczewski, 1999; McHarg, 1969; Nyerges & Jankowski, 2010). Because of their ability to include both experts and stakeholders in the decision-making process (Meerow, 2020; Ranger et al., 2016), multicriteria decision analyses are popular for a number of problems, such as strategic facility siting (Awasthi et al., 2011; Sadler, 2016), transportation infrastructure planning (Barfod & Leleur, 2014; Nalmpantis et al., 2019), environmental conservation (Davies et al., 2013; Portman et al., 2016) and the implementation of green infrastructure (Heckert & Rosan, 2016; Langemeyer et al., 2020).

1.2.2 Ecosystem Services and Co-Benefits of Community Gardens

The most frequently cited ecosystem service of urban community gardens development is its provisioning service, the contribution to urban food systems (Albright, 2020; Okvat & Zautra, 2011). By serving as a local source of fresh produce, community gardens hold the potential to assist in the amelioration of urban food deserts, providing communities with healthier food choices when such options may otherwise be scarce (Egli et al., 2016; Rosan & Pearsall, 2017; Uludere Aragon et al., 2019). Other co-benefits include improvements in health and mental well-being (Branas et al., 2018; Engemann et al., 2019; South et al., 2018), educational opportunities (Cohen & Reynolds, 2014), and the reversal of urban blight by using otherwise underutilized land (Bowman & Pagano, 2004; Branas et al., 2018; Garvin et al., 2013). Community gardens may also serve as placemaking spaces that strengthen a sense of community and promote socialization amongst neighbors (Jerome, 2017; Petrovic et al., 2019; Wesener et al., 2020)

Additional co-benefits are more explicitly environmental in form. Biodiversity outcomes can be improved through the cultivation of urban community gardens by creating habitats for pollinators, birds, and native plants that benefit vegetation within the garden as well as plant and animal life in the vicinity (Goddard et al., 2010, 2013). The spaces also hold the potential to mitigate stormwater runoff by providing permeable groundcover, enabling more infiltration in regions where impervious surfaces may dominate the built environment (Ackerman et al., 2014; Kremer et al., 2016).

Importantly, the greening of the urban landscape serves to ameliorate extreme heat, commonly linked to the urban heat island effect, through evapotranspiration and evaporative cooling (Lin et al., 2018; Lwasa et al., 2014; Zhang et al., 2017), a role especially significant for urban areas in the Sun Belt of the United States. This service leads directly to the questions of LSS and the pattern and shape of land cover patches on heat mitigation (Huang et al., 2011; Li et al., 2013; Zhou et al., 2011). For the most part, but especially for urban areas in relatively dry climates and biomes, this mitigation follows from greening the patches (Li et al., 2016; Myint et al., 2015). Increasing research demonstrates that certain patterns and shapes of green patches, such as that provided by community gardens, increase the potential for heat mitigation (Connors et al., 2013; Li et al., 2016). Patterns and shapes that concentrate the greening appear to have a larger neighborhood or adjacent cooling effect than less concentrated ones; whereas, a more dispersed spatial arrangement of greened parcels has the potential to produce a distinct regional cooling effect, albeit not as pronounced at the local scale (Huang et al., 2011; Zhang et al., 2017). The point is that attention to the LSA or urban morphology of the green spaces matters to their mitigating capacity.

1.2.3 Detriments and Ecosystem Disservices of Community Gardens

It warrants noting that there are several potential detriments or ecosystem "disservices" associated with community gardening (Lin et al., 2017; Russo et al., 2017). Foremost among them is the risk of soil contamination, particularly elevated concentrations of lead, on vacant urban land (McBride et al., 2014; McClintock, 2012; Tresch et al., 2018). A variety of common garden plants absorb heavy metals when grown in impacted soil, providing a potential exposure pathway to humans who consume them (Clarke et al., 2015;

Egendorf et al., 2018; Warming et al., 2015). These hazards can, however, be mitigated through proper testing before development and safe cultivation techniques (e.g., raised garden beds) (Kessler, 2013; U.S. Department of Agriculture, 2016). Other potential environmental hazards include the impacts of improper application of pesticides and fertilizers (e.g., runoff and ingestion) (Lin et al., 2017; Russo et al., 2017), water overuse (Turner, 2011), and the propagation of non-native or invasive species (Goddard et al., 2010; Niinemets & Peñuelas, 2008).

Additional detractors or unintended consequences of community garden development include the potential reinforcement of historical urban inequities and green gentrification (Łaszkiewicz et al., 2018; Safransky, 2014). The nature of the two opposite phenomena, both of which disproportionately affect low-income and majority-minority neighborhoods, constitutes the so-called "green space paradox" wherein communities previously lacking green features may be undercut by their presence (Anguelovski et al., 2019; Faber & McDonough Kimelberg, 2014).

It is well-established that socioeconomically disadvantaged neighborhoods frequently have less vegetation and fewer accessible green spaces (e.g., parks) when compared to more affluent communities (Boone et al., 2009; Harlan et al., 2007) and are, therefore, deprived of the potential co-benefits these features offer. This scarcity can be attributed to factors such as the historical exclusion from the decision-making process and unequal socio-political power (Sampson, 2017; Wesener et al., 2020). Without the meaningful engagement of the array of stakeholders and a transparent planning process, patterns of environmental inequity tend to be amplified (Barron, 2017; Draus et al., 2014;

Heckert & Rosan, 2016). Conversely, when community gardens are developed in socioeconomically disadvantaged communities, their existence may lead to unintended gentrification (Anguelovski et al., 2019; Sbicca, 2019). Community gardens and other forms of urban greening may raise surrounding property values and make neighborhoods more attractive for development (Voicu & Been, 2008; Wolch et al., 2014). As a result, vulnerable residents may be displaced while the co-benefits of the gardens accrue (Sbicca, 2019). Countering the green space paradox is the subject of an ongoing debate that is beyond the scope of this dissertation; however, research suggests that a good remedy may be—among other things—increased institutional support for marginalized residents and substantive stakeholder engagement during the planning process (Anguelovski et al., 2019; Sbicca, 2019).

1.2.4 Community Garden Scholarship at Present

Over the past several years, a multitude of different studies have been dedicated to the impact of urban community gardens, frequently centered around the evaluation or quantification of specific benefits, for example, their contribution to food systems (Clinton et al., 2018; Kremer & DeLiberty, 2011; Uludere Aragon et al., 2019) or the nutritional outcomes of improved food access (Alaimo et al., 2008; Grier et al., 2015; Robinson-O'Brien et al., 2009). A growing body of research has also emerged regarding the more social dimensions of gardening, including the motivations and behaviors of community gardeners (Andreotta et al., 2019; Egerer et al., 2019; Pearsall et al., 2017) and concepts like placemaking (Karge, 2018; Wesener et al., 2020). This work is in addition to that concerning the aforementioned green gentrification of disadvantaged communities (McClintock, 2018; Safransky, 2014; Sbicca, 2019) and environmental equity (Alkon & Agyeman, 2011; Barron, 2017; Draus et al., 2014).

At present, however, no research has emerged that examines the co-benefits of urban community gardens and also accounts for the contextual spatial and non-spatial factors that make these spaces viable. This gap is significant because challenges frequently arise when developing urban community gardens, not necessarily due to a lack of available knowledge about gardening or the services these spaces provide, but due to the largely ad hoc or inconsistent methods that are employed in the decision-making process (Eanes & Ventura, 2015; Saha & Eckelman, 2017). Furthermore, while advances have been made in site-selection through the incorporation of varied remote sensing techniques (e.g., Smith et al., 2017), scholarship considering community gardens as components of a larger network of green spaces rather than individual installations remains nascent (Ackerman, 2012; Uludere Aragon et al., 2019). The systematic siting of community gardens—both in terms of location potential and an optimized distribution of their co-benefits—presents an opportunity to integrate these spaces into the urban landscape as truly multifunctional green infrastructure that possesses additive co-benefits at multiple spatial scales.

1.3 Dissertation Organization

The research presented in this dissertation explores the potential of community gardens as a form of multifunctional green infrastructure and how these spaces can be sited across the Phoenix metropolitan area in a manner that strives to be both systematic and transparent. Through a combination of remote sensing, GIS, spatial, and qualitative analyses, the chapters present an overarching process of how to identify and evaluate potential community garden locations, both as individual sites and as components of a metropolitan-scale network, to inform planning decisions. Chapter 2 establishes a methodology to identify potential community garden locations from an inventory of tens of thousands of vacant parcels. Chapter 3 outlines a way to prioritize these numerous potential parcels for community gardens based on local stakeholder-derived criteria. Chapter 4 demonstrates how optimized metropolitan garden networks could be realized when multiple co-benefit objectives are at play. Finally, Chapter 5 serves as a summary and conclusion. Excluding Chapter 5, each of the chapters outlined below is either published or is in revision for publication.[1]

1.3.1 Identifying Potential Locations for Community Gardens

Chapter 2 examines the challenge of how to efficiently compile a highly accurate inventory of parcels for potential greening/gardening (VPPGs) within the greater Phoenix metropolitan area. The chapter outlines a novel methodological approach to creating such an inventory by utilizing cadastral data, digital elevation data, and high-resolution remotely-sensed imagery. Five land cover classes representing desirable conditions (i.e., bare, shrub, and mesic vegetation) and undesirable conditions (i.e., buildings and impervious surfaces) were established and applied via discriminant analysis to a dataset of thousands of parcels. In addition to demonstrating the new procedure, the assessment also

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[1] Chapters 2, 3, and 4 each constitute an academic paper. The dissertation author served as the lead on the three papers, but all were co-authored. All co-authors have consented to their use (Appendix A).

provides insights regarding the distribution of VPPGs across the post-Great Recession Phoenix metropolis and the potential relationship between high VPPG concentrations and neighborhoods with elevated land surface temperatures or food desert conditions. The study was published in 2017.[2]

1.3.2 Spatially Representing the Siting Potential of Possible Community Garden Locations

Chapter 3 explores how to best represent the potential of a given location to support a community garden. The chapter develops a series of siting indices to evaluate the potential of VPPGs through the use of stakeholder-informed multicriteria decision analysis. A collection of 17 siting criteria was assembled in consultation with 8 urban community gardening experts. Indicators were developed for each criterion using GIS data and were applied to an inventory of Phoenix-area VPPGs compiled using the methodology established in Chapter 2. To establish criteria weights, a survey was created and distributed to community gardening stakeholders via snowball sampling. The 37 local stakeholders who completed the survey rated and ranked two siting criteria categories—Social Characteristics and Physical Setting—and ranked a final comprehensive category. Criterion weights were established using the top seven criteria from each category, and three siting indices were calculated using the corresponding indicators. The study analyzed the resultant indices, assessing scoring distributions, in addition to providing additional

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[2] Smith, J. P., Li, X., & Turner, B. L. (2017). Lots for greening: Identification of metropolitan vacant land and its potential use for cooling and agriculture in Phoenix, AZ, USA. *Applied Geography*, *85*, 139–151. https://doi.org/10.1016/j.apgeog.2017.06.005

insight into the perceptions and priorities of stakeholders. The manuscript is in-press at the time of this dissertation.[3]

1.3.3 Optimizing Community Garden Coverage

Chapter 4 considers how to optimize community garden networks to maximize coverage for high-priority neighborhoods. The bi-objective community garden coverage model (CGMC) considered two community garden co-benefits—urban heat island amelioration and food desert mitigation—and developed indicators for each to represent neighborhoods that are high-priority for coverage. The CGMC also used an inventory of VPPGs (see Chapter 2) with a siting index, informed by the results presented in Chapter 3. Multiple coverage scenarios were conducted with the co-benefits maximized both individually and together. The study explores tradeoffs in benefit coverage for the various scenarios and assesses the coverage of the current Phoenix metropolitan area community garden network compared to our optimized networks. The manuscript has been submitted for publication and is currently under revision at the time of this dissertation.[4]

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[3] Smith, J. P., Meerow, S., & Turner, B. L. (2021). Planning urban community gardens strategically through multicriteria decision analysis. *Urban Forestry & Urban Greening, 58,* 126897. https://doi.org/10.1016/j.ufug.2020.126897

[4] Smith, J. P., Zhang, Y., Tong, D., & Turner, B. L. (2021). Evaluating the Synergies and Tradeoffs of Mitigating Food Deserts and Urban Heat through Spatially-Optimized Urban Community Garden Planning. *Landscape and Urban Planning (in revision).*

1.3.4 Summary and Conclusion

Lastly, Chapter 5 presents a summary and conclusion for the dissertation overviewing of the contributions of the preceding studies, in addition to their limitations and lessons learned. It concludes with a reflection on the potential application of the themes carried throughout the dissertation and potential avenues for future work.

CHAPTER 2

LOTS FOR GREENING: IDENTIFICATION OF METROPOLITAN VACANT LAND AND ITS POTENTIAL USE FOR COOLING AND AGRICULTURE IN PHOENIX, ARIZONA, USA

Abstract

The greening of vacant parcels for urban sustainability continues to gain attention from researchers and practitioners, including its use to ameliorate the urban heat island effect and food deserts. Planning for such uses requires accurate inventories of the amount and distribution of vacant parcels, which may prove difficult to produce for large, sprawling urban complexes. This study provides a systematic approach that combines remote sensing and cadastral data to distinguish different forms of vacant land for the Phoenix, Arizona, metropolitan area while reducing computation time. The approach identifies vacant parcels for potential greening, focusing on privately owned land lacking buildings and impervious surfaces. The results for the Phoenix area reveal hot spots of these parcels, many of which reside along the fringe of the metropolis awaiting development. A large number of vacant parcels, however, reside within the metropolitan core and are suitable for greening as well, potentially serving to mitigate the urban heat island effect and food deserts in this region. The identification method and parcel results are detailed.

2.1 Introduction

Urban sustainability increasingly draws attention from researchers and practitioners (e.g., Karuri-Sebina, Haegeman, & Ratanawaraha, 2016; Seto, Golden, & Turner II, 2017), often framed in terms of the food-energy-water nexus (Romero-Lankao et al., 2017). To this end, international and national agencies seek ways to improve understanding of the nexus for both environmental performance and human wellbeing. One such nexus gaining increased traction is that of greening urban spaces for multiple sustainability concerns, especially confronting climate change (e.g., Heckert & Mennis, 2012).[5] The expansion of green areas in cities is intended to reduce energy use and human health problems due to seasonal extremes of the urban heat island (UHI) effect, especially for cities in warm climates (e.g., Cleveland et al., 2017; EPA, 2017; Lwasa, Mugagga, Wahab, Connors, & Griffith, 2014; Oliveira, Andrade, & Vaz, 2011; Saaroni, Ben-Dor, Bitan, & Potchter, 2000; Santamouris, Cartalis, Synnefa, & Kolokotsa, 2015; Wolch, Byrne, & Newell, 2014). Indeed, the City of Phoenix, part of the metropolitan area examined in this research, has a master plan to increase green spaces within its jurisdiction (City of Phoenix, 2010), a goal that has spawned assessments of the optimal pattern of green spaces for cooling (Zhang et al., 2017). Greening may also involve urban agriculture in an effort to increase access to nutritional foods, especially for urbanites with less access to them, such as those occupying “food deserts” (Bao & Tong, 2016; Firth, Maye, & Pearson, 2011; Grewal & Grewal, 2012; Lin, Philpott, Jha, & Liere, 2017; USDA, 2017; Ver Ploeg et al., 2012;

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[5] Greening urban spaces has multiple sustainability uses and outcomes, including those on environment services other than heat mitigation (e.g., Niemelä et al., 2010) and on human well-being (e.g., Egli et al., 2016). Recognition of these uses requires consideration of the tradeoffs among the outcomes. Such research is in its nascent stage of development and is not pursued here.

Walker, Keane, & Burke, 2010). The PHX Renews program, for example, seeks to use vacant lots within Phoenix for various purposes, including community gardens for local food production (Burns, 2015). In addition, the potential cumulative impact of greening urban spaces is recognized in climate models and assessments of how to combat regional climate change (Georgescu et al., 2014).

To determine the potential for greening urban spaces for these and other purposes requires the identification and assessment of the open or vacant spaces, especially concerning their characteristics (e.g., number, size, location, and pattern), that benefit the mitigation of the UHI effect and the people within food deserts. This identification has proven more difficult than it might otherwise appear, especially for large urban areas (e.g., Colasanti, Hamm, & Mott, 2010; Drake, Ravit, & Lawson, 2016; Eanes & Ventura, 2015; McClintock & Cooper, 2010; Mendes, Balmer, Kaethler, & Rhoads, 2008). Our study provides a method to identify the number, area, location, and distribution of vacant parcels for potential greening (VPPGs) potentially applicable for large urban areas with copious amounts of vacant land. It combines cadastral, remote sensing, and simple elevation data to generate a VPPG inventory for the expansive Phoenix metropolitan area. This inventory is limited to privately owned, vacant parcels (VPs) that display land covers indicating non-occupation such as the absence of structures (e.g., buildings and paved parking lots) and meet size and physical criteria favorable for both heat mitigation and gardening. The suitability of the location and distribution of VPPGs for mitigating the UHI effect and food deserts for the Phoenix metro region is briefly explored.

2.2 Constraints on Vacant Parcel Identification

Tax assessor or appraisal district cadastral data, typically available in electronic formats, constitute the base source for many inventories of VPs (Table 1). It is not unusual, however, for these data to be outdated, to contain transcription errors or mislabeling that has been carried over from year to year (legacy errors), and to provide incomplete details regarding the status of a parcel or its zoning or use designation (Ackerman, 2012; Bowman & Pagano, 2004; Eanes & Ventura, 2015). In addition, cadastral data typically do not provide descriptive information (e.g., physical site conditions) necessary for the determination of the specific uses for which the VPs may be utilized (Bowman & Pagano, 2004; Drake et al., 2016).

These challenges have fostered several studies that incorporate some form of remotely sensed data to create VP inventories (Table 1).[6] The methods used vary, but many studies employ straightforward visual analyses that spatially join cadastral data (sometimes filtered based on other site-selection criteria, such as proximity to undesirable features) and aerial imagery. In this case, visual inspection of the imagery identifies the land cover, including and the presence of structures and other impervious surfaces. Additionally, some studies incorporate field verification, either as a means of accuracy assessment (e.g., Eanes & Ventura, 2015) or as the primary VP identification method itself (e.g., Drake et al., 2016). While these approaches are simple and can often be undertaken by non-experts and

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[6] Table 1 represents a collection of efforts to inventory vacant parcels, largely through remote sensing. The table was adapted from Eanes & Ventura (2015) and expanded through an extensive review of Google Scholar. Numerous studies addressing the UHI effect and urban gardening exist, but few of them directly address remote sensing methods for determining the availability of vacant urban parcels for such use or other greening purposes.

volunteers (Eanes & Ventura, 2015), they constrain assessments of metropolitan areas or require extensive field operations in inventories involving large numbers of parcels.

2.3 Study Area and Definitions

2.3.1 Phoenix Metropolitan Area

The 2010 Census Urban Areas shapefile produced by the U.S. Census Bureau defines the portion of the Phoenix metropolitan area that resides in Maricopa County, Arizona.[7] The 22 cities in the study area maintained a 2010 population of 3.5 million and more than 1.4 million parcels sprawled across more than 3,200 km^2 of the northern Sonora Desert in central Arizona (Fig. 1).[8] Like other fast-growth metropolitan areas in the American Southwest, the Phoenix area is marked by significant residential expansion on the urban-rural fringe, typically generated by a "leapfrog" process that leaves substantial undeveloped lands or VPs within the cities of the metroplex, spaces which are often slow to "in-fill" (Gober & Burns, 2002; Heim, 2001; Kane et al., 2014). In-filling and urban fringe development in the study area were substantially reduced during the subprime mortgage crisis of the mid-2000s and the subsequent Great Recession (Hollander, 2011), generating a large number of VPs for 2010. The metropolitan area also contains pockets of

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[7] The U.S. Census Bureau demarcates urban areas based on population density and land use. The boundary in question removed some mountain parks and agricultural lands within and on the edges of the metropolitan area, but included others, such as North Mountain Park, a municipally owned recreation area. We excluded such parks from our analysis (Fig. 1) as well as Native American reservations.

[8] The federally defined metropolitan statistical area is comprised of 33 incorporated communities in Maricopa and Pinal counties covering almost 23,500 km^2 and occupied by more than 4.2 million people in 2010. The parcel figures considered in this study include only those located within the bounded metro area delineated by the Census Bureau within Maricopa County (Fig. 1).

low-income neighborhoods associated with food deserts (see below) and a sizable UHI effect with substantial impacts on energy and water use and human health (Baker, Brazel, & Westerhoff, 2004; Bleasdale, Crouch, & Harlan, 2011; Guhathakurta & Gober, 2007; Jenerette, Harlan, Stefanov, & Martin, 2011; Wentz et al., 2016).

2.3.2 Clarifying Vacant Parcels, Urban Heat Island, and Food Deserts

The term vacant is defined somewhat fluidly among cadastral datasets of municipalities in the U.S. (Bowman & Pagano, 2004; Northam, 1971; Schukoske, 2000). Generally, a vacant property is a parcel of land that is either unimproved or underutilized. Some local governments consider a parcel to be vacant only if it is devoid of any freestanding structures or modifications. Other jurisdictions may apply the term more broadly to include parcels that are developed but not occupied. Additional information may include zoning or intended land use status, or records may simply designate the property as vacant with no further details provided. Maricopa County does not define the term vacant in its cadastral dataset, but it does designate parcels as belonging to that category. This study begins with the Maricopa County designation, VP, but also applies various methods (Section 2.4) to verify the designation for each individual parcel and establishes their suitability to serve as VPPGs.

Table 1. Examples of Previous Vacant Parcel Inventories

Study & Study Area	Vacant Parcel Criteria						Methods		
	Publicly owned parcels	Privately owned parcels	Cadastral designation of "vacant"	Open land not designated as "vacant" (e.g., parks)	Other open space (e.g., yards, rooftops)	Other suitability criteria applied (e.g., size, slope, soil)	GIS shapefile data visually analyzed against aerial imagery	GIS shapefile data classified using aerial imagery	Field verification conducted (for either accuracy and/or parcel assessment)
Balmer et al., 2005 Portland, OR	✓		✓			✓	✓		✓
Kaethler, 2006 Vancouver, BC, Canada	✓		✓			✓	✓		✓
Horst, 2008 Seattle, WA	✓		✓	✓		✓	✓		
Colasanti et al., 2010 Detroit, MI	✓		✓				✓		
McClintock & Cooper, 2010 Oakland, CA	✓			✓		✓	✓		✓
MacRae et al., 2010 Toronto, ON, Canada	✓	✓		✓		✓	✓		✓
Kremer & DeLiberty, 2011 Philadelphia, PA		✓			✓	✓		✓	
Ackerman, 2012 New York City, NY	✓	✓	✓		✓	✓	✓		
McClintock et al., 2013 Oakland, CA	✓	✓	✓	✓		✓	✓		✓
Eanes & Ventura, 2015 Madison, WI	✓	✓	✓			✓	✓		✓
Drake et al., 2016 Trenton, NJ		✓	✓						✓

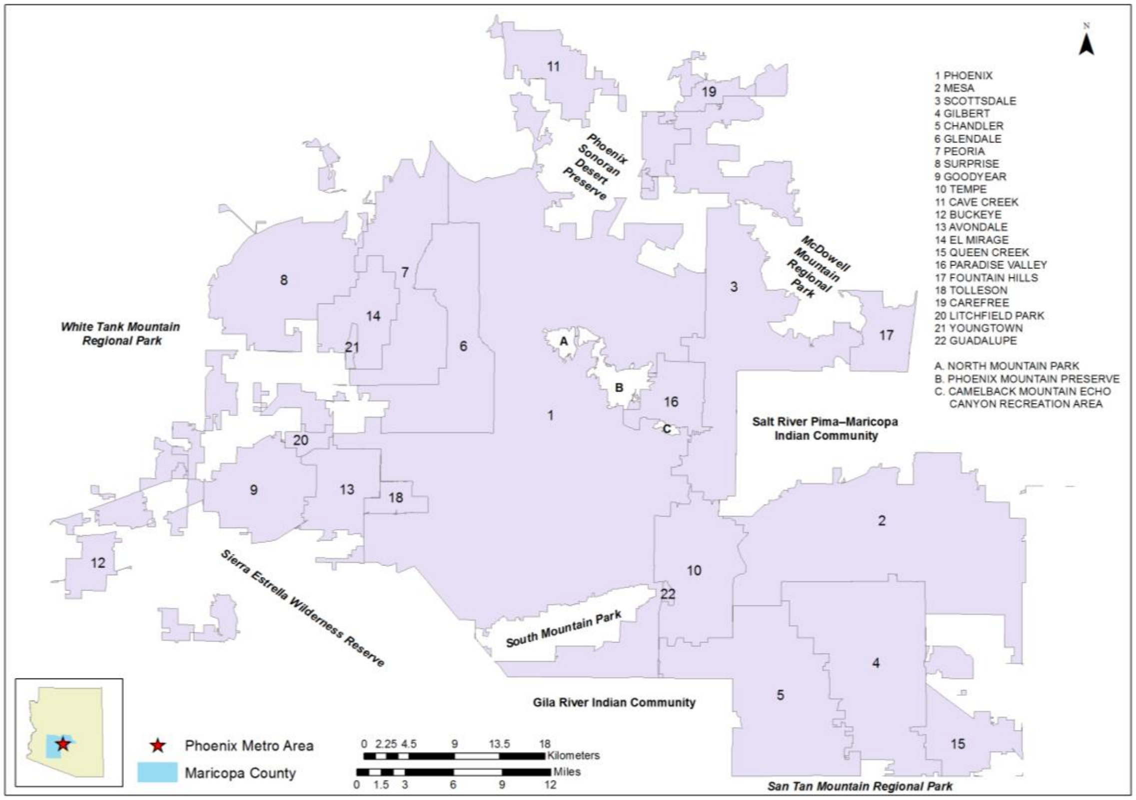

Figure 1: Phoenix Metropolitan Boundary and Cities

The Phoenix metro-area creates a sizable UHI with substantial impacts on energy and water use and human health (Baker, Brazel, & Westerhoff, 2004; Bleasdale, Crouch, & Harlan, 2011; Guhathakurta & Gober, 2007; Jenerette, Harlan, Stefanov, & Martin, 2011; Wentz et al., 2016). For the most part, the UHI effect in the metro-area is larger at night than during the day (Hedquist & Brazel, 2014). The summer daytime temperatures, however, often exceed 43°C for above ground or near-surface air temperature. Such extreme temperatures place a peak demand for energy to cool houses and buildings and are responsible for various human health problems related to excessive heat (Hondula et al., 2014; Jenerette et al., 2016).

The role of vegetated or green spaces in ameliorating the daytime UHI effect is well understood (Section 2.5.4). For the most part, large and more concentrated green spaces have a greater cooling effect on temperature and the size of the area cooled (Li et al., 2017; Spronken-Smith & Oke, 1998).[9] Research on the consequences of the patterning and shape of green spaces on cooling is in its nascent stages of development (e.g., Li et al., 2017; Zhang et al., 2017). Regardless, greening the arid Phoenix area involves significant tradeoffs with water withdrawals (Gober et al., 2009; Wentz et al., 2016).

Food deserts are areas in which fresh fruit, vegetables, and associated healthy foods are wanting, usually owing to inadequate access to the providers of such foods (e.g., Shaw, 2006; Wrigley, Warm, & Margetts, 2003). They are commonly associated with low-income areas, ranging from neighborhoods to counties, with some combination of few full-service food providers and constraints on the population to reach them (Beaulac et al., 2009; Gordon et al., 2011; Walker et al., 2010). Food deserts exist in the Phoenix area, triggering attention to the possibilities of urban gardening (Bleasdale et al., 2011). To our knowledge, no exercises attempting to map these “deserts” for the Phoenix metroplex exist. Various studies, however, indicate that food deserts are common in lower-income neighborhoods (e.g., Apparicio, Cloutier, & Shearmur, 2007; Raja, Ma, & Yadav, 2008; Wrigley et al., 2003). For this reason, low-income Census tracks serve as a proxy for food deserts in our study (Section 2.5.4).

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[9] It is noteworthy that green spaces dominated by tree canopy actually increase nighttime temperatures in the Phoenix metro area, compared to bare soil and rock, with implications for nighttime energy use. The composition of green spaces and the desired tradeoffs between day and night cooling are at play but are not addressed in this study.

2.4 Methods

Figure 2 illustrates the data and methods employed to identify VPs and VPPGs.

2.4.1 Data Collection and Preparation

The identification of VPs employs three types of data: June 2010 imagery from the National Agricultural Image Program (NAIP), 2010 cadastral data from the Maricopa County Tax Assessor's Office, and elevation data from the U.S. Geological Survey. The U.S. Department of Agriculture's Farm Service Agency through the Aerial Photography Field Office administers the NAIP. The program provides 4-band (red, green, blue, and near-infrared) orthophotography imagery at a resolution of 1-meter ground sample distance for the United States during the agricultural growing season. The images are orthorectified, combining the image characteristics of an aerial photograph with the georeferenced qualities of a map. This imagery, mosaicked to the county level, was used to derive land classifications and maps for the Phoenix area (Fig. 2). The results capture the sub-parcel details of the land covers that would otherwise be lost with the use of coarser grain size.

The 2010 cadastral data for Maricopa County includes property use codes (PUCs) for the entirety of the county (1,542,998 parcels). PUCs denote generic land use types for each parcel (e.g., vacant, residential, commercial, recreational) as well as subclasses (e.g., single-family residential, multi-family residential, commercial office building). The delineation of the boundaries of parcels examined in this study employs these data. Identification rules using Python script permitted the computer to identify VP candidates, ultimately reducing the computation time involving the large number of parcels within the Phoenix metropolitan area.

Both the remotely sensed data and cadastral data were re-projected to the North American Datum 1983 (NAD 83), Universal Transverse Mercator (UTM) coordinate system, Zone 12N., and were cropped to the Phoenix metropolitan urban boundary as noted above. This cropping reduced the number of parcels for the study area to 1,436,679.

2.4.2 Vacant Parcel Identification

The identification of VPs for potential use for urban greening necessarily involves the elimination of unsuitable parcels as well as corrections in the parcel designations owing to errors in the cadastral data (Fig. 2). Maricopa County PUC designations identify 112,086 VPs within the urban boundary, 111,784 of which are privately owned (Table 2). Of course, the presence of privately-owned VPs does not ensure that the parcels are available for greening purposes. Indeed, as we note later, a significant portion of the VPPGs in the Phoenix metro-area await development or have begun development with the recovery of the housing market that is underway. Such parcels, however, especially those that have long been vacant and reside within the interior of the metroplex, have the potential to mitigate the UHI effect and food deserts via community gardens and are precisely those that other cities in the United States have begun to green (Bowman & Pagano, 2004; Heckert & Mennis, 2012). Furthermore, open government land (municipal to federal) is held for strategic reasons (e.g., airports, military facilities, flood control), and major public recreational areas (e.g., mountain reserves within the metroplex or playgrounds) are either designated for specific uses or not suited for purposes examined in this study. Our study makes no claims about the propensity of the identified, privately owned candidate VPs to be greened but rather provides an overview of the potential amount and location of such parcels relative to their greening as serving to mitigate extreme summertime temperatures and food deserts.

The PUC designations of parcels in the cadastral data are not always accurate owing to misidentification or out-of-date assessments, leading to incorrect parcel specification of either occupied or vacant. Given the large number of parcels in question, it was not feasible to examine each PUC designation against the imagery. To account for this, a binary PUC correction method for candidate VPs was required as follows. The PUCs for 2009, 2010 (the study year), and 2011 were coded as either vacant or occupied according to the respective data. If the 2010 status of a VP candidate differed from identical 2009 and 2011 designations, the latter designation was assigned for 2010. For instance, if a parcel was coded as vacant in 2010 but was designated as occupied in both the 2009 and 2011 data, it was recoded as occupied. Verification of the new 2010 designations generated in this way involved the visual examination of the 2010 NAIP and Google Earth imagery of a large sample of the redefined parcels, revealing a 90% accuracy of the correction method. The 2010 parcels determined to be incorrectly assigned PUC designations, subsequently recoded as occupied, were eliminated from further consideration in the study.

Some parcels are located in mountainous or hilly terrain within the urban area, raising questions about their suitability for greening. Parcel slopes were calculated using elevation data and were incorporated in the analysis to eliminate those parcels with high runoff potential that reduces soil moisture retention and requires infrastructure costs (e.g., terrace construction) to rectify. The cadastral data were trimmed using 10-meter resolution Digital Elevation Model data collected from the U.S. Geological Survey, and VPs with a slope of 5% or greater identified and eliminated from further consideration. In some cases, however, parcels contain proportions of land with variable slopes. A sizeable number of these had only a small area of ≥ 5% slope, often that portion abutting mountains. For this reason, only parcels fully encompassing ≥ 5% slope were eliminated, potentially enlarging the VPPGs figures provided in this study.

Additionally, VPs with a total area equal to or less than 56 m^2 (600 ft^2), significantly smaller than most other private parcels, were eliminated. This step was taken for three reasons. Urban agriculture, especially in the form of community gardens, involves producing food and promoting social networking (e.g., Egli, Oliver, & Tautolo, 2016). Small plots serve this function less well. Also, the use of larger-size parcels enhances the ease of modeling the regional climatic consequences of greening large urban areas (Georgescu et al., 2014). Finally, considering areas less than 56 m^2 would conflict with attention to individual home gardens, such as those in backyards, which are not the subject of this assessment.

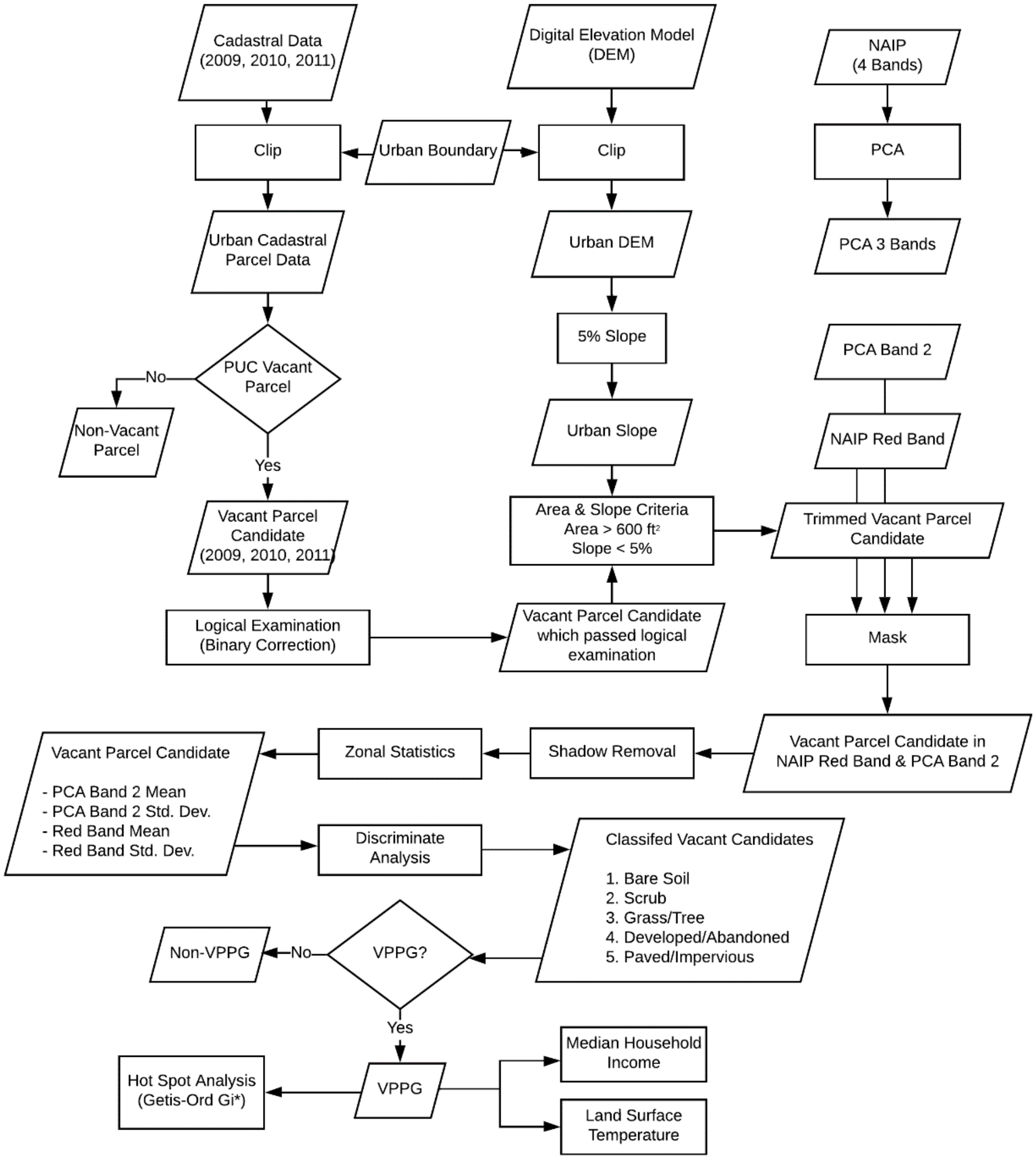

Figure 2. Data and Methods Flow Chart

2.4.3 Vacant Parcels for Potential Greening

The large majority of residential parcels in the metro-area are less than 700 m^2 in size, requiring fine-grain imagery (1-meter resolution NAIP data) to address individual parcel land cover. This resolution necessitates large amounts of computational power and time to process. To overcome these constraints and to emphasize the spectral signature of vegetation and soil, both a Normalized Difference Vegetation Index (NDVI) and a Soil-Adjusted Vegetation Index (SAVI) were employed using red and near-infrared bands of the NAIP data. Principal component analysis (PCA) on the four original spectral bands of NAIP data converted the three visible bands and the near inferred band of the imagery into three new linearly uncorrelated bands (Fig. 2). Comparing the three types of spectral transformation results indicated that the second band of PCA transformation provided similar but more detailed and less confused spectral signatures of vegetation and soil than either the NDVI or SAVI transformation did (Li & Shao, 2013). Therefore, one layer¸ the PCA band 2, captured the vegetation and soil spectral information. Additionally, the red band of the original NAIP image was prepared as an input to capture the presence of structures (e.g., rooftops and pavement). The zonal statistics functions in the ArcGIS software program were used on the PCA band 2 and the NAIP red band for each VP. The mean and standard deviations for these two layers were calculated and used to identify soil, pavement, rooftops, and vegetation, which significantly reduced computation time.

Once the four statistical features (mean and standard deviation, above) were calculated for each VP candidate, a visual examination of several hundred parcels was conducted to determine the appropriate land categories within the parcels. These included Classes 1 - 3, Bare Soil, Scrub Vegetation, and Grass/Trees, respectively, which were considered VPPGs. Classes 4 and 5, Developed/Structure and Paved/Impervious surface, respectively, were unsuited for greening. A supervised classification linked the five categories with the spectral information for computer recognition using 200 training samples with typical spectral reflectance in terms of the mean and standard deviation of the red band and PCA band 2 of each class of parcel. A discriminate analysis function in the SPSS software program permitted the identification of all VP candidates.

Verification of the outcomes employed color aerial photography for 2010. The preliminary accuracy ranged from 86% to 32%, depending on the parcel class. Shadows from adjacent parcel fences or rooftops of neighboring buildings proved to generate lower levels of classification accuracy. Removing the shadows involved shrinking three pixels toward the center of the parcel and rerunning a discriminate analysis. This modification increased the overall classification accuracy to 87.2% (Section 2.5.2).

2.4.4 VPPG Distribution and Mitigation Possibilities

A hot spot analysis available in ArcGIS, using default settings (2.2 km), addressed the distribution of the parcels across the study area. The Getis-Ord Gi* statistics, a common measure of clustering, identified hot spots of VPPGs clustering (Getis & Ord, 2010). The results are reported in terms of statistical significance in which a positive Getis-Ord Gi* statistic corresponds to high clustering and a negative statistic corresponds to a lack of clustering.

Finally, to explore the possible role of VPPGs to mitigate the UHI effect and food deserts, the distribution of VPPGs was compared to seven categories of land surface temperature (LST) and household income (serving as a food desert proxy) at the Census block level, respectively.[10] The exploratory nature of these possibilities precludes the use

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[10] Deriving LST from Landsat data is a common practice described in a large number of studies. For that applicable for this study see Li et al. (2016).

of various statistical and analytical methods, which would enlarge this study substantially and is the subject of further investigation. Rather, our assessment constitutes a matching of VPPGs relative to the locations in which they are most required to address UHI and food desert problems.

2.5 Results and Discussion

2.5.1 Parcel Identification: Number and Area

Figure 3 and Tables 2 - 4 present the results of the VPPG identification. The PUC correction to the 111,784 privately owned VPs designated by Maricopa County and located within the urban boundary reduced the number to 93,194 (Section 2.4.2). Slope and size corrections further reduced the number of parcels to 88,378 and 71,739, respectively (Section 2.4.2). The land cover classification (Section 2.4.3) identified 4,706 cadastral-defined VPs consuming 2,051 ha (5,068 ac or 10% of the VP area) that maintained abandoned structures or paved surfaces, suggesting high costs to convert to green uses and, which were therefore eliminated. The remaining VPs, those with land covers of bare soil, desert scrub, and grass/trees (Table 3), were considered suitable for potential greening. These 67,032 VPPGs cover 19,592 ha (48,413 ac or 90% of the VP area and 6% of the total study area). If geographically consolidated, the VPPG would constitute a unit of land just under 14 km^2 (8.7 mi^2). It is noteworthy that both the number and area of VPs identified far exceeds that found in many other vacant land inventory studies that used remotely sensed imagery (e.g., Balmer et al., 2005; Eanes & Ventura, 2015; Horst, 2008; Kaethler, 2006; Kremer & DeLiberty, 2011; McClintock, Cooper, & Khandeshi, 2013).

Table 2. Number of Parcels: Cadastral Data and Corrections

Parcel Categories	Total Parcels
In Maricopa County*	1,542,998
In urban boundary*	1,436,679
Designated vacant*	112,086
Designated vacant & private ownership*	111,784
After Property Use Codes correction	93,194
After slope correction	88,378
After size correction	71,739
After land cover correction	67,032
Vacant Parcels for Potential Greening (VPPGs)	**67,032**

*Cadastral data only; the remaining categories augmented by the methods described

Table 3. Vacant Parcel Land Cover Classification Statistics

Land Cover Class	No. Parcels	Area (ha)	% VP Area
1 Bare Soil	44,730	7,844	36
2 Scrub	19,190	10,157	47
3 Mesic native vegetation	3,112	1,591	7
Total VPPGs	**67,032**	**19,592**	**90**
4 Developed/Abandoned	1,864	788	4
5 Impervious	2,842	1,263	6
Total Non-VPPGs	**4,706**	**2,051**	**10**

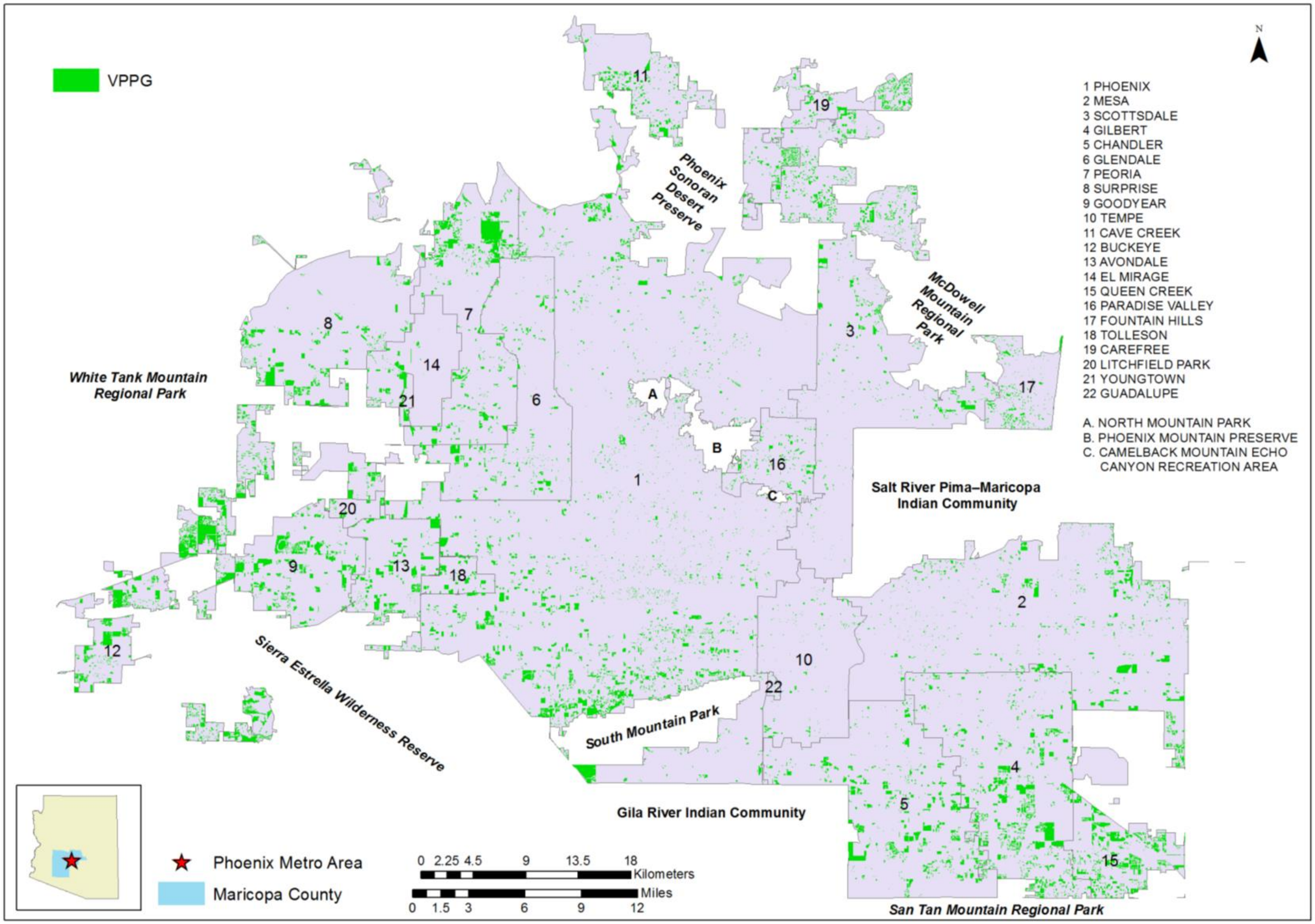

Figure 3. Location of Vacant Parcels for Potential Greening

Table 4. Vacant Parcels for Potential Greening Statistics by City

City	# of VPPGs	Area of VPPGs (ha)	Average Area of VPPGs (ha)	Proportion of VPPGs per City (%)
Phoenix	17,999	4,282.09	0.24	4.24
Mesa	4,252	1,303.28	0.31	3.81
Scottsdale	3,425	1,476.93	0.43	5.45
Gilbert	7,867	1,754.04	0.22	9.26
Chandler	3,240	1,306.13	0.4	7.21
Glendale	2,981	1,021.80	0.34	6.01
Peoria	3,025	1,428.58	0.47	10.44
Surprise	3,513	862.68	0.25	6.33
Goodyear	4,959	1,863.38	0.38	16.73
Tempe	678	111.52	0.16	1.06
Cave Creek	636	516.68	0.81	7.99
Buckeye	6,188	1,375.98	0.22	22.57
Avondale	2,025	655.33	0.32	11.15
El Mirage	756	233.43	0.31	4.25
Queen Creek	3,695	971.16	0.26	18.32
Paradise Valley	427	199.21	0.47	4.84
Fountain Hills	652	236.16	0.36	6.05
Tolleson	143	162.89	1.14	10.73
Carefree	145	88.72	0.61	6.2
Litchfield Park	323	97.49	0.3	10.62
Youngtown	29	72.24	2.49	18.76
Guadalupe	90	9.08	0.1	4.37

This result, we suspect, is a product of the huge size of the metropolitan area examined compared to other studies, which tend to focus on a segment of an urban area, and/or of the impacts of the subprime mortgage crisis in the mid-2000s that left many VPs undeveloped, especially on the outer edges of the Phoenix metro-area. We cannot be sure, however, that our method alone contributed to the larger figure because it has yet to be applied to the other studies noted.

2.5.2 Accuracy of Parcel Identification

Using stratified random sampling in the ERDAS Image 2015 software program, 250 randomly selected parcels (50 parcels per land cover class) explored the accuracy of the identified VPPGs. The actual land cover types were determined by visually detecting them on original photogrammetric NAIP data and Google Earth imagery for the year 2010. The accuracy assessment of the five classes produced an overall accuracy of 87.20% with an overall Kappa statistic of 0.84, indicating robust results (Table 5).

Table 5. Accuracy Assessment of Five Classes Vacant Parcel Classification Scheme

	Class 1- Bare Soil	**Class2- Scrub**	**Class 3- Grass/Trees**	**Class 4- Developed/Abandoned**	**Class 5- Paved/Impervious**
Kappa %	87.50%	89.74%	87.24%	68.45%	87.68%
Reference Totals	50	55	54	44	47
Classified Totals	50	50	50	50	50
Number Correct	45	46	45	37	45
Producer's Accuracy*	90.00%	83.64%	83.33%	84.09%	95.74%
User's Accuracy	90.00%	92.00%	90.00%	74.00%	90.00%

Overall Classification Accuracy = 87.20%   Overall Kappa Statistic = 0.840

*The producer's accuracy corresponds to the number of samples that are correctly classified for each class divided by the total number of reference samples of that class. The user's accuracy, in contrast, is the number of samples that are correctly classified for a given class divided by all of the other samples that were also classified as that class (Congalton, 1991).

The results support the use of the classification method developed in this study for the identification of VPs and VPPGs for large metropoles. Combining statistical and visual analyses permits the assessment of thousands of vacant candidate parcels to identify which fit the criteria in question by a particular study. The method also affords flexibility in its initial design setup. The input parameters for the classification can be easily amended if needed depending on the conditions of a given study area, and other siting criteria can easily be integrated into the resulting inventory.

2.5.3 Distribution of Vacant Parcels for Potential Greening

A cursory observation of the locations of VPPGs (Fig. 3) suggests a skewed distribution toward the edges of the Phoenix metropolitan area in all directions. A clustering analysis using the Getis-Ord Gi* statistics confirmed this observation. Large areas of concentrated hot spots of VPPGs (95%-99% confidence) are located toward the peripheries of the southeast, south-central to the west, and northeast to the northwest (Fig. 4). The VPPG statistics calculated by city confirm this pattern (Table 4). Those cities with high proportions of VPPGs (≥ 10%) tend to be newer, expanding communities along the southern boundaries of the metroplex (e.g., Queen Creek in the southeast; Avondale, Buckeye, Goodyear, Litchfield Park, and Tolleson in the southwest) and northwestern boundaries (Peoria and Youngstown). While the sheer size of the city of Phoenix reduces its proportion of VPPGs, its southern border area is also a hot spot. Along the northern metro-boundary, Cave Creek and Carefree have large average VPPG sizes (0.81 ha and 0.61 ha, respectively), which are relatively high-income parcels awaiting development. In contrast, older communities, most with no areas for expansion (e.g., Glendale, Mesa, Scottsdale, and Tempe) have relatively small proportions of VPPGs.[11] The major

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[11] That Scottsdale appears to have edge growth possibilities is a product of U.S. Census boundaries. To the east and northeast, Scottsdale is blocked by a Native American reservation and a mountain park,

exception is the Paradise Valley hot spot, a community located in the center of the metroplex with exceptionally high land values and many expensive parcels undeveloped in 2010 but currently in the process of development.

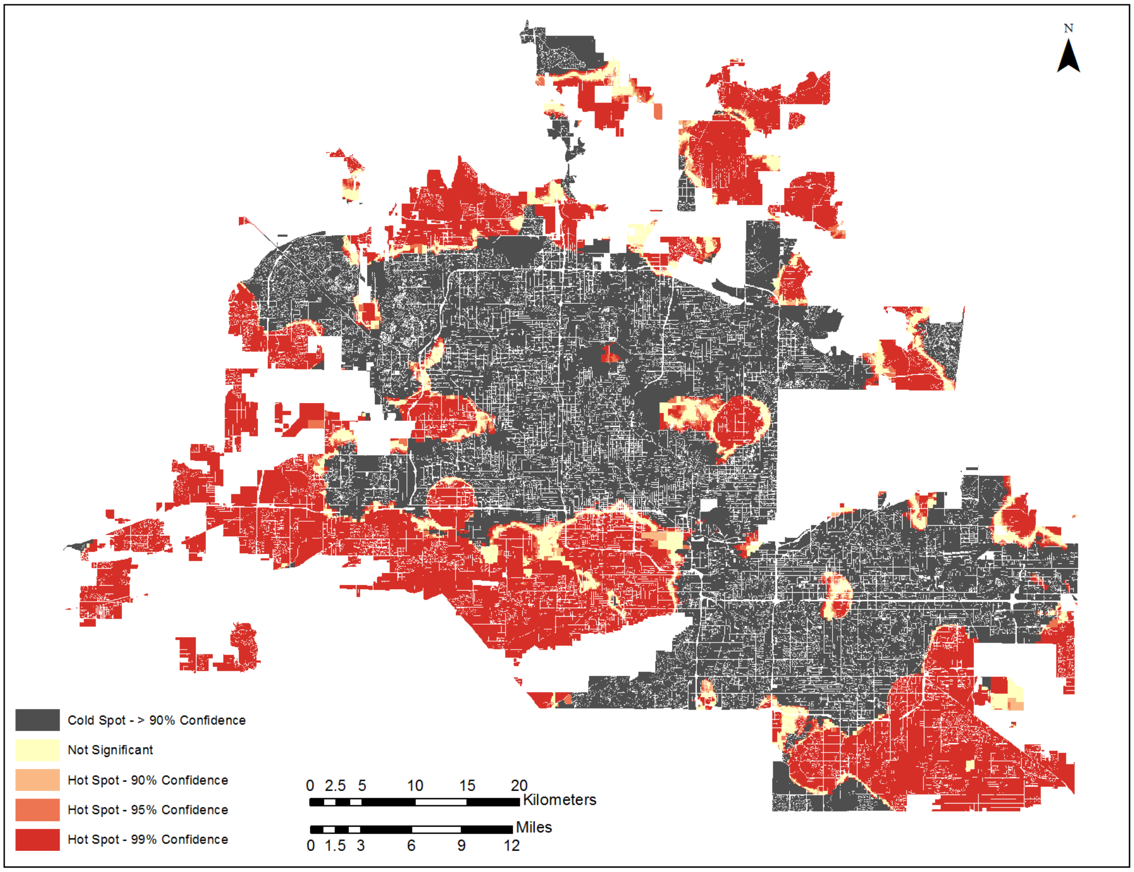

Figure 4. Hot Spots of Vacant Parcels for Potential Greening

2.5.4 Vacant Parcels for Urban Heat Island and Food Desert Mitigation

VPPGs offer opportunities for alternative uses other than those for which they were originally planned. City and county administrators and various non-governmental

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respectively, and to its far northwest by Phoenix, which claims the land between itself and Cave Creek and Carefree, although this area was not declared urban by the Census product.

organizations, respectively, identify two alternatives of significance: spaces that mitigate excessive summer high temperatures associated with the UHI effect and that combat food deserts through community urban gardens. A cursory assessment of the metro-edge hot spots suggests inappropriate locations and distributions relative to the proposed greening uses. This hot spot suggestion, however, belies the total amount, area, and location of VPPGs relative to the potential uses examined.

Desert metropoles tend to maintain two locations of day-time extreme heat (above ground): the metro-core of the classical UHI phenomenon and the metro-edge (Imhoff et al., 2010).[12] The relatively low levels of vegetation cover, high levels of impervious surfaces, and high density of automotive transport in the core, and the low level of vegetation cover on the urban-desert fringe create this pattern of urban temperature. The daytime LST data for Phoenix displays this pattern (Fig. 5), in which the edge VPPGs tend to have minimal vegetation and are awaiting residential development. Once developed, however, residents commonly add sufficient vegetation cover to reduce overall parcel LST (e.g., Wentz et al., 2016), providing a daytime cooling effect (e.g., Imhoff et al., 2010).[13] VPs in the metro core, however, tend to maintain sparse vegetation cover during their long course of non-development, amplifying daytime temperature extremes.

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[12] Imhoff et al. (2010) report a possible urban heat sink for the desert city of Las Vegas, NV, owing to irrigated residential vegetation relative to surrounding desert. The data presented in their Figure 6, however, show higher LST at the edges of Las Vegas and in its core, although the core's LST is less extreme than that of the edge. Phoenix, in contrast, appears to exhibit LSTs in the core that match that of the edges.

[13] The degree of daytime cooling effects linked to household landscaping in desert climates depends on the amount and kind of vegetation employed as well as the presence of pools. "Desert-scaping" or the use of native vegetation supported by drip irrigation in the Phoenix metro area appears to be associated with LSTs that are more akin to unmaintained VPs than to heavily vegetated parcels (Li et al. 2016). The degree of heat mitigation acquired by the development of the VPs on the urban fringe should vary by the landscaping employed (e.g., Wentz et al. 2016).

Examination of Figures 4 and 5 reveals overlap in the location of extreme LSTs (by Phoenix metropolitan standards) and the VPPG hotspot in south Phoenix extending to the west-central section of the metroplex (Fig. 5: oval). This area is recognized in other studies as dominated by lower-income, Latino neighborhoods, which are disproportionately exposed to temperature extremes and the health issues related to them (Harlan et al., 2007). The oval designating the inner "hot spot" of extreme LST (Fig. 5) contains over 7,800 VPPGs consuming an area of about 2,100 ha, affording the opportunity to cool the maximum daytime UHI. Other research focused on the central Phoenix UHI demonstrates the significant potential cooling effect of appropriately cited green spaces in this area by as much as 2°C locally and 0.5°C across a larger area (Zhang et al., 2017). This result involved fewer green spaces than actually exist in the core area identified in Figure 5, suggesting that the full use of all VPPGs may have a larger cooling effect, depending on how they are sited.

It is also noteworthy that more than 25,500 VPPGs reside in the two hottest temperature categories across the metropolitan area, covering just under 26,000 ha. VPPGs increase to more than 41,100 in number and 33,500 ha by adding the third-highest LST category. Excluding the slope constraints in our designation would further increase these figures. Parcels with a 5% slope or more, however, tend to involve high-end residential parcels awaiting development.

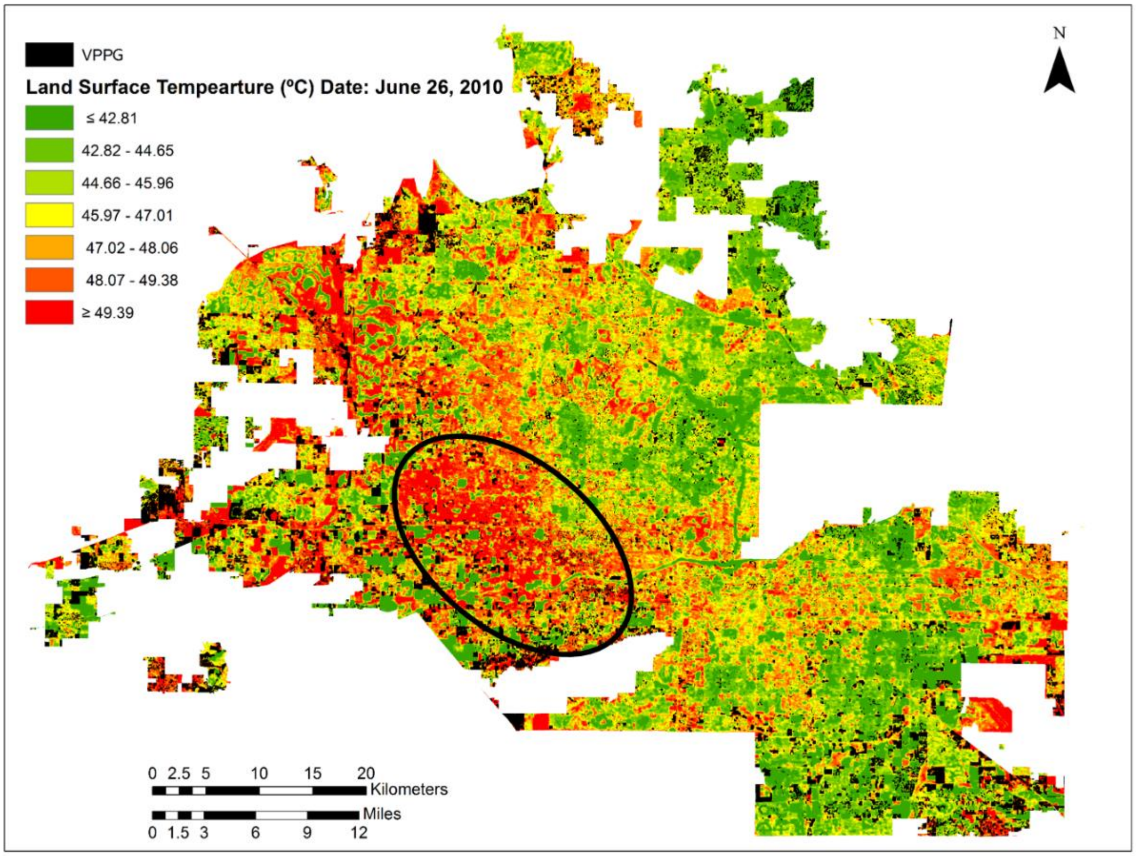

Figure 5. June 2010 Daytime Land Surface Temperature and Vacant Parcels for Potential Greening (The oval corresponds to the metro's core urban heat island)

Table 6. Vacant Parcels for Potential Greening: Distribution & June 2010 Day-Time Land Surface Temperature

Land Surface Temperature (°C)	# of VPPGs	Area of VPPGs (ha)	Average Area per VPPGs (ha)
≤ 42.81	1,963	2,911.40	1.48
42.82 – 44.65	3,753	2,690.70	0.72
44.66 – 45.96	8,308	4,678.50	0.56
45.97 – 47.01	11,854	4,763.40	0.4
47.02 – 48.06	15,641	7,735.40	0.49
48.07 – 49.38	14,877	10,248.90	0.69
≥ 49.39	10,608	15,620.20	1.47

To our knowledge, food deserts have not been calculated and mapped for the Phoenix metropolitan area. Other research, however, identifies neighborhoods with median household incomes of $14,500 as those constituting "low (food) access areas", lacking or having sparse access to fresh produce and healthy food options (Bleasdale et al., 2011, p. 102).[14] It is precisely such locales where several urban garden efforts, with mixed success, have been undertaken in Phoenix. An exploratory examination of Figures 4 and 6 reveals a large number of parcels within the hot spot residing in south Phoenix (north of South Mountain Park), with an extension to the central-west border with Glendale and Peoria (roughly corresponding to the oval area in Figure 5). These are areas dominated by Census block groups composed of the two lowest household income categories (Fig. 6). Indeed, these two block groups throughout the metro-area contain over 8,500 VPPGs covering over 5,500 ha (Table 7). This result indicates a large number and area of VPPGs that could be employed to address potential food deserts through community gardens in the Phoenix area. While other studies have calculated the potential contribution of urban agriculture to supply fresh and locally sourced produce to food deserts (e.g., Colasanti et al., 2010; Kremer & DeLiberty, 2011; MacRae et al., 2010), such analysis does not exist for the Phoenix area and is beyond the scope of this study.

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[14] The food desert areas identified by Bleasdale and colleagues (2011) with the highest median income tallied $23,500. The federal poverty rate in 2010 for household of four was $22,050 (https://aspe.hhs.gov/2010-hhs-poverty-guidelines).

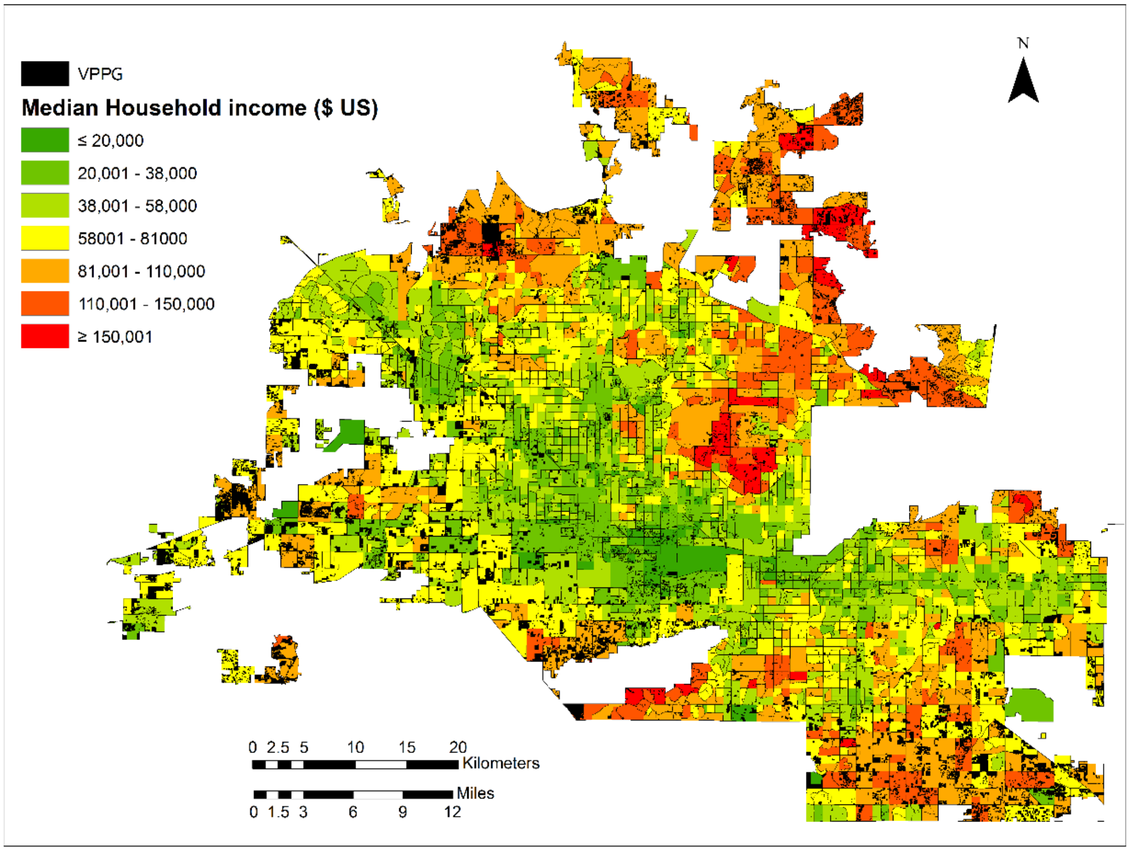

Figure 6. Median Household Income and Vacant Parcels for Potential Greening

Table 7. Vacant Parcels for Potential Greening: Distribution and Median Household Income

Median Household Income by Census Block Group ($ US)	# of VPPGs	Area of VPPGs (ha)	Average Area per VPPGs (ha)
≤ 20,000	1,084	1,112.70	1.03
20,000 – 38,000	7,422	4,418.10	0.6
38,000 – 58,000	10,467	6,447.90	0.62
58,000 – 81,000	20,234	13,265.30	0.66
81,000 – 110,000	19,598	14,371.90	0.73
110,000 – 150,000	7,114	6,994.90	0.98
> 150,000	1,108	2,041.50	1.84

2.6 Study Limitations

The application of the method developed in this study to identify VPs and VPPGs is limited to one desert metropolis. As such, it is not yet clear if the strong accuracy results obtained are applicable for metro-areas in other climates or biomes.

Additionally, the method employed to account for slope likely enlarged the number of VPPGs, especially in terrain abutting mountains. For example, the ridge-line parcels in much of Fountain Hills (Fig. 3) often have only small areas with < 5% slope, and by including them in our assessment the number and area of VPPGs increased. While constituting only a small portion of total VPPGs, adjustments for such parcels may render adjustments in hot spots currently identified.

It is also noteworthy that a greater amount of open land for potential UHI and food desert mitigation exists within the Phoenix metropolitan area than is considered in this study. Excluded from consideration were government and commercial parcels in which only a portion consists of structures, road and highway easements, recreational areas, and Native American reservation land, much of the latter of which is currently in commercial cultivation. Technically, these lands are not VPs and to assign some portion of them as potentially open for greening purposes, as defined here, would require assumptions that this study was not prepared to make. Furthermore, this study does not include an assessment of occupied parcel home gardens. For the most part, occupied parcels tend to have various levels of vegetation, the more vegetated ones already contributing to UHI mitigation. Full greening of parcel landscaping (homes and commercial establishments) would likely have a modest impact on the UHI effect, but at the cost of greater water withdrawals (Wentz et al. 2016).

Finally, simply because a private parcel is vacant does not mean it is available for greening. As noted, a substantial number of VPPGs identified in this study appear to be parcels on the urban fringe awaiting residential development and are unlikely to be available for other uses. An efficient means of creating an inventory of VPPGs, however, is required to assess a metropolitan area of significant size. Other criteria could be included in the assessment to narrow the range of VPs considered: for example, only those parcels located within the lower household income Census blocks or those residing in the core of the metroplex that maintain high LSTs.

2.7 Conclusions

Vacant land in urban areas offers opportunities to focus on issues of urban sustainability involving the creation and use of greenspaces. To address this issue for large metropolitan areas with tens of thousands of vacant parcels requires methods that transcend cadastral data for identification and permit analyses regarding location and patterns. This study provides such a method that has proven robust for the Phoenix metropolitan area applied to privately owned, parcels suitable for two types of interlinked green uses (VPPG)—vegetation cover of some kind and food-producing gardens. The method, however, is applicable for a full array of parcel types and uses, depending on user needs. Whether the method applies to other urban areas in different climatic zones or biomes requires further testing.

The VPPGs identified in this study reveal clusters that constitute urban development and are vacant momentarily, largely on the urban fringe, as well as those residing within the urban core that are questionable concerning their immediate development due to their prolonged vacancy. Our exploration indicates a substantial number and area of VPPGs residing within the Phoenix metro core of the UHI, registered by LST, and suspected food desert regions. This initial observation suggests that mechanisms placing these parcels into various green uses could have substantial impacts on reducing summertime extreme temperatures and improving resident access to nutritious foods. Calculations of the parameters of these effects await further research.

2.8 Acknowledgements

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CHAPTER 3

PLANNING URBAN COMMUNITY GARDENS STRATEGICALLY THROUGH MULTICRITERIA DECISION ANALYSIS

Abstract

Urban agriculture is widely promoted as a strategy to advance sustainability goals. Urban community gardens serve as multifunctional green infrastructure, providing an array of social and environmental co-benefits. While these services, such as increased access to nutritious food, have been studied extensively, research on siting community gardens remains sparse, especially in their multifunctional roles. This paucity is significant because the spatial distribution of gardens determines which residents benefit from them, the long-term garden success, and the multiple co-benefits for neighborhoods and metropolitan areas. To overcome potential biases related to decisions made ad hoc or by community requests, this study presents a systematic stakeholder-driven approach for strategic urban community garden siting through Multicriteria Decision Analysis (MCDA), reducing thousands of potential parcels to a small number for subsequent in-depth site analysis. We apply this methodology in the Phoenix metropolitan area. Utilizing local stakeholder-weighted criteria, we develop siting indices that incorporate physical and sociodemographic factors that either contribute to site potential or represent priority locations for gardens. The resulting indices—a Social Characteristics Index, Physical Setting Index, and Comprehensive Index—are applied to an expansive inventory of vacant candidate parcels across the metro. The three indices identify moderate to high-scoring parcels within the urban core, but siting scores diverge towards the urban fringe. When

tasked with assessing the siting criteria comprehensively, stakeholders prioritize social criteria. Thus, the Social Characteristics and Comprehensive indices prioritize disadvantaged communities in the urban core, potentially excluding aspiring gardeners who live in suburbs. This highlights a potential tradeoff between planning urban community gardens to maximize desired co-benefits and other siting criteria that may influence long-term success.

3.1 Introduction

Urban agriculture is promoted as an advantageous sustainability strategy (Miller, 2015; Rosan & Pearsall, 2017) for providing provisioning, regulating, and cultural environmental (or ecological) services, and increasingly, to assist in environmental problems, such as heat mitigation (Ackerman et al., 2014). Community gardens offer an opportunity to repurpose vacant land into multifunctional green infrastructure (Lin et al., 2017; Lovell, 2010). One of the most frequently cited co-benefits is the contribution to local food quality and security (Albright, 2020; Staub et al., 2019), especially within “food deserts” or areas lacking access to affordable fresh foods, common to many U.S. metropolises (Dutko et al, 2012; Walker et al., 2010). As part of a more sustainable urban food system, increased availability of locally grown fruits and vegetables helps improve nutritional outcomes for households participating in community gardening (Egli, et al., 2016; Miller, 2015). Also, community gardens may reverse urban blight (Drake & Lawson, 2014; Voicu & Been, 2008), provide spaces for social engagement, gardening education, and community cohesion (Bleasdale et al., 2011; Okvat & Zautra, 2011), improve gardeners’ physical and mental health (Engemann et al., 2019; Lin et al., 2017), regulate extreme temperatures (Clinton et al., 2018), ameliorate stormwater runoff (Rogers & Hiner, 2016), and improve biodiversity (Lovell & Taylor, 2013). Through these co-benefits, community gardens hold the potential to help remedy social and environmental inequities across the urban landscape (Jermé & Wakefield, 2013).

Research to date has primarily focused on the social dimensions of community gardening, including individual motivations, politicization issues, and “placemaking” in the planning genre (Guitart et al., 2012; Wesener et al., 2020). Benefits involving the biophysical environment have garnered less (albeit increasing) attention as cities plan for sustainable, multifunctional green infrastructure (Lovell & Taylor, 2013; Uludere Aragon et al., 2019). Much of this infrastructure research has been undertaken beyond the realm of community garden siting, although the linkages of the two are obvious. A more holistic understanding of the potential services community gardens offer is now at play, but it is unclear how the social and environmental dimensions of the problem are incorporated into decisions about where to prioritize or site gardens (Drake & Lawson, 2015b). This siting matters because benefits for gardens’ immediate neighborhoods (e.g., Meenar, 2017) have to be weighed against the optimization of city-wide benefits of green infrastructure, such as heat mitigation (Zhang et al., 2017).

Cities of various sizes tend to have thousands of vacant parcels (Clinton et al., 2018; Smith et al., 2017) that city officials or nongovernmental urban garden organizations (NGOs) could consider for garden development. With limited resources for the site selection process, how might decision-making account for the full range of benefits in question? Siting research has largely focused on the contextual history of particular gardens

(Birky & Strom, 2013; Langegger, 2013), the socio-politics of the selection process (Barron, 2017; Draus et al., 2014), and the social factors for successful community operations (Diaz et al., 2018; Drake & Lawson, 2015a). Systematic and quantitative approaches (e.g. multicriteria decision analysis [MCDA]) for strategic siting have received less attention, especially regarding the garden-green infrastructure duality (Eanes & Ventura, 2015; Smith et al., 2017). While no community garden literature was identified that specifically calls for the application of MCDA as a means of siting community gardens, decision-makers (e.g., government officials, NGO agents, and local stakeholders) worldwide rely on such approaches for many other siting decisions, despite their inevitable simplifications (Murray, 2020; Nyerges & Jankowski, 2010). These decision-support tools help to condense a variety of data into a format that is more accessible for planning. (e.g., Heckert & Rosan, 2016; Kremer et al,, Hamstead, & McPhearson, 2016; Meerow & Newell, 2017) As such, MCDA applied to community garden siting is expected to provide useful insights to complement those obtained from other approaches.

We develop and explore a systematic and quantitative, stakeholder-driven approach for community garden-green infrastructure siting that combines social and environmental criteria related to site functionality in the context of large cities or metro-areas with abundant vacant parcels. MCDA is applied to a selection of vacant parcels in the Phoenix, AZ, metro-area. Three parcel prioritization indices are addressed representing the physical setting, social characteristics, and their combination. The parcel scores from the indices and the distributions of vacant parcels across the study area are used to identify sites of high potential for garden placement. These sites are compared, providing insights about our approach and its outcomes.

3.2 The Challenge of Community Garden Planning

Cities are interested in expanding community gardens as part of a healthier, more sustainable food system (Albright, 2020) and potentially as green infrastructure to mitigate extreme heat and other environmental problems (Keridwen, 2019). Simply increasing the number of gardens is an inadequate strategy because numerous constraints and opportunities per site must be considered to achieve metro-area, municipal, and community goals. Common challenges include insufficient household engagement (Diaz et. al., 2018), land use access (Drake & Lawson, 2014), gentrification and displacement (Lin et al., 2017), and local ordinances and zoning (Rosan & Pearsall, 2017). Other challenges include such concerns as water access and withdrawals (Tong et al., 2020), garden-grown impacts from residual soil contamination (McBride et al., 2014), and other environmental problems to mitigate, such as flooding and the urban heat island effect (Zhang et al., 2017). City and county officials, concerned organizations, and residents may prioritize the “most-needed” challenges differently (Albright, 2020).

Identifying candidate parcels for gardens can be daunting, let alone selecting from among them, especially when thousands of vacant parcels exist. Increasingly, high-resolution remotely sensed imagery and GIS cadastral data can be used to overcome this difficulty in part (e.g., Eanes & Ventura, 2015; Saha & Eckelman, 2017), allowing for a more strategic spatial planning approach. The compilation of parcels, however, varies across studies (e.g., size, ownership, local infrastructure, and amenities) (Eanes & Ventura, 2015; Smith et al., 2017). This variance raises issues about which criteria to use and their standardization.

Additionally, site inventory studies tend to present a parcel as either suitable or unsuitable for community garden development (e.g., Drake et. al., 2016; Saha & Eckelman, 2017). In reality, site quality is nuanced, even in cases where site selection is constrained by community considerations (e.g., food insecurity), existing or absent infrastructure (e.g., stormwater drainage), and parcel ownership. Two somewhat similar parcels in the same general vicinity may not have similar siting potential, owing to their ease of access, community's willingness to participate, political and power issues, or capacity to mitigate extreme heat (Bleasdale et al., 2011; Zhang et al., 2017).

The approach explored in this study is useful for synthesizing the multiple factors that should be considered in identifying potential sites. Moreover, it provides a transparent, systematic approach for city and regional planners and urban community garden NGOs to reduce the thousands of potential parcels to a small number for subsequent in-depth site analysis. The approach is intended to overcome biases related to decisions made ad hoc or by community requests that may reinforce existing unequal patterns of urban investment and increase economic disparities (Meenar, 2017), and to optimize social and environmental objectives that deserve greater attention in site selection approaches (Lovell & Taylor, 2013).

3.3 Multicriteria Decision Analysis for Community Garden Siting and Its Exploration for the Phoenix Metropolitan Area

Multicriteria decision analyses (MCDAs) have long been used to inform site selection in the face of competing priorities, providing a means to assess the relative suitability of locations through the use of multiple, spatially-represented criteria (Malczewski, 1999; Nyerges & Jankowski, 2010). These criteria can be priority weighted by researchers (Uy & Nakagoshi, 2008) or through input from experts or stakeholders (Meerow & Newell, 2017). MCDA has been used for siting green infrastructure and agriculture (Heckert & Rosan, 2016; Kremer et al., 2016; Meerow & Newell, 2017; Mendas & Delali, 2012), but only a few exist for urban agriculture, including both garden-level and large-scale projects (Leiter et al., 2016; Parece et al., 2017; Rogers & Hiner, 2016).

Among these, Parece and associates (2017), focusing on census blocks, employed ten equally weighted social and environmental criteria, to create a 0 to 10 priority scale for siting various types of urban agriculture in Roanoke, VA. Rogers and Hiner (2016) derived two equally weighted physical setting criteria pertaining to soil for siting urban agriculture as green infrastructure in Austin, TX. Additionally, an unpublished model developed by Leiter and colleagues (2016) utilized an online MCDA pilot platform, including 13 physical/built environment criteria, to site urban gardens on vacant parcels in San Diego, CA.

We explore the use of MCDA, informed by local expert-stakeholder priorities to identify potential sites for community gardens across the Phoenix metro-area. Our study expands on previous applications of MCDA to evaluate prospective locations by joining the dual garden-green infrastructure roles, thus considering both social and environmental criteria, and deriving criteria and their weights with experts' and stakeholders' involvement. Assembling the top criteria into three indices—Social Characteristics, Physical Setting, and Comprehensive—and applying them to thousands of vacant parcels across the Phoenix metro-area, we examine the distinctions among site outcomes, comparing scoring trends and spatial distribution across the metroplex.

3.4 Data and Methods

Urban community gardens frequently consist of small-size plots or concentrations of them on parcels, managed by neighborhood residents, sometimes with the support of non-profit organizations or the government (Lin et al., 2017). In this study, "community garden" refers to any form of cultivation sited on vacant or open (e.g., lacking infrastructure, such as buildings or pavement) private land in which production is undertaken primarily by voluntary residents. As such, individual household and rooftop gardens and commercial urban agriculture are not considered in this assessment. Neither are public spaces, such as school or park grounds. The rationale for their exclusion, which could be considered in future work, is the existence of a robust data set of vacant parcels for potential gardening (VPPGs; Smith et al. 2017). These parcels constitute long-standing, undeveloped and abandoned private parcels, as well as vacant, predevelopment parcels generated through land speculation or sustained economic conditions halting development.

The number of VPPGs for the Phoenix metro-area is large, facilitating our exploration of the MCDA approach in question.

An online survey of metropolitan Phoenix expert-stakeholders (officials involved with and proponents and actual practitioners of urban/community gardens) rated and ranked two sets of siting criteria (Social Characteristics and Physical Setting). The criteria were developed from the literature and with expert-stakeholder input. A third, Comprehensive set combining all criteria was also evaluated. The rankings were used to derive weights for indicators of the criteria. Through MCDA, three siting indices were applied to the VPPG inventory. Bivariate Pearson Correlation coefficients compare the relationship between the indices, and a sensitivity analysis was administered. Potential sites identified as low, medium, or high for potential siting refer to the indices used.

3.4.1 Phoenix Metropolitan Area and Available VPPGs

The Phoenix metro-area holds more than 4.8 million people spread across 3,200 km^2 of the northern Sonora Desert in Maricopa County, AZ (Fig. 7). Like other Sun Belt metropolises, it is marked by low-density residential expansion and a “leapfrog” pattern of development creating a patchwork of undeveloped or underutilized vacant land, including within the central city’s urban core and other metro-cities (e.g., Mesa and Tempe), and along the urban fringe (Smith et al., 2017). Additionally, the urban core contains pockets of low-income neighborhoods also designated as food deserts; approximately 12% of the study area’s residents live within census tracts formally characterized as such (USDA, 2017b). Many parts of the metro-area, including food desert tracts, also experience intense urban heat island effects, with major implications for energy, water use, and human health (Harlan, et al., 2013), all of which are anticipated to be exacerbated by climate change and status quo forms of urban expansion (Hunt et al., 2017). A VPPG inventory was compiled for the year 2017 for privately owned parcels, as designated by the Maricopa County Tax Assessor (Uludere Aragon et al., 2019) through the use of remote sensing data and machine learning. The vacant parcels with pervious groundcover (i.e., bare, scrub/shrub, or mesic vegetation to facilitate gardening) were identified via one-meter National Agriculture Imagery Program (NAIP) imagery (88% accuracy), and digital elevation data determined which parcels had a slope ≤ 5% (to reduce erosion and facilitate irrigation). This inventory was further reduced by an area threshold of 7,500 ft^2 (697 m^2) and 22,500 ft^2 (2,090 m^2) to identify VPPGs sufficiently large for community gardens (e.g., room for plots, tool sheds, and socialization areas) green infrastructure, but not so big that they are attractive for large-scale development (Balmer et al., 2005; Mack et al., 2017). The analysis was also limited to parcels that had been vacant for at least seven years, a period available from a VPPG study (Smith et al., 2017). This eliminated the many vacant parcels along the urban fringe ready for suburban development, pending recovery from the Great Recession.

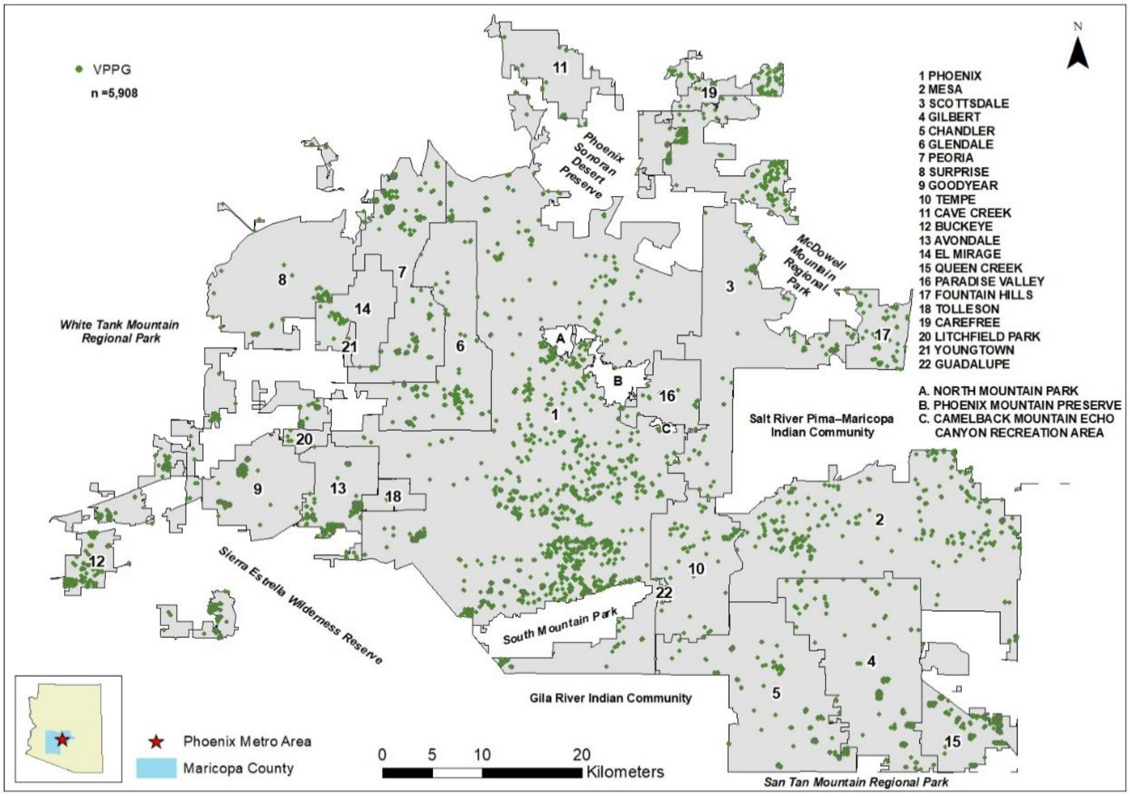

Figure 7. Phoenix Metropolitan Area and Vacant Parcels for Potential Gardening, adapted from Smith et al., 2017

From the roughly 39,000 VPPGs in the initial inventory, the criteria yielded a total of 5,908 VPPGs throughout the metro-area for evaluation in this study (Fig. 7). Ideally, each parcel should have access to water—a major limit on crop growth in the desert Southwest—which is not confirmed here. Almost all VPPGs identified, however, are surrounded by urban uses indicating that parcel access to water infrastructure is highly likely (ADWR, 2019; Tong et al., 2020).

3.4.2 Stakeholder Input and the Siting Criteria

An online survey was administered using Qualtrics to various local community gardening and urban planning organizations via snowball sampling (Noy, 2008) to ascertain stakeholder attitudes regarding perceived siting criteria priority.[15] In total, 37 individuals fully completed the survey, of which twenty-seven (73%) were in planning, policy, or governmental positions or were experienced community gardeners (Appendix C).

Stakeholders rated siting criteria using a modified five-point scale (Allen & Seaman, 2007): 5 – Extremely Important, 4 – Very Important, 3 – Moderately Important, 2 – Less Important, and 1 – Not Important. For added reliability, stakeholders were asked to rank the same criteria in order of importance within each respective category and comprehensively (Malczewski, 1999). Due to the large number of criteria (17) and considerations of data reliability (Nyerges & Jankowski, 2010), a pair-wise comparison of the criteria was not conducted (Appendix C).

3.4.2.1 Siting Criteria

Ultimately, 17 siting criteria thought either to improve the long-term success of community gardens or to denote areas that would benefit the most from the gardens' environmental services were identified by experts. Some criteria initially considered were excluded because of data limitations or an inability to be represented spatially. The 17 criteria were separated into Social Characteristics and Physical Setting categories (Table 8). Most of their category placement is obvious. A few of the criteria, however, could fit in either category (e.g., community space proximity). These criteria were categorized by the intent of the stakeholders—their notion that a criterion was a social or

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[15] IRB approval is documented in Appendix B.

biophysical/infrastructural one. This intent and many of the criteria, in general, are not easily matched by extant data, requiring various manipulations of those data for each criterion. Recall, however, that the MCDA and large inventory of VPPGs constitutes an exploration of the approach more than a definitive outcome assessment.

Representative indicators for each criterion were developed using ArcMap 10.6 (Appendix C). All of the indicators were standardized (between 0 and 1) using a linear scale transformation, with higher values corresponding with higher potential/priority areas for community gardening (Malczewski, 1999).

Table 8. Community Garden Siting Criteria

Siting Criterion	Indicator (and Source)
Social Characteristics	
Food Deserts	Percentage of census tract population who are low-income and low-access at 1 mile (USDA, 2017)
Community Health	Percentage of census tract population who are uninsured (US Census, 2019)
Lower-Income Neighborhoods	Percentage of census tract population who is at or below the poverty level (US Census, 2019)
Park-Poor Neighborhoods	Number of parks inside or within a 10-minute walk of a census block group boundary (MAG, 2014)
Community Space Proximity	VPPGs within a 10-minute walk of a park, community center, public library, religious institution, or school (ADE, 2018; MAG, 2014; MAG, 2017; MCTAO, 2017)
Minority Neighborhoods	Percentage of census tract population who identify as ethnic or racial minorities (US Census, 2019)
Heat Vulnerable Neighborhoods	Heat Vulnerability Index Score (US Census, 2019; USDA, 2017; Fraser et al., 2017)
Physical Setting	
Residential Proximity	VPPGs within 100m of developed residential parcels (MCTAO, 2017)
Population Density	Census tract population density (US Census, 2019)
Commercial Proximity	VPPGs within 100m of developed commercial parcels (MCTAO, 2017)
Extreme Temperature Areas	Calculated average land surface temperature by census block group (USGS, 2019)
Stormwater Runoff	Calculated percentage impervious surface and building coverage area by census block group ((Li et al., 2014)
Bikeability	VPPG within 100 m of a bike lane/bikeway/bike path (MAG, 2019)
Mass Transit Accessibility	VPPG is within a 10-minute walk from a bus stop or light rail stop station (Valley Metro, 2019a; Valley Metro, 2019b)
Bare Groundcover	VPPG with bare groundcover (Uludere Aragon et al., 2019)
Scrub/Shrub Vegetated Groundcover	VPPG with scrub/shrub vegetated groundcover (Uludere Aragon et al., 2019)
Mesic Groundcover	VPPG with mesic groundcover (Uludere Aragon et al., 2019)

Social Characteristics Criteria and Metrics

Food Deserts

The concept of food deserts is popular in the literature, used by governmental agencies and NGOs, but contested. Research has demonstrated the existence of food deserts and the viability of the term (Walker et al., 2010), and the U.S. Department of Agriculture (USDA) maps their existence across the U.S. and funds research to mitigate them (USDA, 2017b). In contrast, various social scientists critique the concept, from the means of their identification and mapping (Dutko et al., 2012; Thomas, 2010), to the failure to focus on the root causes of food deserts' existence and various problems that follow from policies that do not account for these conditions (Shannon, 2014). Such critiques notwithstanding, surveyed stakeholders overwhelmingly identified food deserts as pivotal for garden siting.

Perhaps the most commonly employed definition, adopted by the City of Phoenix and numerous other municipalities throughout the U.S., is provided by the USDA (Albright, 2020; Uludere Aragon et al., 2019): a census tract where at least one-third of the population (or at least 500 residents) live more than one mile from a supermarket, and the tract is considered economically disadvantaged (Appendix C) (USDA, 2017b). Using this metric, 95 of the 904 census tracts within the boundaries of the study area are designated as food deserts (USDA, 2017b). Classification aside, many tracts within the study area outside the USDA definition also contain residents with low-levels of financial means and food access who experience food desert conditions. To include these residents, food deserts were represented in our MCDA as the percentage of each tract's population classified as both low-income and low-access in the 2015 USDA Food Desert Research Atlas (USDA, 2017b). Census tracts with higher population shares of low-income and low-access residents were considered more appropriate for community gardens.

Community Health

Participation in gardening has been shown to lead to varying degrees of nutritional improvement and the adoption of healthier habits as well as increased levels physical of outdoor activeness, particularly among young adults and children (Egli et al., 2016; Staub et al., 2019; Twiss et al., 2003). It may, therefore, be strategic to site gardens in areas with elevated levels of poor community health. Capturing the health conditions of a given neighborhood, however, can prove difficult given poor access to fine-grain health data (Parece et al., 2017). To represent these areas in the MCDA, insurance coverage is used as a proxy. Low levels of health insurance are directly linked to decreased preventative care and widespread negative health conditions (Christopher et al., 2016; Sommers, et al., 2017). In the MCDA, community health is measured by the percentage of uninsured individuals within a census tract. Census tracts with higher percentages of uninsured individuals are prioritized for community garden development.

Lower-Income Neighborhoods

Issues associated with low levels of food access or food insecurity are not restricted to food deserts. Even in areas with ample supermarket access, many low-income households may not seek nutritious or fresh food due to cost, among other reasons (Coleman-Jensen, et al., 2019; Jetter & Cassady, 2006). Lower-income neighborhoods were identified as the population percentage of residents within a census tract living at or below the poverty level. Census tracts with higher percentages of low-income residents are considered to be more food and nutritionally insecure and, therefore, would receive a greater benefit from community garden participation than wealthier areas.

Park-Poor Neighborhoods

Access to parks and other open spaces across most metropolitan areas is not equitably distributed and represents a major urban environmental disparity (Harlan et al., 2007; Wolch et al., 2014). The addition of accessible, vegetated communal open spaces for neighborhood gatherings is a frequently cited co-benefit of community gardens (Lin et al., 2017; Lovell, 2010). To represent an inclusive metric for access, a 10-minute walking threshold was applied. A typical adult can walk about 756 m to 780 m in 10 minutes (Bohannon & Williams Andrews, 2011; Yang & Diez-Roux, 2012), a threshold advanced by various park advocacy groups (e.g., https://10minutewalk.org). Park poverty is represented as the number of public parks within 780 m of a census block group’s boundaries (MAG, 2014). Block groups with lower park access are considered higher potential for community gardens.

Community Space Proximity

Placing gardens near established community spaces (e.g., community centers, schools, and public parks) where individuals already congregate can help to integrate gardens into the existing social fabric and community life of the neighborhood (Kaethler, 2006; McClintock & Cooper, 2010). The aforementioned 10-minute walking threshold (780 m) was applied, so VPPGs within 780 m of a school, a public space (i.e., community centers, senior centers, public parks, and libraries), or a religious institution (e.g., churches, mosques, temples) are prioritized for garden development (ADE, 2018; MAG, 2014; MCTAO, 2017).

Minority Neighborhoods

Minority communities have been shown to support community gardens to foster cultural identity through foods and customs and develop a sense of place, especially in areas undergoing transition (Birky & Strom, 2013; Langegger, 2013). Community gardens may be used to cultivate produce not sold in local supermarkets (Companion, 2016). Minority populations within neighborhoods were represented using the percentage of the census tract population that is non-white, and higher percentage minority tracts are prioritized for community garden development.

Heat Vulnerable Neighborhoods

Increased vegetative cover provides cooling benefits in areas of extreme heat, particularly if the pattern and shape of vegetation are optimized (Jenerette et al., 2016; Zhang et al., 2017). Heat-related illnesses due to extreme temperatures, however, do not affect all communities equally. Residents' heat vulnerability within the Phoenix metro-area varies considerably and cannot be reduced simply to neighborhood temperature. Rather, it is influenced by several socio-demographic factors, such as advanced age and access to cooling (Harlan et al., 2013; Reid et al., 2009). Under different scenarios, even with the effects of climate change, sustainable urbanization that incorporates greening, including micro-scale strategies like community garden development, has the potential to reduce heat vulnerability across the metro-area (Hondula et al., 2014). A Heat Vulnerability Index (HVI) was calculated for the study area using methods originally developed for the Phoenix metro-area (Appendix C) (Harlan et al., 2013; Wright et al., 2019). Tracts with higher HVI scores would benefit more from the cooling potential of community gardens than less vulnerable tracts.

Physical Setting Criteria

Residential Proximity

Many studies note the benefits of siting community gardens within the neighborhoods they serve, including easier access to the gardens themselves, engendering community cohesion and socialization space, and reversing neighborhood blight (Bleasdale, 2015; Okvat & Zautra, 2011; Voicu & Been, 2008). Furthermore, the development of community gardens in residential areas as a key criterion was heavily emphasized by stakeholders during the development of the survey since many garden benefits accrue nearby to residents (Birky & Strom, 2013; Mack et al., 2017; Poulsen et al., 2017). The Maricopa County cadastral data (2017) was used to identify all developed single and multi-unit residential parcels within the study. Because of the multitude of parcels within the metro-area (over 1.5 million), residential properties were identified using property use codes (PUCs). To approximate for “close” proximity VPPGs within 100 m of currently developed single and multi-family housing were considered higher potential for gardens.

Population Density

Given the role of residential proximity, siting gardens in areas with larger versus smaller population densities means co-benefits for more people (Lovell, 2010; Taylor & Lovell, 2012). Additionally, more people means a larger pool of potential gardeners to care for the space (Kaethler, 2006), and this is important because participant recruitment remains a challenge of community gardening in general (Bleasdale, 2015; Diaz et al., 2018). VPPGs in census tracts with higher population densities are favored for garden sites over lower density tracts.

Commercial Proximity

Recognizing gardening as a means of dealing with stress and reducing blight, companies and local governments across the U.S. have begun siting urban/community gardens near workplaces and other commercial districts (Lin et al., 2017). Additionally, proximity to an individual's home is not always a reliable indicator of preference as many consumers travel over the day; locations along commuter routes, within proximity to places of work, or near regular shopping locations may be more preferable (Tong et al., 2012). Our survey experts supported this selection criterion. All general retailers and office buildings within the study area were identified using Maricopa County cadastral data (2017). Service stations and businesses related to automobiles (e.g., sales, repair) were excluded. VPPGs within 100 m vicinity of developed commercial areas are prioritized, the distance being commensurate with that used for other criteria.

Extreme Temperature Areas

Due to the urban heat island effect, land surface and air temperatures in Phoenix are dramatically higher in urban areas, especially where vegetation is sparse, resulting in higher household utility expenditures and decreased thermal comfort (Harlan et al., 2007; Jenerette et al., 2016; Wentz et al., 2016). Fine-grain data on air temperature across a large study area were not available. As such, land surface temperature—correlated with air temperature (Good, 2016)—was used, data indicating vegetated parcels are cooler. Extreme temperature neighborhoods within the study area were identified using 30-m Landsat Provisional Surface Temperature imagery (USGS, 2019). August 16, 2017 daytime land surface temperature values, representing extreme summertime heat in the Phoenix area, were averaged across each census block group, with higher temperature neighborhoods prioritized for garden development.

Stormwater Runoff

Heavily developed urban areas, marked by large amounts of impervious land cover commonly produce more stormwater runoff than areas dominated by other land covers, contributing to flooding. Community gardens have the potential to ameliorate these impacts by absorbing rainfall (Rogers & Hiner, 2016). The percentage of impervious surface for each block group was derived using a 2010 one-meter NAIP land cover map for the study area (Li et al., 2014). Census block groups with a higher percentage of impervious surface land cover would benefit more from pervious groundcover that community gardens provide than less-developed areas.

Bikeability and Mass Transit Accessibility

Transportation access to community gardens is not restricted exclusively to walking or driving alone. Numerous studies recommend that community gardens be sited close to transit infrastructure, particularly when tools are located onsite (Balmer et al., 2005; McClintock & Cooper, 2010). While household car ownership in the Phoenix metro-area is sizeable compared to other U.S. cities, pockets within the urban core remain where households rely on other means of transportation. Additionally, the promotion of alternative forms of transportation is concordant with sustainability goals set by the City of Phoenix and other cities in metro-area (e.g., Tempe). VPPGs within 10 minutes (i.e., 780 m) of either a bus stop or light rail station are considered to have a higher potential for community garden development (Valley Metro, 2019a, 2019b). To represent bikeability, VPPGs within 100 m of dedicated bike lanes, bikeways, or bike paths are considered to have a higher potential for garden sites (MAG, 2019).

Vacant Parcel Groundcover

VPPGs with groundcover facilitating cultivation reduces the cost of garden development (Smith et al., 2017; Uludere Aragon et al., 2019) compared to parcels with buildings and pavement, although other factors, in the end, may overcome this cost.

Various stakeholders identified this issue, focusing on the need for permeable groundcover, which in the study region invariably appear as bare soil, and scrub or mesic vegetation (Smith et al., 2017). These three groundcovers were designated as having a high potential for garden siting. The MCDA considers each VPPG of the three groundcover types its own designated category. To identify and differentiate groundcover conditions considered for site selection, one-meter NAIP imagery was employed (Appendix C).

3.4.3 Developing the Siting Indices

The siting criteria ratings and rankings obtained from the stakeholder survey were compared to check for internal consistency (Table 9). The top seven criteria from each category were selected, and weights were established using a rank-sum procedure (Eq. 1):

$$w_j = \frac{n - r_j + 1}{\sum_{k=1}^{n}(n - r_k + 1)} \tag{1}$$

$$\sum_{j=1}^{n} w_j = 1 \tag{2}$$

where w_j is the weight of criterion j (all of the criterion weights sum to 1 [Eq. 2]), n is the total number of criteria, and r_j is the rank assigned to criterion j (from 1 to 7) (Nyerges & Jankowski, 2010). The number of criteria from each category was restricted to seven because the weights increasingly diminish in power with each additional criterion, and ranking data tends to become less reliable with more than seven criteria (Malczewski, 1999; Nyerges & Jankowski, 2010). The resulting weights were applied to corresponding criteria indicators in ArcMap 10.6. Three separate weighted linear combinations, one for each siting criteria category, produced a set of three scores for each of the 5,908 VPPGs in the study area. To allow for greater precision, siting scores were multiplied by 100 to create a scale from 0 to 100, wherein higher scores correspond to higher VPPG potential for use. Correlation amongst the siting indices was assessed using bivariate Pearson Correlation (Meerow & Newell, 2017) and a sensitivity analysis was administered (Malczewski, 1999).

3.5 Results

Both the rating and ranking results from the stakeholder survey revealed a consensus among the respondents regarding the categorization (social vs. physical), importance, and the relative prioritization for the siting criteria. Six of the top eight criteria in the Comprehensive Index were social criteria, generating a similarity between that index and the Social Characteristics one. All three siting indices generally score VPPGs within the urban core as moderate to high potential for community gardens. VPPG values deviate outside of this core: the suburbs and urban fringe locations tend to score lower for the Social Characteristics Index versus the Physical Setting Index.

3.5.1 Stakeholder Survey

Survey participants' rankings and ratings for the different criteria were generally consistent (Tables 9A & 9B). The top Social Characteristics criterion, both in terms of ranking and rating, was food deserts (mean rating: 4.11). The next four highest-ranked criteria were community health (3.95), lower-income neighborhoods (3.89), park-poor neighborhoods (3.92), and community space proximity (3.84). Minority neighborhoods (3.24) and heat vulnerable neighborhoods (3.24) tied as the lowest-rated social criteria. Among the Physical Setting criteria, residential proximity was by far the most important criterion (4.51), followed by population density (3.84), bikeability (3.68), mass transit accessibility (3.68), and bare groundcover (3.43). The remaining Physical Setting criteria ranged from 3.24 to 2.87 in mean scores. Social criteria dominated the Comprehensive ranking (Table 9C): food deserts (rank: 2), lower-income neighborhoods (3), park-poor neighborhoods (4) community health (5), and community space proximity (7). Only two criteria – residential proximity (1) and population density (6) – were physical.

3.5.2 Community Garden Siting Indices

From the nearly 6,000 parcels unused for ≥7 years in the Phoenix metro-area, 703 VPPGs scored moderate to high (≥ 50) for all three indices, predominantly concentrated within the City of Phoenix's urban core. VPPG scores generally decrease as a function of distance from the core (Fig. 8). Surprisingly, the VPPGs resulting from the Social Characteristics Index receive on average lower scores than those in the other two indices (Fig. 9A), since many of the high values for social criteria are concentrated in a small area of the metro. The mean parcel siting score for this index is 33.7, with a top score of 83. Those VPPGs concentrated in downtown and south-central Phoenix score in the moderate to high range (Fig. 8A). South-central Phoenix is marked by low-income and high-minority population neighborhoods, multiple food desert tracts, extreme temperatures, and a "punch card" distribution of smaller, formerly residential VPPGs.

Table 9. Community Garden Siting Criteria Survey Results

A. Social Characteristics Criteria

	Food Deserts	Community Health	Lower-Income Neighborhoods	Park-Poor Neighborhoods	Community Space Proximity	Minority Neighborhoods	Heat Vulnerable Neighborhoods
Rating							
Mean	4.11	3.95	3.89	3.92	3.84	3.24	3.24
STDEV	1.18	1.18	1.25	0.94	0.89	1.08	1.32
Rating Order	1	2	4	3	5	6	6
Ranking							
Mean	2.97	3.41	3.46	3.81	4.05	4.87	5.43
STDEV	2.2	1.65	1.67	1.81	2.03	1.76	1.62
Ranking Order	1	2	3	4	5	6	7

B. Physical Setting Criteria

	Residential Proximity	Population Density	Bikeability	Mass Transit Accessibility	Bare Groundcover	Commercial Proximity	Extreme Temperature Areas	Scrub/Shrub Vegetated Groundcover	Stormwater Runoff	Mesic Groundcover
Rating										
Mean	4.51	3.84	3.68	3.68	3.43	3.24	3.19	2.95	2.87	2.87
STDEV	0.68	1.03	1.12	1.01	1.26	1.02	1.23	1.06	1.07	1.21
Rating Order	1	2	3	3	5	6	7	8	9	9
Ranking										
Mean	2.97	4.32	4.81	5.14	5.27	6.16	6.41	6.46	6.68	6.78
STDEV	2.41	2.47	2.43	2.21	2.97	2.58	2.78	2.81	2.73	2.75
Ranking Order	1	2	3	4	5	6	7	8	9	10

C. Comprehensive Criteria*

	Residential Proximity	Food Deserts	Lower-Income Neighborhoods	Park-Poor Neighborhoods	Community Health	Population Density	Community Space Proximity
Ranking							
Mean	2.97	3.41	4.46	3.81	4.05	4.87	5.43
STDEV	2.2	1.65	1.67	1.81	2.03	1.76	1.62
Ranking Order	1	2	3	4	5	6	7

* See Appendix A for all Comprehensive category results.

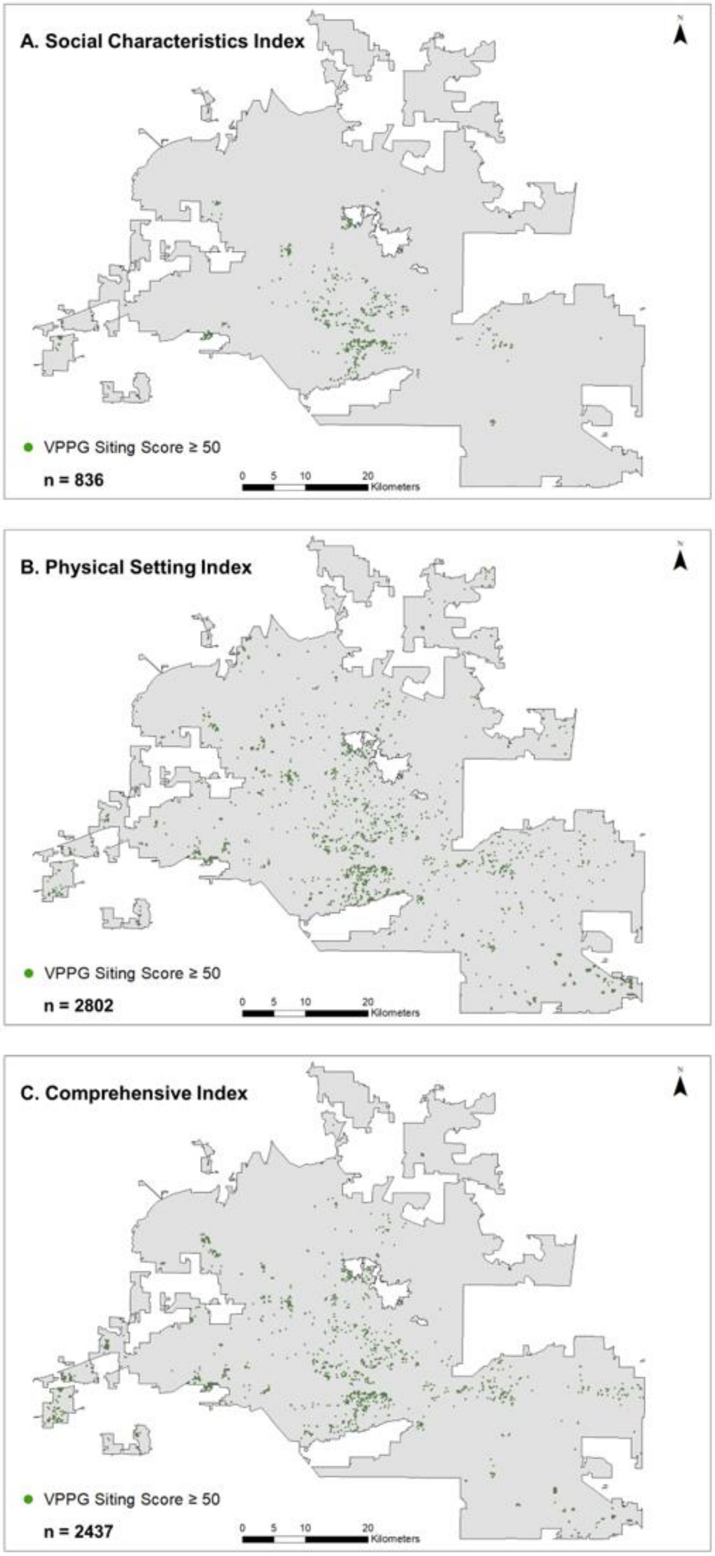

Figure 8. Moderate to High Scoring VPPGs Within the Study Area

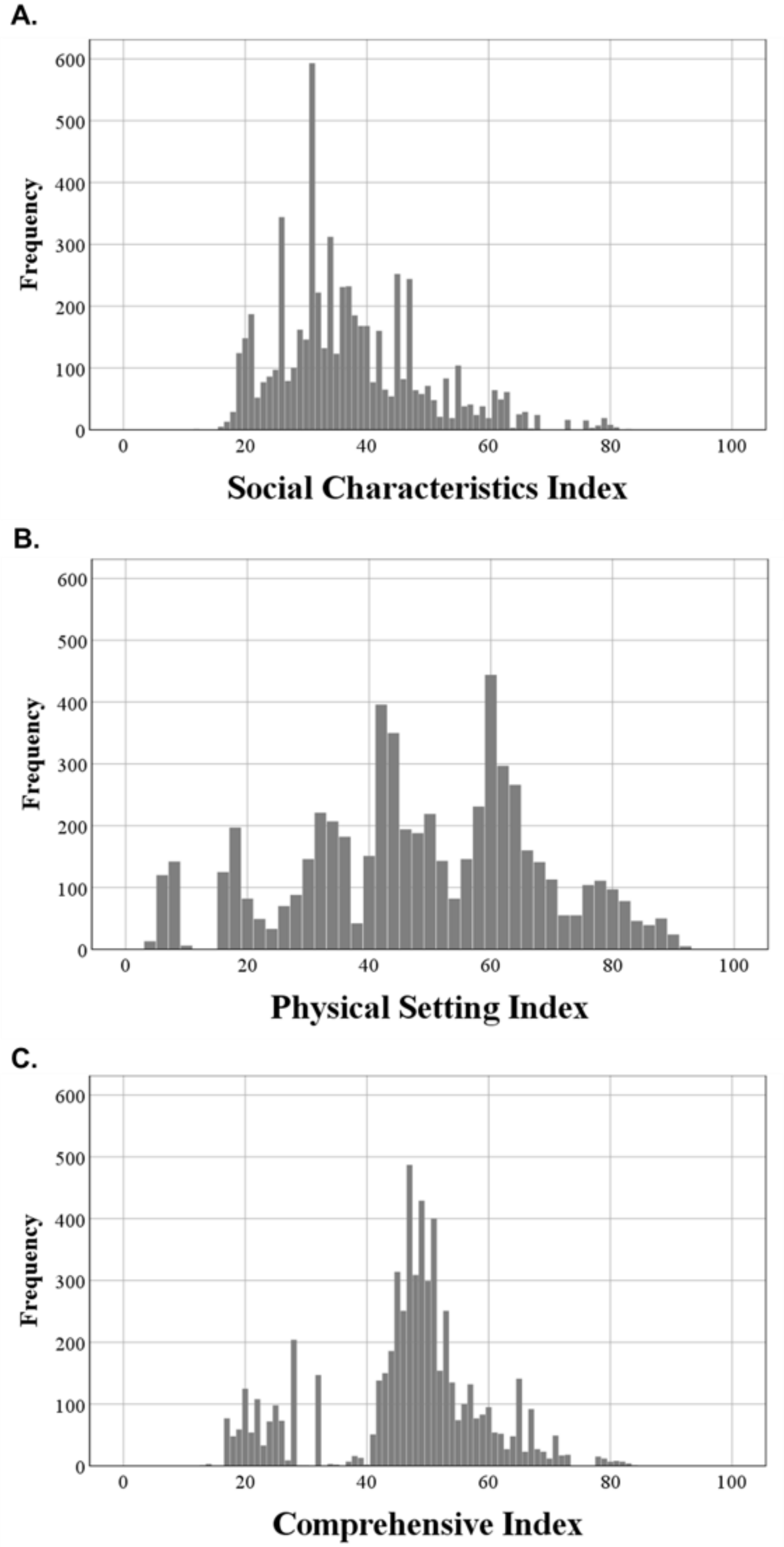

Figure 9. Community Garden Siting Indices Score Distribution

Table 10. Siting Indices Descriptive Statistics

Siting Score	**Social Characteristics Index**		**Physical Setting Index**		**Comprehensive Index**	
	# of VPPG	Area (ha)	# of VPPG	Area (ha)	# of VPPG	Area (ha)
90 - 100	0	0.0	17	2.2	0	0.0
80 - 89	13	1.3	285	31.1	27	2.7
70 - 79	60	6.1	430	48.2	123	13.4
60 - 69	276	29.5	1,094	120.3	582	61.0
50 - 59	487	51.7	976	108.3	1,705	188.3
40 - 49	1,224	117.8	1,307	154.3	2,317	275.4
30 - 39	2,344	268.0	830	94.2	189	18.2
20 - 29	1,332	165.8	285	30.5	777	81.6
10 - 19	172	18.9	407	42.1	188	18.7
< 10	0	0.0	277	28.0	0	0.0
Mean Score	37.1		47.8		46.5	
Median Score	35		48		48	
Score STDEV	12.0		19.5		12.9	

Scores in the Physical Setting Index (Fig. 9B) are more evenly distributed, with mean and top scores of 47.8 and 91, respectively. Moderate to high scoring parcels are distributed throughout the study area, from the urban core into the surrounding suburbs (Fig. 8B). Lower scoring parcels are primarily located near the less populous urban fringe.

The parcels that received moderate to high scores under both the Social Characteristics and Physical Setting indices are almost exclusively in Phoenix’s urban core. Given the divergent scoring trend beyond this location, however, the two indices are only modestly correlated (0.243, $p < 0.01$) (Table 11). The total area for parcels receiving siting scores ≥ 50 under the Social Characteristics Index (89 ha) and Physical Setting Index (310 ha) differ considerably. The indices differ most noticeably in middle to upper-income urban and suburban areas where the Physical Setting scores are higher than Social Characteristics scores. Conversely, some Social Characteristics criteria, such as food deserts and low park access, are restricted to a few parts of the metro-area that are not equally served by transportation infrastructure. Also, VPPG scores in some urban fringe housing developments are elevated despite their low population numbers because of large swathes of vacant land. For the most part, these parcels are part of former agricultural fields awaiting housing development (Smith et al., 2017).

The performance of the Comprehensive Index displays a distinct bimodal distribution, largely the result of the binary residential proximity criterion (Fig. 9C). Of the 4,752 VPPGs that scored > 40 in the Comprehensive Index, a total of 4,746 (99.9%) are proximate to a residential area. Of the 1,156 VPPGs that scored ≤ 40, only 30 (2.6%) are near residential areas. The mean Comprehensive Index score is 46.5; higher-scoring VPPGs tend to be concentrated within the urban core (Fig. 8C). The index's low scoring VPPGs are largely located either in predominately industrial or commercial corridors involve clusters of VPPG awaiting residential development. A total of 265 ha of moderate to high scoring VPPGs are available under this index, which is moderately correlated with the Social Characteristics and Physical Setting indices (0.625 and 0.457, respectively [$p < 0.01$]) (Table 11).

Table 11. Siting Indices Correlation

	Social Characteristics Index	Physical Setting Index	Comprehensive Index
Social Characteristics Index	-	0.243**	0.625**
Physical Setting Index	0.243**	-	0.457**
Comprehensive Index	0.625**	0.457**	-

** Correlation is significant at the 0.01 level

To test the indices' sensitivity to stakeholder weights, each index was modified using equally weighted criteria (Appendix C). Mean siting scores increase for the Modified Social Characteristics Index (43.2), decrease for the Modified Physical Setting Index (45.2), and essentially remain the same for the Modified Comprehensive Index (46.8). The distribution of moderate to high scoring VPPGs changes. The most pronounced change is observed in the Modified Social Characteristics Index wherein higher siting scores are present across the metro-area, not just predominately in the urban core. As expected, the survey-derived rankings of the MCDA affect the outcomes, particularly for the social criteria, reinforcing the relevance of a well-structured participatory planning process.

3.6 Discussion and Limitations

The MCDA approach applied to a large pool of potential parcels constitutes an exploration of a quantitative and strategic means to inform the siting of community gardens. This exploration demonstrates how thousands of potential parcels are reduced to a much smaller set of candidate locations: 5,908 VPPGs reduced to 703 high-to-medium scoring sites based on survey-weighted evaluation criteria.

High-scoring parcels are either concentrated in Central Phoenix—an area scoring high on social criteria—or spread across the metro-area based on physical criteria. The number of sites and their location provides a nuanced, yet transparent and systematic assessment for decision making. The need for such a strategic approach is amplified by the multiple food-to-green-space roles that community gardens may serve and the various mandates of communities and government officials. Both individual site selections and the composite pattern of all selected sites matters for the receiving neighborhood (e.g., food) and metro-area at large (e.g., heat mitigation).

Given that urban community gardens may serve as green infrastructure, it is perhaps surprising that the Physical Setting criteria scored so low among the survey participants' Comprehensive criteria rankings. The two largest participant groups, urban planning/policy practitioners (16) and community gardeners (11) apparently focused on food benefits of gardens and ranked the social criteria higher on average than the physical ones in the comprehensive evaluation. This result, especially the focus on food deserts, indicates an interest in targeting populations thought to need food and nutrition benefits, consistent with the long-term rationale for community gardens as spaces to address social disparities (e.g., Lin et al., 2017; Parece et al., 2017). Notably, the results of our Social Characteristics Index heavily reflect those found by Parece and associates (2017) whose MCDA also overwhelmingly identified elevated priority areas for community gardens in neighborhoods with predominantly socio-economically disparate populations. Fusing green infrastructure with food-nutrition is a relatively new concept (Guitart et al., 2012;

Lovell & Taylor, 2013). Adding a large pool of participants focused on environmental sustainability and its focus on green infrastructure could produce different results.

It is noteworthy that community gardeners are neither homogenous nor exclusively located within the urban core (Birky & Strom, 2013; Blaine et al., 2010). Indeed, 31 of the 76 operating community gardens in the Phoenix metro-area are located in suburban areas (CGMC, 2017; Mack et al., 2017). The majority of these suburban community gardens received low or very low Social Characteristics scores but high Physical Setting scores. This observation points to a potential mismatch between concept-based siting (e.g., serving food deserts or mitigating heat) and siting based on neighborhood demand. Ideally, MCDA approaches would benefit from including a criterion registering neighborhood demand for gardens or neighborhoods designated for governmental or NGO attention to generate and sustain that demand.

In addition to enlarging and diversifying the survey pool and providing information on neighborhood demand, this exploration would likely be more robust and yield somewhat different results with additional criteria. For example, the consequences of green infrastructure siting (location and patterns) for various environmental concerns are not available for most metro-areas and were not included in our assessment. Additionally, information regarding parcel-level water access and potential soil contamination was not available for each VPPG. Elevated heavy metal concentrations sometimes found in urban soils could pose a health risk if ingested (McBride et al., 2014). Though data on soil characteristics were not available at the parcel-level scale, examinations of current community gardens in the Phoenix metro-area show low levels of lead and cadmium

(Holmes et al., 2018). Urban soil sampling throughout the region generally identified low concentrations of lead, with relatively elevated readings in minority neighborhoods with older homes (Zhuo et al., 2012). Regardless, soil testing is considered a best practice prior to garden development, and mitigation methods (e.g., raised garden beds) exist (USDA, 2016). These considerations should be added as part of due diligence in the phase of decision-making subsequent to the MCDA. Other factors such as parcel property values, tax liens, VPPG availability, utility costs, municipal regulations, and potential conflicts with existing land use plans were out of the scope of this study but should be examined before making final siting decisions.

Additionally, as with any project reliant on stakeholder input, it is important to strive for equity and inclusion in the engagement process (Barron, 2017; Draus et al., 2014). This study attempted to do this through initial consultation with two local non-profit organizations specializing in community gardens targeting in low-income areas and at-risk youth. Furthermore, while the MCDA identifies many promising parcels in priority areas (e.g., low-income neighborhoods), it would be necessary to engage the community to determine whether residents are interested in gardening. Indeed, our survey does not account for this interest or for the expenditures required to introduce and advance community participation.

Sharpening criteria by local empirical evidence and improving proxies could also alter and improve results. The time and distance metrics, for example, are drawn from the literature and not based on metro-area evidence where, for example, large disparities may exist between extreme summer heat and cool winters concerning preferred walking and bicycling distances. Likewise, the percentage of uninsured individuals per census tract is, at best, a loose proxy for the health of the tracts' residents. Improving these metrics and adding those missing (above) would compound assessment costs. Additional studies are required to determine if the robustness of the results would improve by adding this information and by how much.

3.7 Conclusion

Community gardens can help address various urban sustainability challenges, but site selection is critical to their success and determines who or what actually benefits from them. While previous work on urban/community gardens emphasizes the importance of selecting the right location to maximize co-benefits, systematic approaches to siting multifunctional gardens are sparse. The spatial planning of community gardens requires decision-makers to choose from thousands of potential sites. These decisions take place within a broader social-environmental context in which multiple co-benefits are at play, in addition to other factors that could potentially influence gardens' long-term viability.

Through the use of MCDA, our study provides a stakeholder-driven, transparent, and systematized means of community garden siting across an entire metropolitan area that provides multiple indices delimiting thousands of parcels for potential garden development. Applying the approach in the Phoenix metro-area shows that prioritized sites differ based on the categories of criteria used and locally derived priorities. Assessed comprehensively, our survey participants' prioritization of social criteria for site selection—possibly the result of the sample—strongly favored the notion of community gardens as food-provisioning social spaces (targeting disadvantaged areas) over other metro-level physical environment concerns. Additionally, the favored criteria are not always consistent with the locations of existing, successful community gardens in the metro-area. To address this, other criteria such as community demand for garden space, along with other considerations, such as redevelopment initiatives and other needs specific to a given neighborhood, should be part of follow-on assessments or future applications of this approach. Finally, while our study provides a metro-level assessment, the overall methodological approach can be applied at multiple scales (e.g., city or neighborhood), and the weighted criteria that comprise it can be changed or adjusted accordingly to meet the user's needs. The MCDA-based methodology we develop is both flexible and replicable and could prove to be a beneficial tool for community garden development for governmental entities, community organizations, and aspirant gardeners across the U.S. and beyond.

3.8 Acknowledgments

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CHAPTER 4

EVALUATING THE SYNERGIES AND TRADEOFFS OF URBAN HEAT AND FOOD DESERTS THROUGH SPATIALLY-OPTIMIZED URBAN COMMUNITY GARDEN PLANNING

Abstract

Urban community gardening represents a promising strategy to help advance sustainable planning goals for decision-makers across the globe. We develop a bi-objective Community Garden Coverage Model (CGCM) to spatially optimize locations for community gardens and maximize their potential to mitigate food deserts and ameliorate elevated land surface temperatures (LST) primarily attributed to the urban heat island effect. Our coverage assessment for the Phoenix, Arizona, metropolitan area assigns priority scores to neighborhoods based on need. The CGCM additionally incorporates the siting potential of several thousand possible community garden locations across the metro-area, thereby allowing the model to prefer better-suited sites when multiple options are available.

We solve multiple coverage scenarios where the two coverage objectives are evaluated independently and jointly using different weighting values. The CGCM produces differing spatial patterns for the two objectives and indicates that fewer community gardens are necessary to cover food desert priority neighborhoods than LST priority neighborhoods. When solved jointly, though, it is revealed that weighing food desert priority slightly higher than LST priority yields a balanced benefit outcome for the

study area. Additionally, we compare our optimized solutions to the theoretical coverage provided by the metro-area's current community garden network and find that strategic, spatially-optimized community garden locations provide greater coverage of high-priority areas than the present community garden network. These results highlight how the CGCM may inform decision-makers concerning which available locations hold the greatest potential to serve communities where community garden benefits are needed the most.

4.1 Introduction

As urban regions around the world continue to expand, so too do the challenges they face. Sustainability is increasingly one challenge that confronts a changing climate and the unintended consequences of the legacies of and present-day urban planning and development decisions (Murray, 2020). Of the multiple avenues to mitigate two parts of this sustainability challenge, foremost "food deserts" and the urban heat island effect, is through urban agriculture, especially community-sustained gardens. Community gardens constitute multifunctional green infrastructure with the potential to address food security and nutrition and ameliorate extreme temperatures, in addition to providing a host of other social and environmental services (or "co-benefits) (Langemeyer et al., 2021; Newell et al., 2020; Nicholls et al., 2020; Russo et al., 2017; Smith et al., 2021).

The widest-promoted service of urban community gardening is its potential to supply local fresh and nutritious food. As such, these gardens are frequently developed in food deserts, or neighborhoods in which residents have sparse access to affordable fresh, nutritious food options. An array of factors is linked to this phenomenon, foremost disparities in access to food as a function of location and the physical distance to quality food retailers, the potentially prohibitive cost of healthier food options for low-income households, or some combination of both (Rhone et al., 2019; Walker et al., 2010). The conceptualization of food deserts is contested for a variety of reasons, however, including disagreement regarding which metrics should be used to identify and delineate them and insufficient attention to the underlying root causes of the phenomenon beyond the physical presence of and distance to a major supermarket (Bao et al., 2020; Lucan & Chambers, 2013). These critiques notwithstanding, various governmental agencies, NGOs, and urban researchers worldwide recognize the existence of food deserts, if variously defined (Walker et al., 2010).

Through the provisioning of healthier food choices, community gardens have been shown to play a role in improving access to sufficient and fresh foods for participating households, yielding positive nutritional health outcomes (Grier et al., 2015; Litt et al., 2011). Furthermore, they can serve as community spaces that promote physical activity, mental wellness, and socialization, all of which have the potential to further enhance the urban landscape (Engemann et al., 2019; Firth et al., 2011). Urban community gardens also assist in the reversal of urban blight and environmental problems through the conversion of vacant or underutilized land into greenspace, especially important in neighborhoods where such space is sparse (Bowman & Pagano, 2004; Branas et al., 2018). In this capacity, community gardens not only improve neighborhood aesthetics but may also serve as green infrastructure offering environmental co-benefits like stormwater attenuation and fostering urban biodiversity, among other services (Newell et al., 2020).

Importantly, multifunctional green infrastructure, including community gardens, also holds the potential to mitigate the urban heat island (UHI) effect. Cities, particularly the sprawling metropolises of the Sun Belt of the United States, experience elevated daytime and nighttime temperatures due to the replacement of natural, vegetated groundcover with pavement and concrete (Chow et al., 2012; Hunt et al., 2017). This is particularly significant in lower-income neighborhoods where vegetation is often scarcer than in wealthier communities (Harlan et al., 2013). As cities continue to develop and expand, in conjunction with a warming climate, the impacts of the UHI (i.e., extreme above-ground air temperature and land surface temperature [LST]) are felt by residents in the form of increased utility expenditures and heat-related morbidity (Fraser et al., 2017; Guhathakurta & Gober, 2010). The increased green cover gained from even micro-scale vegetative features, as found within community gardens, holds the potential to cool neighborhoods through evapotranspiration and reduction of reradiated heat, providing both local and—when incorporated into sustainable urban planning practices—cumulative cooling impacts across a warming urban landscape (Oliveira et al., 2011; Zhang et al., 2017).

As such, the integration of community gardens into land use planning continues to be advocated as a means of promoting urban sustainability goals (Albright, 2020; Nicholls et al., 2020). Community garden research at present, however, largely consists of studies focusing on the social dimensions of these spaces (Barron, 2017; Bleasdale, 2015), and the co-benefits community gardens offer, chiefly their contribution to urban food systems (Russo et al., 2017; Saha & Eckelman, 2017; Uludere Aragon et al., 2019). Growing attention is also being paid to the environmental services provided by community gardens as a type of multifunctional green infrastructure (Clinton et al., 2018; Russo et al., 2017). In contrast, much less attention has been paid to the spatial arrangement of community gardens and how their distribution across the urban landscape can be optimized to best serve high-priority neighborhoods and urban areas at-large (Mack et al., 2017; Tong et al., 2020). Our study seeks to further this line of research through the development of a new community garden location model.

The Community Garden Coverage Model (CGCM) introduced in this study consists of both social and environmental objectives. The first objective is to maximize the coverage of populations experiencing food desert conditions within the metro-area, and the second is to maximize the coverage of neighborhoods experiencing elevated LST (largely attributed to the UHI effect). The model is used to evaluate the optimal number and configuration of multiple urban community gardens in the Phoenix, AZ, metropolitan area using an extensive inventory of "vacant parcels for potential gardening" (VPPGs) to serve as candidate sites (Uludere Aragon et al., 2019). In addition to analyzing the CGCM's optimized solutions, the results are contrasted with the metro's current community garden network. Our study demonstrates that community gardens can have potentially wide-spread social and environmental co-benefits when sited systematically at the metropolitan-level, providing insight into how future applications of the CGCM could inform more sustainable urban planning.

4.2 Siting Community Gardens

The development of community gardens varies across urban areas (Eanes & Ventura, 2015; Saha & Eckelman, 2017; Smith et al., 2017). They are frequently sited on vacant parcels located in neighborhoods perceived to be high-need (e.g., a food desert) or within a community that holds aspiring gardeners (Drake & Lawson, 2014; Rosan & Pearsall, 2017). In addition to site selection criteria, community capture strategies and other forms of support (e.g., gardener education/support programs, special lease agreements, flexible city ordinances) are important for the sustained success of community gardens (Diaz et al., 2018; Newell et al., 2020). Such approaches, however, tend to lead to an ad hoc or incremental garden development, commonly small in number. In contrast, increased access to high-resolution areal imagery and various mapping or geodesign tools have allowed for systematized assessments of metro-areas, addressing substantial inventories of potential urban community garden sites (e.g., Saha & Eckelman, 2017; Smith et al., 2017). Such assessments have largely been utilized to examine VPPG distribution and the potential area of cultivatable land (Clinton et al., 2018; Smith et al., 2017), or the potential quantity of produce contributed to local food systems (Nicholls et al., 2020; Uludere Aragon et al., 2019).

The use of these inventories to assess optimized urban community garden networks— spaces or parcels providing the most benefit in terms of urban area coverage and need—remains underexplored in the urban planning process. This scarcity is somewhat surprising given that spatial optimization models (Church & Davis, 1974; Tong & Murray, 2012) have been employed for a variety of urban planning issues, such as improving access to transportation infrastructure (Wei et al., 2017), enhancing emergency services coverage (Li et al., 2011), and ameliorating extreme temperatures via strategic greenspace development (Zhang et al., 2017). The application of spatial optimization applications has shown that micro-scale decisions hold the potential to have significant cumulative impacts (Murray, 2020; Tong et al., 2020).

While underexplored, spatial optimization as it relates to urban community gardening has also garnered recent attention. In particular, the maximal covering location problem (MCLP) has been recently used to support community garden site selection. Broadly, the MCLP allocates a predefined number of facilities to maximize the total covered demand for some given objective(s) (Murray et al., 2010). Recognizing the advantages of MCLP approaches, Mack and associates (2017) employed an extensive inventory of vacant parcels to establish a network of community potential gardens within the Phoenix metro-area, seeking to maximize the number of food desert residents covered. Vacant land identified in the county cadastral data with a minimum area threshold of 5,000 ft^2 (464.5 m^2) and within one mile or less from the population centroid of a given census tract designated as a food desert by the U.S. Department of Agriculture (USDA) was employed as potential garden sites. The study, however, did not consider the geographic setting of prospective locations (e.g., whether or not the parcel was located proximate to a residential area) or incorporate other potential environmental services that the community gardens could provide beyond food production. A similar coverage assessment undertaken by Bao and colleagues (2020) sought to maximize food desert coverage in Tucson, AZ, through the use of hypothetical small, independent food retailers rather than community gardens. Lastly, another community garden optimization assessment was recently conducted by Tong and associates (2020). The researchers developed a series of models to maximize overall urban community garden food production in Tucson by selecting the optimal garden sites (public vacant parcels) as well as different forms of renewable water use (i.e., rainwater harvesting and utilizing reclaimed water). Potential sites were identified through county cadastral data and were aggregated at the block group-level. While they were able to establish an optimized gardening scheme, the researchers (e.g., Mack et al. [2017]) only considered the benefits of community gardens as related to addressing food deserts (i.e., food production) and did not account for individual site potential or benefits beyond food production.

In contrast, in this study we propose the CGCM (a variation on the classic MCLP) to examine two different urban community garden functions—food desert mitigation and LST amelioration—using an extensive inventory of available VPPGs within the Phoenix metro-area. In addition to neighborhood priority (i.e., areas with large food desert population or extreme temperatures), the siting potential of each VPPG is also factored into the optimization. This introduces a level of practical site consideration that prioritizes locations better-suited for sustaining future community gardens when multiple parcels are available. Our approach demonstrates how micro-scale land use decisions can be incorporated strategically into the urban landscape, potentially yielding both local and regional impacts. Such an approach to community garden development holds the promise of informing sustainable development objectives for local governments in contrast to more ad hoc siting practices which can—at times—be both unreliable and perpetuate urban disparities (Meenar, 2017; Newell et al., 2020).

4.3 Study Area

The Phoenix metropolitan area is located in the northern Sonora Desert in Maricopa County, AZ, and maintains a population of 4.8 million (U.S. Census Bureau, 2019). Phoenix, like many other American Sunbelt metropolises, experienced substantial growth during the second half of the 20th Century and presently encompasses over 3,200 km^2 (Fig. 10). A sprawling "leapfrog" pattern of development has resulted in extensive, low-density suburban and peri-urban communities and a sparse infill of existing vacant properties within the metro's urban core (Gober & Burns, 2002). This, coupled with the adverse economic conditions of the mid to late 2000s, has resulted in large quantities of undeveloped or underutilized vacant land across the region (Smith et al., 2017). Even with the post-Great Recession recovery, a surplus of land still exists both within the urban core and along the urban fringe (Smith et al., 2021; Uludere Aragon et al., 2019).

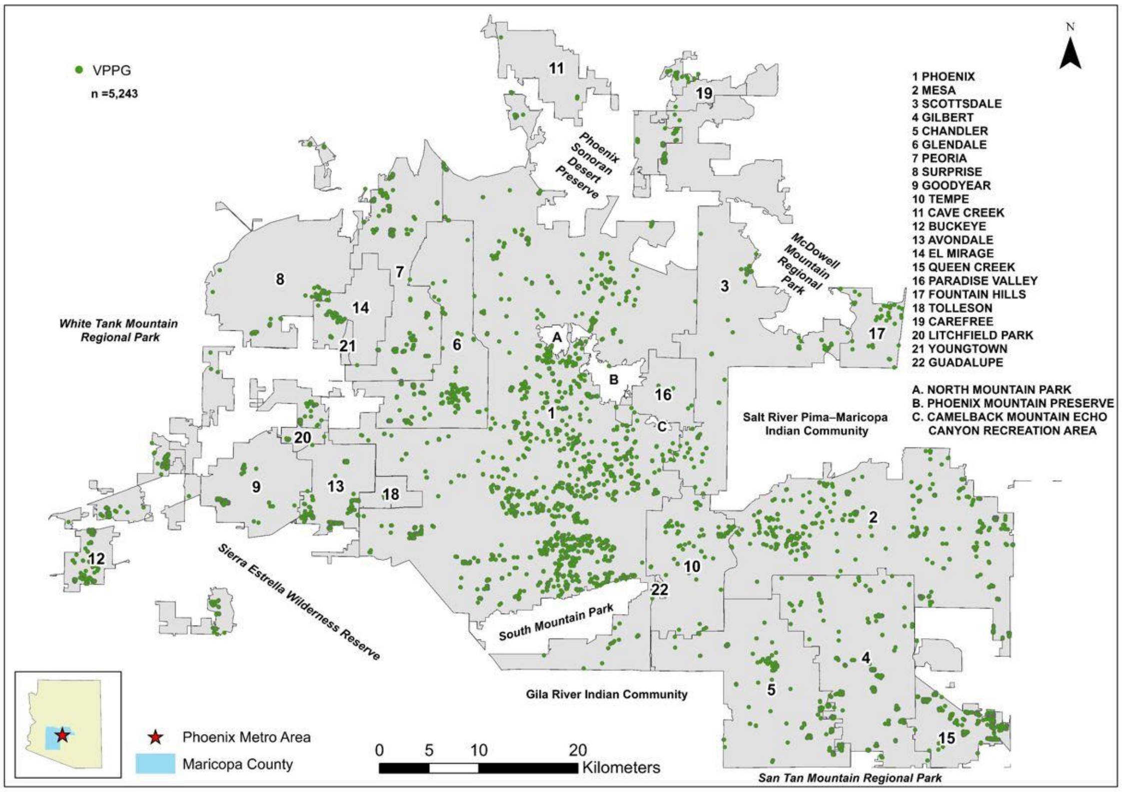


Figure 10. Phoenix Metropolitan Area and Vacant Parcels for Potential Gardening, adapted from Smith et al., 2017

Within the study area, both food desert conditions and the impacts of the UHI effect create challenges for residents. Food deserts are delineated at the census tract-level. As such the food environment (i.e., the spatial distribution of affordable, nutritious food sources) may change significantly when moving from one tract to another. Food desert conditions do not necessarily carry over into the other surrounding tracts), especially because it is not uncommon for food desert neighborhoods in the metro-area to be isolated or to consist of highly localized clusters of just a few tracts. Such distribution is noted in the metro-area’s USDA-designated food desert census, many of which are primarily located within the urban core. In totality, these designated tracts hold approximately 12%

of the study area's residential population (Rhone et al., 2019). Affected households in the associated neighborhoods are disproportionately racial/ethnic minorities and have incomes well below the study area's median value of $57,935 (U.S. Census Bureau, 2019). Additionally, many neighborhoods within the study area that do not necessarily meet the official USDA food desert threshold still have populations with low-incomes and low-access to major food retailers (USDA, 2017). These include several tracts on the urban fringe that have undergone a recent change from primarily agricultural land use to residential subdivisions where commercial development (e.g., supermarket construction) may be lagging.

Compared to the location-specific distribution of food deserts, the UHI effect is pervasive across the Phoenix metro-area (Chow et al., 2012; Hunt et al., 2017). Green cover (e.g., residential landscaping decisions) and its distribution across the built environment influences above-ground air temperature and LST at both micro and macro scales (Heris et al., 2020; Li et al., 2016). While cooling via evapotranspiration is primarily associated with above-ground air temperature (Spronken-Smith & Oke, 1998), its documentation across the Phoenix metro-area is insufficient to address the VPPGs used in this study. In contrast, LST can be calculated for every VPPG and is correlated with immediate above-ground air temperature (Good, 2016), suggesting that cooling benefits of community garden vegetation would accrue in areas with elevated LST. It is also noteworthy that neighborhoods experiencing food desert conditions also bear disproportionate impacts from extreme heat, including increased water use and energy consumption, as well as other implications detrimental to human health and overall quality of life (Guhathakurta &

Gober, 2010; Harlan et al., 2013). As such, mitigating the UHI is essential within the metro-area.

As of 2017, the metro-area held 76 active community gardens of varying sizes (Community Gardeners of Maricopa County, 2017; Mack et al., 2017). Prior work by Mack and associates (2017) found that the tracts within the vicinity of a community garden typically had populations with greater racial/ethnic diversity and lower socioeconomic characteristics (e.g., educational attainment and median household income). These gardens, however, are not distributed evenly across the metro-area, leaving large swaths of the study area underserved. Of these gardens, ~ 46% are located within the metro's "urban core" (i.e., the portion of the region centralized around Phoenix-proper). Underserved areas include not only more affluent suburbs but also multiple middle-to-lower-income communities near the urban fringe, both of which may also hold aspirant community gardeners.

4.4 Data and Methods

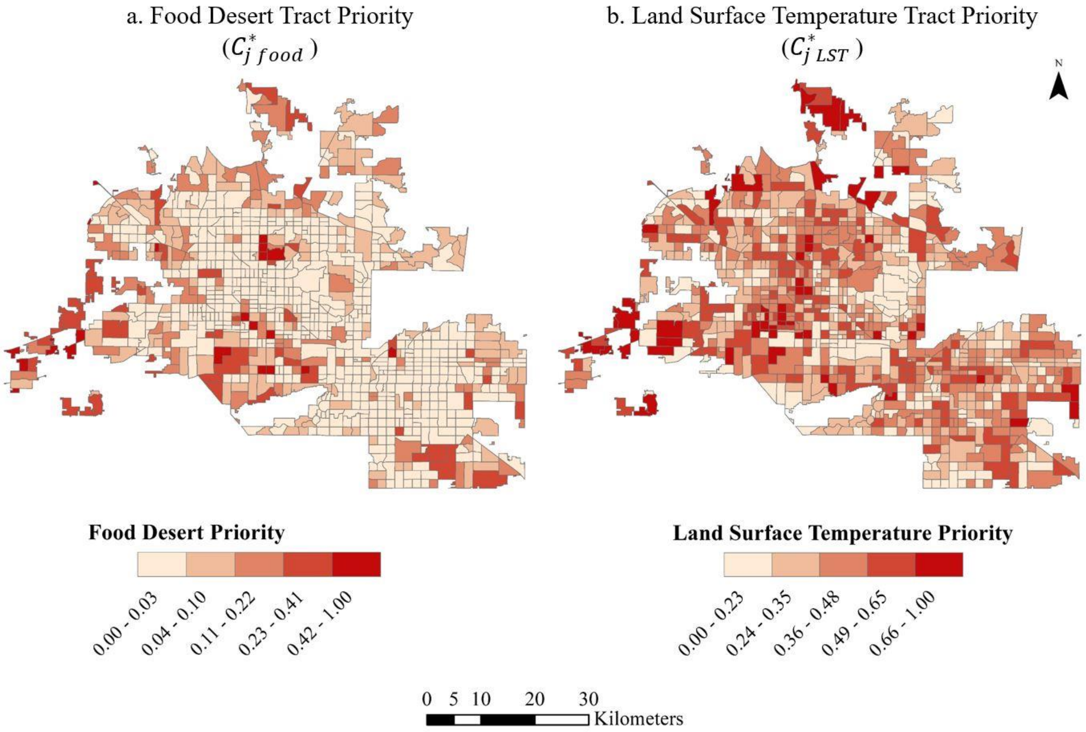
4.4.1 Data

This study used a 2017 shapefile inventory of 38,993 VPPGs within the metro-area produced by Uludere Aragon and colleagues (2019) to identify urban community garden sites. VPPGs represent properties lacking large amounts of impervious surface or freestanding structures, making them more suited for garden development (Smith et al., 2017; Uludere Aragon et al., 2019). Residential yards, public parks, and unused or green commercial space were not included in the inventory as the objective of the VPPG assessment—and ours—is to convert underutilized, open land in a metro-area with an abundance of vacant parcels. Future work may explore the use of other types of parcels and varieties of urban agriculture as part of an optimized urban food system.

The 2017 VPPG inventory was further refined based on siting potential and parcel area using ArcMap 10.6. In our study, siting potential constitutes the potential of a VPPG i to support a community garden based on the geographic context of where the parcel is located. The siting index (S_i) is a modified version of that developed by Smith and associates (2020) that uses multicriteria decision analysis and employs stakeholder-derived weights. Using the weights established by their community gardening stakeholders, our index combines five criteria in order of stakeholder priority: VPPG proximity to residential areas, census tract population density, VPPG proximity to community spaces (i.e., schools, community centers, religious institutions, and parks), area bikeability, and mass transit access. Due to the number of parcels evaluated, the index cannot account for site-specific conditions (e.g., utility access or soil contamination) beyond those considered when developing the VPPG inventory (i.e., the parcel is “true” open vacant land). Ultimately, any site considered for potential garden development, in reality, would need to be examined further in a follow-up assessment. Furthermore, the site selection process, in general, would need to be conducted in tandem with the local community members as buy-in is fundamental to the long-term viability of any community garden (Draus et al., 2014). Despite these limitations, however, for our study, the siting index provides a level of detail beyond whether or not a parcel is vacant and allows for further discrimination when considering thousands of potential sites. Additional details regarding the formulation of the siting index and the data used are included in Appendix D.

After a siting score was computed for each VPPG, only those scoring moderate to high (≥ 0.5 on a scale of 0 to 1) were used in the study. Additionally, minimum and maximum area thresholds of 7,500 ft^2 (697 m^2) and 22,500 ft^2 (2,090 m^2) were used to discriminate for parcels maintaining an area sufficient for garden facilities (e.g., multiple garden plots, tool sheds, and pathways) but which are not so large that it may be attractive for future development (Bowman & Pagano, 2004; Mack et al., 2017). These steps ultimately reduced the 2017 inventory to 5,243 VPPGs that were ultimately used in the CGCM.

To represent food deserts and the urban heat island, and establish neighborhood priority (C_j), two indicators were developed for each census tract j using ArcMap 10.6 (Fig. 11). For food desert priority (C_{j_food}) (Fig. 11a), while the conceptualization of what constitutes and how to best represent a food desert spatially can vary (Lucan & Chambers, 2013; Walker et al., 2010), our study adopts the USDA metric that is frequently used by municipal governments in the United States Under this definition, a census tract is considered to be a food desert if it is both low-income and low-access (i.e., $\geq 33\%$ of the population must travel > 1 mile [1.6 km] from a major food retailer) (USDA, 2017). Under this definition, 95 of the metro’s 904 census tracts are classified as food deserts. However, the region contains other pockets of residents who are also low-access and low-income but their tract is not technically designated as a food desert because it does not meet the 33% threshold. To capture these households, rather than a binary classification, our study uses the percentage of a tract’s population who experience food desert conditions, regardless of their formal designation (Smith et al., 2021; USDA (U.S. Department of Agriculture), 2017a).


a. Food Desert Tract Priority ($C^*_{j\,food}$)

b. Land Surface Temperature Tract Priority ($C^*_{j\,LST}$)

Figure 11. Census Tract Priority. Priority Values represent either the percentage of tract residents experiencing food desert conditions (11a) and the average LST for the tract (11b). Values have been normalized and adjusted for population (see Section 4.4.1). Darker colors represent higher priority tracts for community garden development.

For LST priority (C_{j_LST}) (Fig. 11b), extreme temperatures were represented by averaging the summer daytime LST for each tract j using 30-m Landsat Provisional Surface Temperature imagery dated August 16, 2017 (USGS, 2019). Higher temperature tracts represent higher priority locations for garden development. Both food desert and LST values were normalized across the study area using a linear scale transformation wherein larger values correspond to higher priority tracts. In addition to tract priority regarding the co-benefits, the assessment also incorporated the potential population covered by the gardens. A normalized population multiplier (P_j) was calculated and applied to tract priority values (see Eqs. 10 & 11). With this consideration, the resultant adjusted priority values account for where community gardens could potentially have a greater impact.

4.4.2 The Community Garden Coverage Model Design

Consider the following notation for our CGCM:

i = index of VPPGs

j = index of census tracts to be covered

B_{ij_food} = the food desert benefit value that census tract j receives from VPPG i if i is developed into a garden

B_{ij_LST} = the LST benefit value that census tract j receives from VPPG i if i is developed into a garden

Ω_{food} = the summation of all food desert benefit values received by the covered census tracts

Ω_{LST} = the summation of all LST benefit values received by the covered census tracts

Max Ω_{food} = the largest possible total food desert benefit value wherein all tracts that can feasibly be covered are

Max Ω_{LST} = the largest possible total LST benefit value wherein all tracts that can feasibly be covered are

d_{ij} = the distance between the centroids of VPPG i and tract j

D = the distance threshold of the urban community garden coverage

$$y_{ij} = \begin{cases} 1 \text{ if the distance, } d_{ij}\text{, between VPPG } i \text{ and census tract } j \text{ is less than } D \\ 0 \text{ if not} \end{cases}$$

p = number of urban gardens to be developed

$$X_i = \begin{cases} 1 \text{ if VPPG } i \text{ is developed into a garden} \\ 0 \text{ otherwise} \end{cases}$$

$$Z_{ij} = \begin{cases} 1 \text{ if census tract } j \text{ is covered by VPPG } i \\ 0 \text{ otherwise} \end{cases}$$

The model is specified as:

$$Maximize \;\; \Omega_{food} = \sum_{ij} B_{ij\_food} Z_{ij} \qquad (1)$$

$$Maximize \;\; \Omega_{LST} = \sum_{ij} B_{ij\_LST} Z_{ij} \qquad (2)$$

Subject to:

$$Z_{ij} \leq y_{ij} X_i \qquad \forall i, j \qquad (3)$$

$$\sum_i Z_{ij} \leq 1 \qquad \forall i, j \qquad (4)$$

$$\sum_i X_i = p \qquad \forall i \qquad (5)$$

$$X_i \in \{0,1\} \qquad \forall j \qquad (6)$$

$$Z_{ij} \in \{0,1\} \qquad \forall i, j \qquad (7)$$

The Objectives (1) & (2) seek to maximize the sum of gardening benefits (food and LST, respectively) received by census tracts. Constraints (3) define census tract j will not be covered by VPPG i, unless i is developed into a garden and the distance between i and

j is less than or equal to the service distance of a community garden, D. Constraints (4) specify census tract j will be assigned to no more than one garden. Constraint (5) specifies the number of gardens to be developed. Constraints (6) and (7) impose binary restrictions on the decision variables X_i and Z_{ij}.

Specifically, the benefit values, B_{ij_food} and B_{ij_LST}, consider the priority of tract j and the adjusted siting score of VPPG i, as follows:

$$B_{ij\_food} = C^*_{j\_food} \times S^*_i \tag{8}$$

$$B_{ij\_LST} = C^*_{j\_LST} \times S^*_i \tag{9}$$

Where:

$C_j{}^*$ is the adjusted priority score of census tract j (Eqs. 8 & 9) and is calculated based on either the normalized food desert or LST priority of tract j (C_j), respectively, multiplied by the normalized population of tract j (P_j):

$$C^*_{j\_food} = C_{j\_food} \times P_j \tag{10}$$

$$C^*_{j\_LST} = C_{j\_LST} \times P_j \tag{11}$$

And:

S^*_i is the adjusted siting score of VPPG i that incorporates both parcel's siting score (S_i) and an area adjustment score (A_i) (Eq.12). This incentivizes the CGCM to not only select VPPGs with higher siting potential scores but also provides a slight bonus to larger parcels when multiple sites with similar siting values are in close proximity:

$$S^*_i = S_i \times A_i \tag{12}$$

The original VPPG siting scores (S_i) were converted from [0.5, 1] to [0.8, 1.2] with the median siting score (0.69) was rescaled to 1. In this way, higher-scoring VPPGs are slightly rewarded and more moderately scoring parcels are slightly penalized in the CGCM. The area multiplier (A_i) was created by reclassifying VPPG area into three values, centered at 1 (Eq. 13). In the equation, 15,150 ft^2 and 9551 ft^2 are the top and bottom 20th area percentiles in the inventory:

$$A_i\text{: Area adjustment score of VPPG } i\text{; } A_i = \begin{cases} 0.8 \text{ if } i < 9{,}551 \text{ ft}^2 \\ 1 \text{ if } 9{,}551 \text{ ft}^2 \leq i \leq 15{,}150 \text{ ft}^2 \\ 1.2 \text{ if } i > 15{,}1450 \text{ ft}^2 \end{cases} \tag{13}$$

4.4.3. Model Implementation

The CGCM was developed and solved using the ArcMap 10.6 and Gurobi Python API 9.0. Ultimately, D = 1.5 miles (2.4 kilometers) was selected to use in the CGCM, resulting in 96% tract coverage. While it is slightly larger than the USDA food desert standard of 1 mile (which only achieved 87% tract coverage), considering the car-oriented design of Sun Belt metro-areas like Phoenix, a somewhat relaxed D is a reasonable threshold. Future work can further explore how various distance values in the CGCM will yield different results.

In the CGCM, the selection of p (i.e., the number of sites to be developed) is key due to the reality of limited resources for urban community garden planning. We solved the model iteratively with a range of different p values for both food deserts and LST to observe how coverage changes with additional community gardens, eventually determining the largest p necessary to achieve the maximum possible objective benefit

(Max Ω) (i.e., every census tract within the study area that could feasibly be covered by a given VPPG is covered).

We solved the bi-objective CGCM using the weighted sum method (Eq. 14) and further assessed the trade-offs between the two objectives Ω_{food} and Ω_{LST}:

$$\text{Maximize} \quad w\Omega_{food} + (1-w)\Omega_{LST} \tag{14}$$

where $w \in [0,1]$. The CGCM was solved for different values of w in increments of 0.01 to evaluate the trade-offs between food desert and LST benefit at p = 50, 76, 100, and 125. The value 76 was selected to compare the outcomes of the model to the potential food desert and LST benefit values generated by the study area's current community garden network (p = 76).

4.5 Results

We solved the coverage objectives of food deserts and LST separately. Figure 12 summarizes the trends between the optimal benefit values Ω_{food} and Ω_{LST} and the number of gardens to be sited (p). For both, as p increased, Ω_{food} and Ω_{LST} values grew (Fig. 12). This growth was logarithmic, however, and the overall marginal benefit gains diminished with the addition of each new community garden until Max Ω for each objective was reached. In Figure 12, Max Ω on the y-axis indicates the maximum possible benefit value that can be reached for each objective; when all of the tracts that can be feasibly covered by a garden are served, Max Ω is achieved, and increasing p will not yield any additional benefit. To standardize the comparison of the two objectives, we converted all the optimal Ω values to the *relative percentage* of Max Ω and plotted them against the corresponding

p values. The trend curves provide critical insights in determining the suitable range of p when allocating limited land resources.

When the CGCM was tasked with maximizing the food desert benefit Ω_{food} (Eq. 1), we found that even with a relatively low number of gardens (p = 20), 50% Max Ω_{food} can be achieved (Fig. 12). As anticipated with the MCLP in general, gains in coverage with the CGCM diminish as p increases. For instance, at p = 83, 90% Max Ω_{food} was achieved. An additional 116 gardens were necessary to ultimately reach 100% Max Ω_{food} at p = 200.

For Ω_{LST} (Eq. 2), due to the wide-spread nature of the UHI effect across the study area when compared to the locally clustered food deserts, more community gardens were required to achieve a comparable percentage of Max Ω. As a result, the number of gardens almost doubled from 20 to 39 to reach 50% of Max Ω_{LST} (Fig. 12). The CGCM reached 90% Max Ω_{LST} at p = 128. As p increased, however, the same overall trend of diminishing gains observed with the food desert benefit was also noted for LST. It was not until p = 290 that 100% Max Ω_{LST} was reached, almost double that required to achieve 90% Max Ω_{LST}.

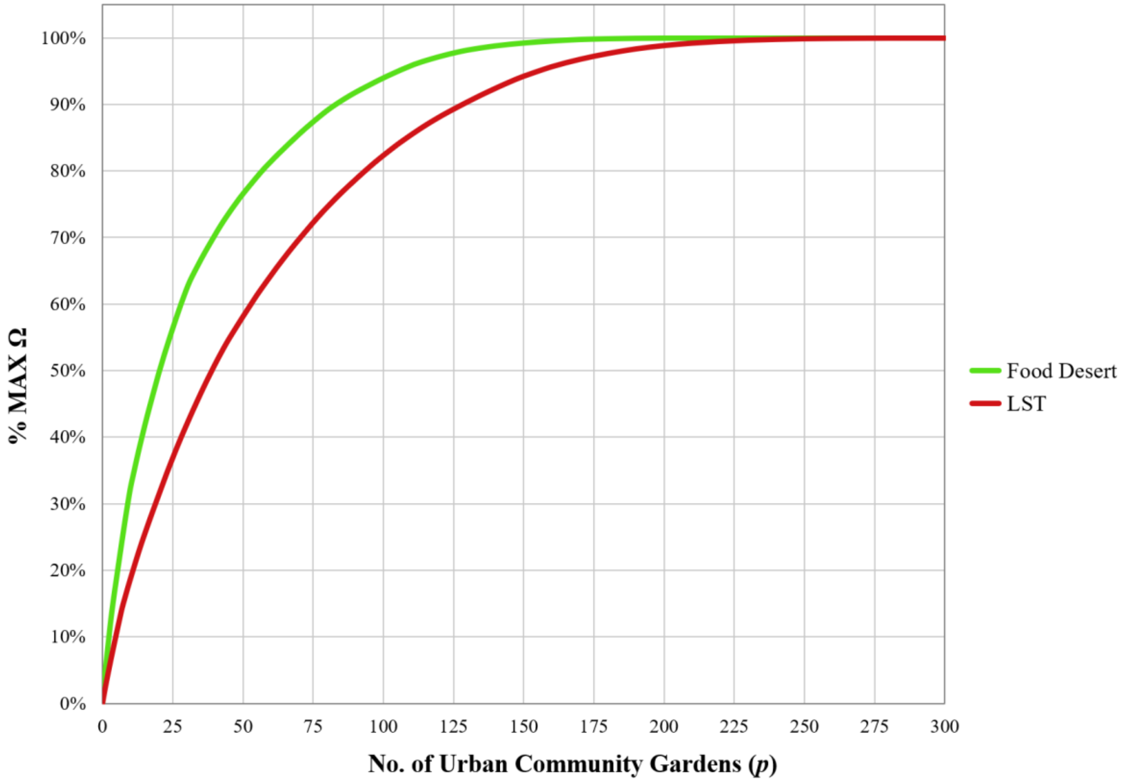
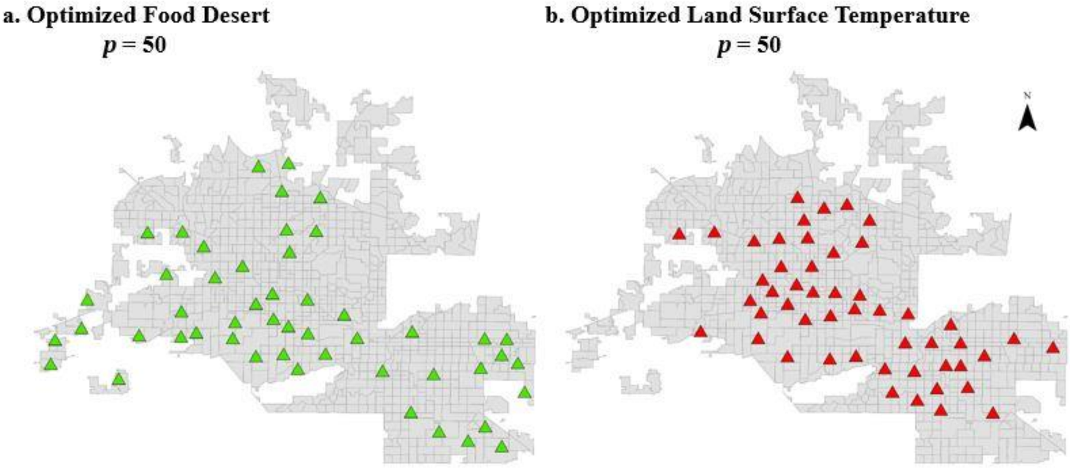


Figure 12. Numbers of urban community gardens to be sited (*p*) and the optimal benefit value curves for the Food Desert and Land Surface Temperature objectives

For illustrative purposes, we mapped the optimized community garden locations for *p* equals 50 and 100 for both objectives to explore the spatial pattern differences between two reasonably-sized garden networks. When compared, the optimal garden locations of the two objectives varied at both the urban core and fringe (Fig. 13). For solutions with lower values of *p* (e.g., *p* = 50), the food desert garden locations appeared to be scattered both within the urban core and in communities nearer to the urban fringe (Fig. 13a). In contrast, for that same value of *p* = 50, the optimized LST garden locations concentrated more within the urban core and other "inner" suburban communities, with very few gardens sited towards the fringe (Fig. 13b). For higher values of *p* (*p* = 100), the distributions of both objectives generally expand outwards. The food desert garden locations continued to maintain a greater presence on the fringe (Fig. 13c), however, compared to the more “evenly” distributed LST garden locations (Fig. 13d).

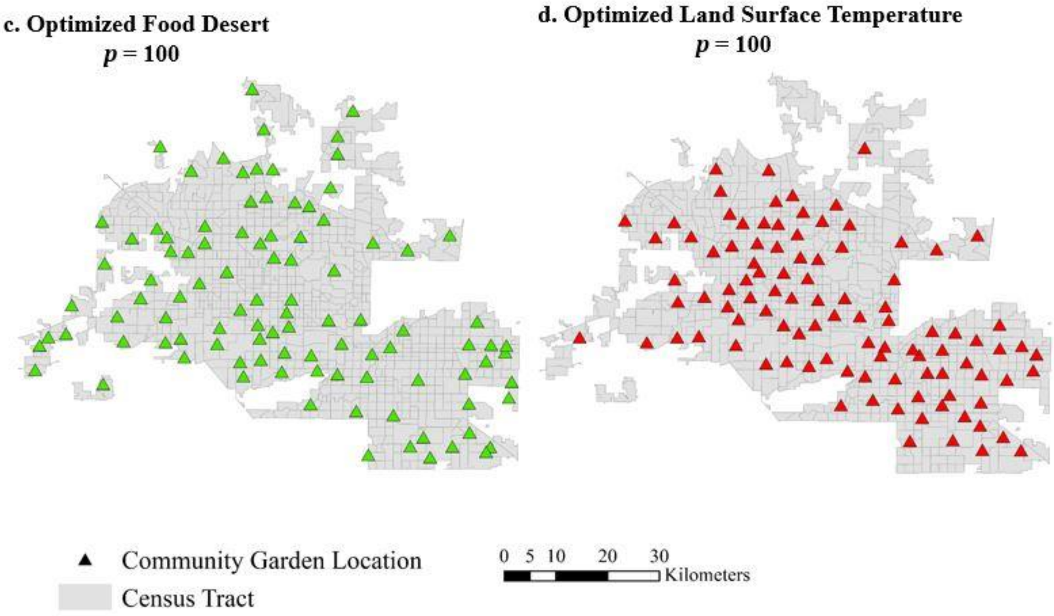
We then solved the bi-objective CGCM under different priority weighting scenarios (Eq. 14) and assessed tradeoffs between the coverage objectives of food deserts and LST for p = 50, 76, 100, and 125 (Fig. 14). Those p values were selected based on the p-optimized benefit value curves shown in Figure 3. When p ranges from 50 to 125, approximately 60% to 90% of the Max Ω can be reached for both the food desert and LST objectives.

When w = 1, it is the equivalent of solving just for the food desert objective separately, and when w = 0, it is the equivalent of solving only for LST. Under all weighting schemes for w, benefits accrued for both coverage objectives to varying degrees. The values of w that produced the most balanced benefits for both objectives ranged from 0.63 to 0.67. For example, at p = 50, w = 0.67 achieved 56.6% Max Ω_{food} and 56.6% Max Ω_{LST}. For p = 125, w = 0.66 yielded 89.2% and 88.9% of Max Ω_{food} and Max Ω_{LST}, respectively. These results suggest that when both co-benefits are equally desired, weighing food deserts slightly more than LST actually produces a more balanced outcome.



a. Optimized Food Desert
$p = 50$

b. Optimized Land Surface Temperature
$p = 50$



c. Optimized Food Desert
$p = 100$

d. Optimized Land Surface Temperature
$p = 100$

Figure 13. Optimized Food Desert and Land Surface Temperature Urban Community Garden Locations

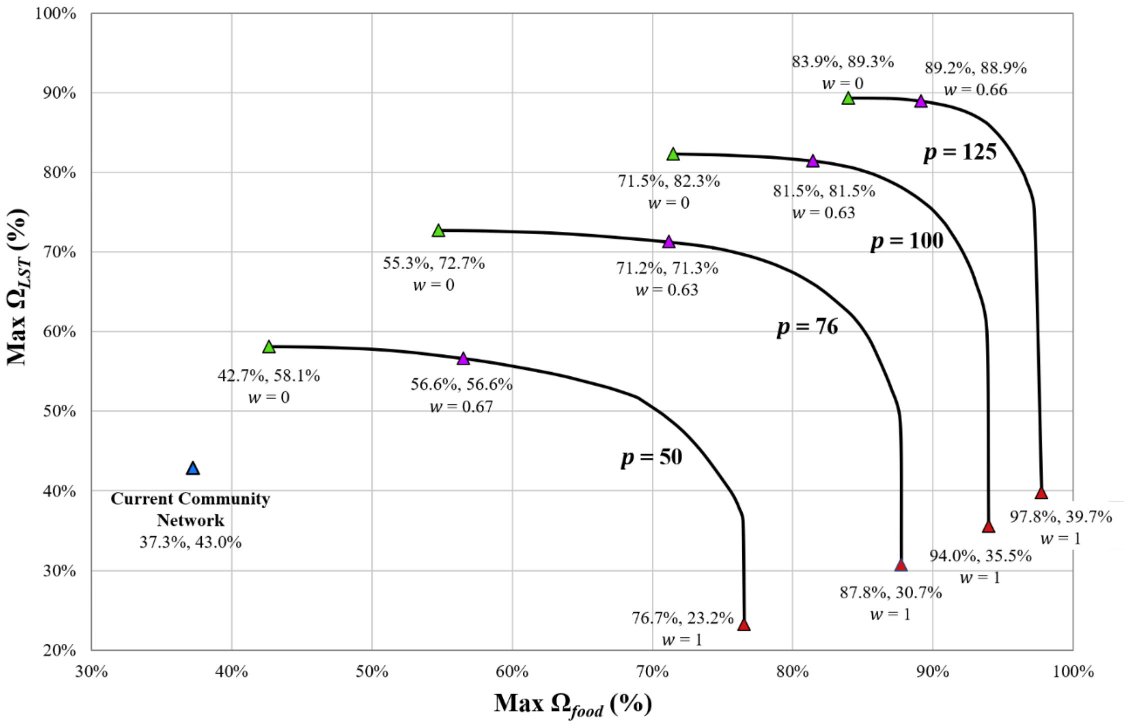


Figure 14. Objective Tradeoff Curves with Weight (w) ranging from 0 to 1. Note that coordinates for each marker are ordered as (% Max Ω_{food}, % Max Ω_{LST}).

Lastly, we computed and plotted the maximum potential benefits of the 76 current community gardens in the Phoenix metro-area. We assumed that each garden has a service distance of 1.5 miles and held the highest possible adjusted siting score (i.e., S_i^* = 1.44) and followed Equations 1 & 2, accordingly. We found that even under these ideal conditions, the current community garden network only provided 37.3% Max Ω_{food} and 43.0% Max Ω_{LST} for the study area. As shown in Figure 14, the current community garden network's benefit values are substantially less than the optimal solutions (i.e., the p = 76 curve) produced by the CGCM and they are largely concentrated in the urban core (Fig. 15a). By comparison, when the two objectives are solved separately at p = 76, the CGCM yielded 87.8% Max Ω_{food} and 72.7% Max Ω_{LST}. Also, the balanced solution of the benefits tradeoff scenario for the bi-objective CGCM (p = 76 and w = 0.63) achieved higher benefit results with 71.2% and 71.3% Max Ω_{food} and Max Ω_{LST}, respectively.

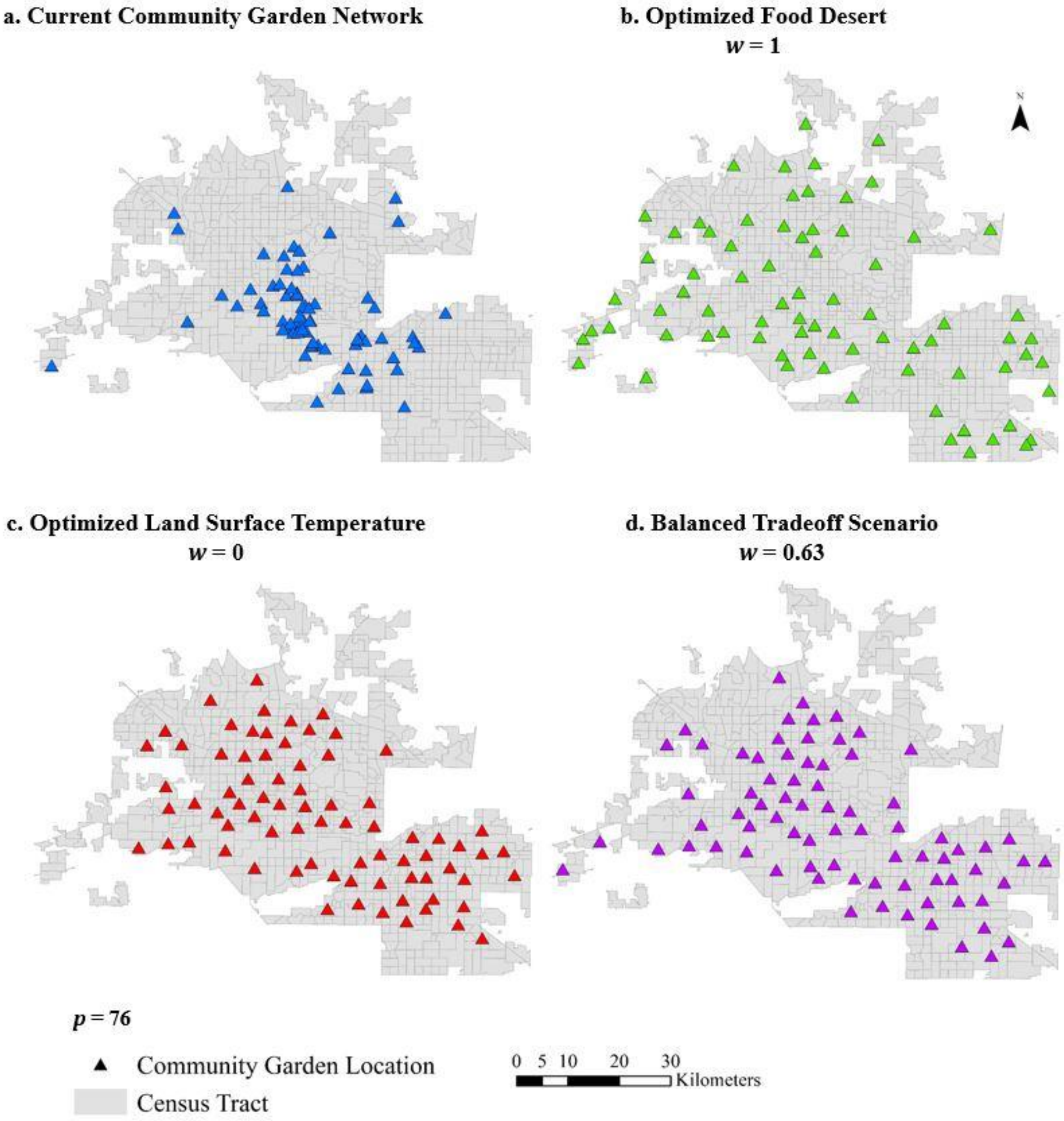


Figure 15. Current and Optimized Community Garden Location Comparisons

4.6 Discussion and Limitations

The application of the CGCM demonstrates how an optimization approach to siting urban community gardens can produce metropolitan-level networks specifically tailored to optimize one or more priority co-benefits in high-need areas. In our assessment, the two principal co-benefits considered—food deserts and neighborhoods with elevated LST—yield different results in terms of the optimal locations and the number of gardens necessary to achieve the maximum benefits for the Phoenix metro-area. While their patterns may be different when modeled independently, our findings provide insight into how these two co-benefits may ultimately be complementary when weighted accordingly. Furthermore, our study illustrates that, when subject to the same constraints and criteria as the CGCM, the Phoenix metro-area's current urban community garden network leaves much of the study area's high-priority neighborhoods underserved compared against the results of our optimized scenarios.

While food deserts pose a major challenge for the Phoenix metro-area, because of the aforementioned location-specific nature of the problem, a single food desert tract or cluster of tracts may ultimately be surrounded by non-food deserts [Fig. 11a]. Furthermore, the actual number of tracts in the study area with $C^{*}_{j\_food}$ greater than zero is 431 (out of 897) and in only 161 of those tracts in which $C^{*}_{j\_food}$ exceeds 0.1. Therefore, relatively few community gardens are necessary to achieve decent coverage (Fig. 12a), and the CGCM initially focuses on the scattered high-priority food desert hot spots. This result translates into spatially-optimized food desert locations appearing somewhat strewed across the metro-area, especially when p is low (Fig. 13a). Even when additional garden locations are added, the overall pattern remains dispersed (Fig. 13c).

Conversely, the ubiquity of the UHI effect produces an elevated LST gradient that spans numerous tracts throughout the study area (especially in the densely-developed areas farther away from the urban fringe) (Fig. 11b). As a result, in LST-optimized solutions, more community gardens are necessary to attain percentages of Max Ω_{LST} (Fig 3b), similar to those described in the preceding paragraph. The distribution of these spaces generally appears more uniform than the optimized food desert results. Potential community garden locations tend to be concentrated in densely developed urban and suburban communities within the study area's interior where the UHI effect is most prolific. This is particularly evident at low values of p (Fig. 13b). As p increases, the network eventually radiates outwards into communities located on the fringe (Fig 4d). It warrants noting that these tracts may also have elevated LSTs but hold smaller populations. This results in a lower $C^*_{j\_LST}$ value, which makes them a lower priority for the CGCM. Future applications of the model could explore different ways of accounting for population when determining UHI priority areas.

The aforementioned spatial patterns also affect trade-offs between the two objectives. Because locations optimized for LST are distributed across the study area in a fairly even pattern, many high-priority food desert tracts (namely those within the urban core) also are covered in an LST-oriented community garden network (Figs. 13 & 15). Consequently, as shown in Figure 14, when w is weighted fully on LST, the solution yields high LST benefit and provides moderate food desert benefit. In contrast, if w is weighted fully on food deserts, the solution produces high-food desert benefit but very low-LST benefit. To achieve a balanced trade-off, food desert is weighted slightly more than LST, resulting in a w value of approximately 0.65. For example, for p = 76, when w changes from 0 to 0.63, food desert benefit increases significantly from 55.3% to 71.3% Max Ω_{food}, compared to the relatively minor decrease in LST benefit (from 72.7% to 71.2% Max Ω_{LST}).

This relationship is visible in Figure 15. The distributions between the optimized LST (Fig. 15c) and the balanced tradeoff scenarios (Fig. 15d) are similar. The main difference is that several garden locations in the balanced scenario move from the interior of the study area and are sited on the urban fringe. The overall distribution maintains its regular pattern covering the highest-priority LST tracts, but the few outlying high-priority food desert tracts are served as well. The ability of the CGCM to redistribute potential garden locations to achieve some desired outcome demonstrates the flexibility of the model. In our case, we solved w iteratively to achieve essentially equal co-benefit values, but the weighting scheme is inherently flexible to meet the needs or priorities of the user. By affording decision-makers the capability to consider tradeoffs between the two coverage objectives, the CGCM provides yet another layer of nuance not present in the traditional, ad hoc community garden siting process

When considering the overall coverage offered by the Phoenix metro-area's current community garden network (p = 76), because of its clustering within the urban core (Fig. 15a), roughly one-third of the study area's population resides within 1.5 miles of a community garden. This leaves the majority of the study area (primarily suburban and urban fringe communities) underserved. Additionally, the extant network ultimately covers 52 of the metro's 95 USDA-defined food desert tracts. This insufficient coverage is further underscored when tract priority is incorporated with the network, achieving only 37.25% Max Ω_{food} and 42.88% Max Ω_{LST} compared to our optimized scenarios (Figs. 15b, 15c, & 15d). Our finding is consistent with the conclusions of Mack and associates' (2017) community garden assessment, which identified an extensive lack of coverage in the majority of Phoenix-area neighborhoods experiencing food desert conditions. While it is infeasible to completely rebuild the metro's current community garden network, our assessment suggests that the evident disparity between the populations covered and the underserved, high-priority areas could potentially be abated in the future through a systematic siting-approach as illustrated in our model. This possibility may prove especially advantageous as major cities like Phoenix explore the role of community-driven agriculture as part of a more resilient urban food system (Albright, 2020; Nicholls et al., 2020).

There are some limitations associated with our approach, however. Firstly, the CGCM is not meant to be the final authority on where community gardens should be site but is rather intended to demonstrate the potential of a more systematic and deliberate co-benefit approach to urban community garden development. Any number of considerations concerning the community in which a garden could be potentially developed and to site-specific conditions would have to be part of either a prior or subsequent assessment (Smith et al., 2021). Furthermore, the identification of a neighborhood as high-priority does not necessarily translate into the community's desire for a garden (Bleasdale, 2015; Diaz et al., 2018). A well-intentioned project may ultimately fail due to insufficient buy-in from residents (Draus et al., 2014; Rosan & Pearsall, 2017). Community support, along with considerations regarding green gentrification, the equitable distribution of resources, sufficient gardening education, and local priorities, makes engagement with a diversity of stakeholders throughout all stages of garden development paramount (Barron, 2017; Meenar, 2017; Sbicca, 2019). With advanced knowledge, future applications of the CGCM could restrict the tracts included in the model to just those which are known to contain communities potentially interested in community gardening and site gardens to reflect this desire.

Significant site-specific conditions, such as soil contamination (McBride et al., 2014) and access to water (Tong et al., 2020), are also not captured in the CGCM. The concentrations of heavy metals (e.g., lead and cadmium) within urban soils vary across the study area. While sampling has shown concentrations to be low in current community gardens (Holmes et al., 2018), slightly elevated levels of lead have been found in older neighborhoods' soils (but below remedial action levels) (Zhuo et al., 2012). Regardless, community garden development guidance strongly recommends soil testing before breaking ground and includes suggestions for how to mitigate potential risks (e.g., raised garden beds) (USDA, 2016). Additional uncertainties, like those related to land tenure, may also pose siting issues, both in terms of initial development and its overall lifespan (Diaz et al., 2018; Newell et al., 2020). We attempted to account for potential competing development objectives by restricting our VPPG inventory to parcels that were relatively modest in size, making them less attractive for future development (Bowman & Pagano, 2004). Factors such as infill and gentrification and an absence of municipal or policy protections may shorten the ability of a site to maintain a community garden in the long-term (Newell et al., 2020; Sbicca, 2019). This adds another level of complexity to the garden planning process that is unfortunately beyond the scope of the CGCM. Other barriers including but not limited to VPPG availability, parcel value, local ordinances, neighborhood association restrictions, development cost, and existing municipal land use plans would also need to be considered ahead of final site selection decisions (Smith et al., 2021).

Finally, a potential limitation within the design of the CGCM is the fact that it only assigns a census tract to one VPPG. Although the model does not prevent a community from being served by multiple gardens, only the maximal benefits from an individual garden are accounted for in the final Ω_{food} or Ω_{LST} values. Future applications of the model could explore the potential of tracts, particularly high-priority neighborhoods, being covered by multiple community gardens rather than just one.

4.7 Conclusion

The variety of co-benefits that urban community gardens offer makes their development an advantageous strategy to advance urban sustainability goals. Despite this array, community garden planning has been largely ad hoc and not necessarily focused on providing optimal coverage, co-benefits or not. Consequently, established urban community garden networks may not effectively cover high-priority neighborhoods at the metropolitan scale. The resources required to develop community gardens and the urgency of the sustainability challenges (e.g., the need to provision co-benefits) necessitates a more strategic methodology for decision-makers to optimally site these spaces and maximize their coverage.

Inspired by the classic MCLP model, our CGCM underscores the potential of a systematized approach to inform the urban community garden planning process and advance sustainability goals for users across the globe. Our model considers two important community garden co-benefits—food desert amelioration and UHI abatement—and demonstrates how optimal coverage of high-priority neighborhoods can be determined through the use of an extensive inventory of candidate parcel locations, and how that coverage varies based on the number of community gardens proposed. Through its application, we demonstrate how nearly two-thirds of tracts that are presently underserved by the Phoenix metro-area's community garden network could be covered more effectively when the problem is approached from a spatial optimization lens. The targeted nature of the CGCM makes it capable of identifying high potential sites in priority census tracts with a precision not capable in more conventional planning methods. Such a strategy can better ensure that limited resources are being allocated in a way that is more transparent and more equitable for the neighborhoods that stand to gain the most from the presence of a community garden when thousands of potential sites are available.

The co-benefits selected in our study correspond to priority issues for the Phoenix metro-area, but the CGCM's ultimate approach can be used to promote any of the environmental services that community gardens offer. Furthermore, through its ability to assign weights to the two objectives and the adjustability of other components such as the coverage distance threshold or the scale of the assessment (e.g., regional or neighborhood), the CGCM allows users the ability to customize co-benefit coverage. This flexibility could be a boon for decision-makers, whether they seek to balance co-benefits or desire to assess tradeoffs between coverage objectives to meet the needs of their particular community.

4.8 Acknowledgments

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CHAPTER 5

SUMMARY AND CONCLUDING THOUGHTS

“This city should not exist — it is a monument to man's arrogance."

—Margaret Hill concerning Phoenix, Arizona

Hill’s assessment—albeit harsh— underscores a difficult truth facing the Phoenix Sonoran Desert metropolis. The uninhibited sprawl of the post-war period, coupled with a rapidly changing climate in an already summer extreme environment, presents a panoply of issues for Phoenix and the numerous other Sun Belt metropolises like it (Gober & Burns, 2002; Hunt et al., 2017). While the built environment has exacerbated adverse phenomena, such as the urban heat island, a shift to a more sustainable model of urban land use may be able to ameliorate these challenges (Reenberg & Seto, 2014; Turner, 2016).

Part of this amelioration involves the design of the metropolitan area, foremost altering the urban landscape by changing its land cover or—alternatively—the incorporation of multifunctional green infrastructure, generating a new urban morphology or land system architecture. The cities of Phoenix, Tempe, and others in the 20-city metropolis are engaged in efforts to envision and design urban land cover to address extreme heat and its water and energy implications (Kaplan, 2020; Keridwen, 2019). While research is underway to serve these interests, various federal to local agencies are concerned about the health and nutrition of disadvantaged neighborhoods and communities that lack easy access to sources of nutritious food stocks (Hilliard, 2017; Malloy, 2020), designating the areas in question as “food deserts”. One plan to confront the food desert problem is through community gardens or the use of open spaces where the collective of neighborhoods can raise foods for their consumptive use, presumably healthy and traditional food stocks not readily available in the proximity of the garden. Such urban gardens also constitute green infrastructure which may serve to reduce extreme heat, among other services. Indeed, extreme heat (i.e., urban heat island) and food deserts (often found in lower-income communities) tend to overlap spatially throughout parts of the metro-area (Harlan et al., 2007; Jenerette et al., 2011). Despite this association, the co-benefits of this form of green infrastructure have been undervalued in various assessments (e.g., Iwaniec et al., 2020) and among the agencies involved in planning for heat amelioration and nutritional food improvement.

This dissertation addresses the incongruencies in question. It explores a series of systematic steps that can be employed to address the siting of community gardens such that derive superior co-benefits of urban spaces. Through established and emergent spatial-analytical methods and qualitative stakeholder analysis, this dissertation explores these co-benefits to advance urban sustainability goals. Each chapter demonstrates different methodologies that can be integrated into the community garden-green space planning process and inform decision-makers in a way that is both systematic and transparent. The chapters focus on three general themes: where are open spaces to site community gardens, which sites hold the best potential for garden development, and how can those sites be assembled into an optimized garden network to maximize the food-cooling co-benefits?

5.1 Summaries of the Three Research Themes

Chapter 2: Identifying Open Plots at the Metro-Level

The second chapter examined the current state of assembling vacant parcel inventories for community garden siting and proposed a novel approach that could be implemented efficiently at the metropolitan scale. Prior assessments have largely relied on time-consuming visual analyses of aerial imagery, cadastral designations, and limited field enumerations. The methodology presented in Chapter 2 combined high-resolution remotely-sensed imagery with extensive cadastral records, in addition to topographic data, to establish land cover classes to distinguish thousands of vacant parcels for potential greening/gardening (VPPGs) from other non-viable vacant parcels. Two distinct VPPG patterns were noted in the Phoenix metro-area: one consisting of a patchwork of smaller vacant parcels within the urban core—largely resulting from incomplete historical infill—and the second corresponding to large concentrations of vacant awaiting development along the urban fringe. The distribution of VPPGs within the urban core revealed hot spots that appeared to correspond with lower-income food desert communities and regions experiencing the urban heat island effect.

Chapter 3: Multicriteria Decision Analysis for Site Selection

The third chapter represents a first-of-its-kind stakeholder-weighted multicriteria decision analysis (MCDA) for the assessment of prospective urban community garden sites. The development of urban community gardens is frequently ad hoc and restricted in scope to either the proposed garden site itself or its immediate surroundings. Such practices may neglect known factors that contribute to the long-term potential of a garden location or which may allow the social and environmental co-benefits to accrue in the communities that they are needed most. This is despite a large body of literature dedicated to the co-benefits of community gardens and the challenges these spaces encounter throughout their lifespan. The MCDA presented in Chapter 3 endeavored to approach the siting process from a spatial perspective by devising a methodology to assess thousands of VPPG in the Phoenix metro-area using prioritized criteria obtained directly from stakeholders.

Three siting indices —a Social Characteristics index, Physical Setting index, and Comprehensive index—were developed and applied to a VPPG inventory. The assessment found that under the Social Characteristics index (composed primarily of socio-demographic features), moderate-to-high scoring parcels were predominantly concentrated within the metro-area's urban core. This result was in no small part due to the powerful food desert community criterion which represents a highly location-specific phenomenon in contrast to the resultant distribution of the Physical Setting index (composed primarily of features related to the built and natural environment) which saw a more regular distribution of moderate-to-high scoring VPPGs across the entirety of the study area, including more affluent suburban communities. The study also found that when presented with a comprehensive collection of siting criteria, stakeholders prioritized the Social Characteristics criteria rather than the Physical Setting criteria, suggesting that socio-demographic factors may be at the forefront of stakeholders' minds when considering the question of which sites hold the greatest potential for community gardening. This result may indicate a potential conceptualization of community gardens as spaces for nutritional intervention in vulnerable communities. Such a focus, however, potentially neglects communities outside of the urban core—namely suburbs—which will not necessarily benefit the most from the accrual of co-benefits but may ultimately hold aspirant gardeners who could lend long-term support to a community garden project.

Because of the flexibility of the MCDA approach, decision-makers can retool or change the weights and criteria as they see fit. The methodology presents a systematic means of assessing thousands of VPPGs at the metropolitan scale such that lower potential sites can be eliminated from consideration and higher potential sites can be further studied for future community garden development.

Chapter 4: Spatially-Optimized Planning

The fourth chapter presented a systematized method of siting urban community gardens through spatial optimization. In addition to considering site potential using a modified index like those described in Chapter 3, the study incorporated two key services of urban community gardens: food desert amelioration and urban heat mitigation. With consideration to these co-benefits, the Community Garden Coverage Model (CGCM) was capable of targeting priority for gardens while simultaneously giving deference to the best available parcels within the vicinity. Through hundreds of iterations, the CGMC was able to produce a myriad of different scenarios wherein both the number of gardens to be developed and the co-benefit weights were modified.

The solutions ultimately generated by the CGMC depicted varying but frequently complementary spatially-optimized garden networks, depending on the input parameters.

When the two co-benefits were assessed independently, the distribution of optimal locations frequently mirrored the nature of the prioritized phenomena. For instance, when optimized for maximum food desert benefit, the configuration of potential sites appeared more scattershot across the Phoenix metro-area, reflecting the geographically-specific nature of the food deserts themselves. This was in contrast to solutions optimized to maximize the land surface temperature cooling benefit which displayed a more regular distribution across the study area, mimicking the broadly ubiquitous urban heat island phenomenon. In terms of achieving maximal coverage, because the number of high-priority food desert tracts within the Phoenix metro-area is relatively small, fewer gardens were necessary to achieve high food desert benefit than the number needed to reach comparable benefit values for LST benefit. In both cases, gains in benefits decreased exponentially as more gardens were specified in the model. For scenarios when both benefits were maximized together under different weighting scenarios, the most optimal solutions were generated when food deserts were weighted slightly more than LST. Once the model was able to cover the comparably few, scattered food desert priority tracts, it was able to fill in the rest of the garden network to cover the more pervasive extreme temperature tracts.

When subject to the same constraints and criteria as the CGCM, an assessment of the Phoenix metro-area's current urban community garden network (p = 76) covered less of the region and amassed lower benefit values than results of the CGCM's optimized scenarios. This comparison ultimately suggests that the evident disparity between the populations covered and the high-priority neighborhoods that remain underserved by the metro-area's current network could potentially be diminished in the future using a systematic siting-approach as outlined in the study. In essence, the CGCM demonstrated how an optimized approach to urban community garden planning can allow for both better overall coverage and more equitable distribution of co-benefits

5.2 Lessons Learned and Moving Forward

The studies presented in this dissertation each outline one potential component of a systematized approach to siting urban community gardens at a metropolitan scale. The incorporation of advanced remote sensing techniques, MCDA, and spatial optimization can facilitate strategic garden planning as metropolitan areas increasingly begin to consider these spaces as multifunctional green infrastructure. Bearing this in mind, it is important to consider multiple recurrent lessons that arose with each study that could potentially make urban community garden siting more challenging.

One of the larger drawbacks of each of the methodologies outlined is that—while they proved effective—they were also labor-intensive. The remote sensing study in Chapter 2, for example, proved overall efficiency compared to more conventional VPPG assessments, but the classification portion of the evaluation in which the model was "trained" was time-consuming. Hundreds of archetypical samples for each of the land use classes had to be compiled, and even after that, the accuracy between classes varied significantly due to features like shadows in the imagery. Such challenges necessitated workarounds that were ultimately effective but required additional time to implement.

The MCDA and the CGCM both required months to build. The MCDA in Chapter 3 incorporated a large number of criteria (17) in its stakeholder survey. This large number likely discouraged some would-be survey participants as repeated rating and ranking became daunting, and it did not allow for more complex weighting derivations (e.g., pairwise comparison). While the calculations used to assign siting potential scores under the MCDA were fairly straightforward, the results offered in Chapter 4 were derived from 658 discrete optimized solutions using the CGCM. The resources at the disposal of the Environmental Geoinformatics and Remote Sensing Lab in which this research was undertaken were such that the computing power necessary to run the model hundreds of times was not an issue; however, future applications may be problematic if high-speed processing is not accessible.

Additional challenges rose from general limitations associated with metropolitan-scale analyses that assess thousands of individual parcels. As with any God’s-eye spatial approach, this breadth necessitates assumptions, generalizations, and omissions that may or may not influence the final results. For instance, the openness or vacancy of a parcel does not mean that it could feasibly be developed into a community garden. Treating each open or vacant lot as a viable space for development was an assumption necessary to conduct the various analyses using robust VPPG datasets. In practice, however, a host of factors exist that contribute to whether or not a vacant parcel represents a possible garden location. Some properties are vacant as a result of abandonment, lack of investment, or foreclosure; whereas, others may be held as a speculative investment in anticipation of future neighborhood change. It is not possible to capture this level of nuance for every prospective site while conducting a wide-scale analysis even though such information would likely cull the pool of VPPGs before any analyses are conducted. Other site-specific considerations were difficult to incorporate into the analyses because they represent characteristics that are not easily identified using a sweeping metropolitan-level analysis. Beyond easily identifiable conditions like landcover and slope, variables like soil quality and water access could not be ascertained from available metropolitan-scale data. The incorporation of these and additional site characteristics would also influence the actual viability of VPPGs.

Perhaps the greatest challenge facing the employment of community garden decision support tools that emphasize spatially-represented relationships is the incorporation of "the human element." It is well documented that one of the largest barriers to garden success is adequate community buy-in, but the MCDA and CGCM assumed an equal interest in community gardening across the metro-area. Because a neighborhood is determined to be high priority, it does not guarantee that it will hold a population large enough to support a community garden. Simply put, it is far easier to identify where gardens may be *needed* rather than where they may be *wanted*. The data necessary to derive a metric or indicator capable of capturing something as nuanced as community attitude were simply not available.

The omission of many site-specific factors and the inability to account for community interest are recurrent limitations of the approaches presented in this dissertation and present an important caveat for how the results should be treated. The methodologies outlined were never intended to act as the arbiters of where community gardens *should* be developed. They are, instead, meant to assist in and inform the siting process by narrowing thousands of parcels into a more manageable inventory of VPPGs that possibly warrant further assessment. As with many decision support tools, these methodologies may prove to work best in concert with other initiatives such as concerted stakeholder engagement and pre-or post-assessment due diligence.

Despite the limitations outlined in the preceding paragraphs, a handful of modifications could be made to improve future applications of the methodologies. To overcome some of the labor-intensity previously noted, future applications (particularly of the VPPG identification methodology) may benefit from ever-evolving machine learning techniques that could potentially afford for analyses of greater complexity that require less oversight on the part of the user.

The MCDA may ultimately benefit from the inclusion of fewer criteria or the combination of highly-correlated criteria, as well as improved criterion indicators and a larger, broader pool of stakeholders. A potential first step to achieve this would be by conducting targeted surveying in communities deemed to be “high-priority.” Such attitudinal data would generate a richer picture of what residents truly desire and guide decision-makers in how to approach future community garden planning.

The CGCM may also prove to be more expedient as part of targeted assessments (e.g., a neighborhood-scale assessment) based on the needs of a specific community rather than a vast metropolitan-level approach. Additional consideration could be given to how to represent co-benefit distance thresholds in a more realistic manner, recognizing that these processes may operate at different spatial scales. This would move the CGCM away from a fixed one-size-fits-all measure in favor of dynamic service areas tailored for each specific ecosystem service. Such modifications in scope, however, may potentially necessitate a change from the maximal covering location problem to another optimization strategy, but the overall concept will remain the same.

The incorporation of certain additional characteristics could also help negate some of the site-specific limitations. Duration of parcel vacancy represents an indicator that may inform the likelihood of a location to be amenable to community garden development. While imperfect, an argument can be made that the longer a site has been vacant, the less likely it is going to be developed in the near-term. Time-in-vacancy could either be used as a screening variable (as it was in Chapter 3) to narrow the VPPG inventory, or it could be built into a model as an additional constraint, allowing for preference to be given to longer-vacant parcels over those with shorter durations.

Attention to factors like utility access, soil quality, and tax liens will need to be considered either ahead of the creation of the VPPG inventory or through subsequent in-depth site assessments. The same also applies to factors like community interest and potential concerns like green gentrification. Diverse stakeholder participation (particularly during criteria development and surveying) may mitigate these challenges. Efforts could also be made to incorporate constraints representing community interest, however, such a metric would be difficult to ascertain in practice without extensive surveying and stakeholder engagement.

Future VPPG inventories may also find it advantageous to revise the property ownership criterion. Our methodology outlined in Chapter 2 (and subsequently applied in Chapters 3 and 4) generates inventories limited to only sites that are privately owned. This excludes the often-numerous vacant parcels that are also held by public entities (e.g., city, county, and state governments). While these parcels are almost certainly not as abundant as privately-owned vacant properties in a metro-setting, they still may constitute candidate sites for community gardens worthy of consideration.

Given the unique nature of public lands, however, (e.g., a vacant government property may be choice for divestment, or it may be presently held for strategic future use or preservation) direct coordination with administrative entities when gathering initial vacant parcel records may help avoid the need for speculation concerning actual availability. Development status notwithstanding, future compilations of VPPGs could benefit from either the inclusion of these additional parcels or even a primary focus specifically on vacant publicly-owned sites, provided the same rigor is applied in the assembly of these inventories as was presented in Chapter 2.

A final consideration for future applications of the urban community garden planning tools should be an embracement of their inherent flexibility. Each of the methodologies presented affords a level of customizability to meet the needs of the user. For example, opportunistic land use classes for VPPGs may vary regionally. The VPPG identification process can incorporate any land use classes into its analysis. The MCDA can ultimately serve as a scaffolding to be built upon by decision-makers and stakeholders, allowing for the incorporation of adapted criteria, indicators, and weights to suit the specific community. Lastly, the CGCM only accounts from two of the host of co-benefits provided by urban community gardens. In reality, any of the garden services can be built into the model based on the unique priorities and sustainability goals. Furthermore, the number of gardens allocated per neighborhood and the service distance for a given garden can be easily modified if desired, once more allowing for a level of customizability to befit the study area accordingly.

Parting Thoughts

This dissertation contributes to a trove of research that presents new and innovative ways for decision-makers to approach planning green infrastructure. The actual outcomes of such decision support scholarship in general, however, are mixed. As with urban community gardens and the populations they are meant to serve, decision support tools must be practicable to meet the needs of stakeholders. Moreover, they must actually fulfill a need that truly exists.[16]

In my own experience, the planners who helped contribute to the development of Chapter 3's survey were all very enthusiastic about the prospect of being equipped to assess thousands of parcels in one pass. Paraphrasing, "I [the practitioner] would have never thought of that!" was a consistent message that I heard from my stakeholder collaborators, often followed by, "When will you have it done?"

While a large emphasis is frequently placed on academics to reach out to decision-makers (a point with which I wholeheartedly believe), I do not believe that this exchange should be seen as unidirectional. One of the reasons I was hired as a planner for my first post-graduate position was—in part—because I presented a vision of the Harris County Community Services Department that seeks out strategic partnerships with academic institutions. I have already witnessed an unmet need for decision-support tools in my

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[16] Anecdotally, I have seen several seemingly good decision support tools which—in all actuality—were not wanted by practitioners.

department, but an awareness of emergent methodologies has not made its way to their intended users. As such, the ad hoc or inefficient methods like those described throughout this dissertation vis-à-vis community garden planning persist.

Special relationships like those between the School of Geographical Sciences and Urban Planning and governmental entities such as Maricopa County and the City of Phoenix are not is not as common as between academics and practitioners as I had once thought. For innovative decision support tools to reach their target audience, it is incumbent upon the planning community and academia to continue to foster these relationships. In time, perhaps my experience on both sides of the fence can help advance the mission of the Community Services Department.

Final Summation

The challenges facing urban regions are many, but some may not be insurmountable. Cities across the world have reexamined the role of nature in planning and how green infrastructure can help facilitate a more sustainable urban form. Community gardens harbor great potential as multifunctional green infrastructure to enhance both urban sustainability and resilience, be it through the provisioning of fresh foods or the amelioration of extreme heat, among many others (Langemeyer et al., 2021). For the ecosystem services delivered by these gardens to have a substantive impact, though, they must be integrated into the urban landscape through strategic, inclusive planning. This planning will require a significant shift on the part of decision-makers and community groups away from present-day siting strategies that are frequently ad hoc or too narrow in scope.

The methodologies outlined in this dissertation present one avenue to facilitate a new planning approach that considers where urban community gardens can be sited, which prospective locations possess the greatest potential for garden development, and how optimized networks can be assembled to distribute their co-benefits across a metropolitan area. Through inclusion in the planning process, stakeholders and decision-makers can work together to advance their visions of the community via urban gardening to serve their neighborhoods and metro-areas in abating extreme heat, providing a source of fresh and nutritious foods, fostering a sense of place, promoting urban biodiversity, and much more.

REFERENCES

Ackerman, K. (2012). *The potential for urban agriculture in New York City: Growing capacity, food security, and green infrastructure*. http://urbandesignlab.columbia.edu/files/2015/04/4_urban_agriculture_nyc.pdf

Ackerman, K., Conard, M., Culligan, P., Plunz, R., Sutto, M. P., & Whittinghill, L. (2014). Sustainable food systems for future cities: The potential of urban agriculture. *Economic and Social Review*, *45*(2), 189–206.

ADE (Arizona Department of Education). (2018). *AZ Schools Dataset*. https://lib.asu.edu/geo/data

ADWR (Arizona Department of Water Resources). (2019). *CWS Service Area*. gisweb2.azwater.gov

Alaimo, K., Packnett, E., Miles, R. A., & Kruger, D. J. (2008). Fruit and Vegetable Intake among Urban Community Gardeners. *Journal of Nutrition Education and Behavior*, *40*(2), 94–101. https://doi.org/10.1016/j.jneb.2006.12.003

Albright, R. (2020). *2025 Food Action Plan*. City of Phoenix. https://www.phoenix.gov/sustainabilitysite/Documents/FINAL 2025 Phoenix Food Action Plan Jan 2020.pdf

Alkon, A. H., & Agyeman, J. (2011). *Cultivating food justice: Race, class, and sustainability.* MIT Press.

Allcott, H., Diamond, R., Dubé, J.-P., Handbury, J., Rahkovsky, I., & Schnell, M. (2017). Food Deserts and the Causes of Nutritional Inequality. In *SSRN* (No. 24094; Working Paper Series). https://doi.org/10.3386/w24094

Allen, I. E., & Seaman, C. A. (2007). Likert Scales and Data Analyses. *Quality Progress*, 64–65. http://asq.org/quality-progress/2007/07/statistics/likert-scales-and-data-analyses.html

Andersson, E., Langemeyer, J., Borgström, S., McPhearson, T., Haase, D., Kronenberg, J., Barton, D. N., Davis, M., Naumann, S., Röschel, L., & Baró, F. (2019). Enabling Green and Blue Infrastructure to Improve Contributions to Human Well-Being and Equity in Urban Systems. *BioScience*, *69*(7), 566–574. https://doi.org/10.1093/biosci/biz058

Andreotta, M. D. R., Tapper, A., Clough, D., Carrera, J. S., & Sandhaus, S. (2019). Understanding the intrinsic and extrinsic motivations associated with community gardening to improve environmental public health prevention and intervention. *International Journal of Environmental Research and Public Health*, *16*(3). https://doi.org/10.3390/ijerph16030494

Anguelovski, I., Connolly, J. J. T., Garcia-Lamarca, M., Cole, H., & Pearsall, H. (2019). New scholarly pathways on green gentrification: What does the urban 'green turn' mean and where is it going? *Progress in Human Geography*, *43*(6), 1064–1086. https://doi.org/10.1177/0309132518803799

Apparicio, P., Cloutier, M.-S., & Shearmur, R. (2007). The case of Montreal's missing food deserts: evaluation of accessibility to food supermarkets. *International Journal of Health Geographics*, *6*(1), 4. https://doi.org/10.1186/1476-072X-6-4

Aspinall, R., & Staiano, M. (2019). Ecosystem services as the products of land system dynamics: lessons from a longitudinal study of coupled human–environment systems. *Landscape Ecology*, *34*(7), 1503–1524. https://doi.org/10.1007/s10980-018-0752-7

Awasthi, A., Chauhan, S. S., & Goyal, S. K. (2011). A multi-criteria decision making approach for location planning for urban distribution centers under uncertainty. *Mathematical and Computer Modelling*, *53*(1–2), 98–109. https://doi.org/10.1016/j.mcm.2010.07.023

Baker, L. A., Brazel, A. T., & Westerhoff, P. (2004). Environmental consequences of rapid urbanization in warm, arid lands: case study of Phoenix, Arizona (USA). *WIT Transactions on Ecology and the Environment, 72*. https://doi.org/10.2495/SC040161

Balmer, K., Gill, J., Kaplinger, H., Miller, J., Peterson, M., Rhoads, A., Rosenbloom, P., & Wall, T. (2005). The Diggable City: Making Urban Agriculture a Planning Priority. In *Master of Urban and Regional Planning Workshop Projects*. http://pdxscholar.library.pdx.edu/usp_murp/52

Bao, K. Y., & Tong, D. (2016). The Effects of Spatial Scale and Aggregation on Food Access Assessment: A Case Study of Tucson, Arizona. *The Professional Geographer*, *0124*(February), 1–11. https://doi.org/10.1080/00330124.2016.1252271

Bao, K. Y., Tong, D., Plane, D. A., & Buechler, S. (2020). Urban food accessibility and diversity: Exploring the role of small non-chain grocers. *Applied Geography*, *125*(June), 102275. https://doi.org/10.1016/j.apgeog.2020.102275

Barfod, M. B., & Leleur, S. (2014). Multi-criteria decision analysis for use in transport decision making. *DTU Transport Compendium, Part 2*, 75.

Barron, J. (2017). Community gardening: cultivating subjectivities, space, and justice. *Local Environment*, *22*(9), 1142–1158. https://doi.org/10.1080/13549839.2016.1169518

Beaulac, J., Kristjansson, E., & Cummins, S. (2009). A systematic review of food deserts, 1966-2007. *Prev Chronic Dis*, *6*(3), A105. researchonline.lshtm.ac.uk/491627/

Benedict, M. A., & Mcmahon, E. T. (2001). *Green Infrastructure:* 12–18.

Birch, E., & Wachter, S. (2008). *Growing greener cities : urban sustainability in the twenty-first century*. University of Pennsylvania Press.

Birky, J., & Strom, E. (2013). Urban perennials: How diversification has created a sustainable community garden movement in the United States. *Urban Geography*, *34*(8), 1193–1216. https://doi.org/10.1080/02723638.2013.784086

Blaine, T. W., Grewal, P. S., Dawes, A., & Snider, D. (2010). Profiling Community Gardeners. *Journal of Extension*, *48*(6), 1–12.

Blanco, H. (2014). Range of Contemporary Urban Patterns and Processes. In A. Reenberg & K. C. Seto (Eds.), *Rethinking Global Land Use in an Urban Era* (pp. 275–298). MIT Press.

Bleasdale, T. (2015). *Gardens of Justice: Food-Based Social Movements in Underserved, Minority Communities [Doctoral dissertation]* [Arizona State University]. https://repository.asu.edu/items/29858

Bleasdale, T., Crouch, C., & Harlan, S. (2011). Community Gardening in Disadvantaged Neighborhoods in Phoenix, Arizona: Aligning Programs with Perceptions. *Journal of Agriculture, Food Systems, and Community Development*, *1*(3), 1–16. https://doi.org/10.5304/jafscd.2011.013.007

Bohannon, R. W., & Williams Andrews, A. (2011). Normal walking speed: A descriptive meta-analysis. *Physiotherapy*, *97*(3), 182–189. https://doi.org/10.1016/j.physio.2010.12.004

Boone, C. G., Buckley, G. L., Grove, M. J., & Sister, C. (2009). Parks and people: an environmental justice inquiry in Baltimore, Maryland. *Annals of the Association of American Geographers*, *99*(4), 767–787.

Boone, C. G., Redman, C. L., Blanco, H., Haase, D., Koch, J., Lwasa, S., Nagendra, H., Pauleit, S., Pickett, S. T. A., Seto, K. C., & Yokohari, M. (2014). Reconceptualizing land for sustainable urbanity. In K. C. Seto & A. Reenberg (Eds.), *Rethinking global land use in an urban era* (pp. 313–330). MIT Press. https://doi.org/10.7551/mitpress/9780262026901.003.0016

Bowman, A. O., & Pagano, M. A. (2004). *Terra incognita: Vacant land and urban strategies.* Georgetown University Press.

Branas, C. C., South, E., Kondo, M. C., Hohl, B. C., Bourgois, P., Wiebe, D. J., & MacDonald, J. M. (2018). Citywide cluster randomized trial to restore blighted vacant land and its effects on violence, crime, and fear. *Proceedings of the National Academy of Sciences*, *115*(12), 2946–2951. https://doi.org/10.1073/pnas.1718503115

Brelsford, C., Lobo, J., Hand, J., & Bettencourt, L. M. A. (2017). Heterogeneity and scale of sustainable development in cities. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(34), 8963–8968. https://doi.org/10.1073/pnas.1606033114

Burns, D. (2015, July). PHX Renews: Transforming vacant lots into community spaces. *Green Living Arizona Magazine*.

Cabral, I., Keim, J., Engelmann, R., Kraemer, R., Siebert, J., & Bonn, A. (2017). Ecosystem services of allotment and community gardens: A Leipzig, Germany case study. *Urban Forestry and Urban Greening*, *23*, 44–53. https://doi.org/10.1016/j.ufug.2017.02.008

Campbell, S. D. (1996). Green Cities, Growing Cities, Just Cities?: Urban Planning and the Contradictions of Sustainable Development. *Journal of the American Planning Association*, *62*(3), 296–312. https://doi.org/10.1080/01944369608975696

Campbell, S. D. (2016). The Planner’s Triangle Revisited: Sustainability and the Evolution of a Planning Ideal That Can’t Stand Still. *Journal of the American Planning Association*, *82*(4), 388–397. https://doi.org/10.1080/01944363.2016.1214080

Camps-Calvet, M., Langemeyer, J., Calvet-Mir, L., & Gómez-Baggethun, E. (2016). Ecosystem services provided by urban gardens in Barcelona, Spain: Insights for policy and planning. *Environmental Science and Policy*, *62*, 14–23. https://doi.org/10.1016/j.envsci.2016.01.007

Carpenter, S. R., Mooney, H. a, Agard, J., Capistrano, D., Defries, R. S., Díaz, S., Dietz, T., Duraiappah, A. K., Oteng-Yeboah, A., Pereira, H. M., Perrings, C., Reid, W. V, Sarukhan, J., Scholes, R. J., & Whyte, A. (2009). Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(5), 1305–1312. https://doi.org/10.1073/pnas.0808772106

Castro, D. C., Samuels, M., & Harman, A. E. (2013). Growing Healthy Kids: A community garden-based obesity prevention program. *American Journal of Preventive Medicine*, *44*(3 SUPPL. 3), S193–S199. https://doi.org/10.1016/j.amepre.2012.11.024

Chollet, S., Brabant, C., Tessier, S., & Jung, V. (2018). From urban lawns to urban meadows: Reduction of mowing frequency increases plant taxonomic, functional and phylogenetic diversity. *Landscape and Urban Planning*, *180*(August), 121–124.

https://doi.org/10.1016/j.landurbplan.2018.08.009

Chow, W., Brennan, D., & Brazel, A. (2012). Urban Heat Island Research in Phoenix, Arizona: Theoretical Contributions and Policy Applications. *Bulletin of the American Meteorological Society*, *93*(4), 517–530. https://doi.org/10.1175/BAMS-D-11-00011.1

Chowdhury, R. R., Uchida, E., Chen, L., Osorio, V., & Yoder, L. (2017). Anthropogenic Drivers of Mangrove Loss: Geographic Patterns and Implications for Livelihoods. In *Mangrove Ecosystems: A Global Biogeographic Perspective* (pp. 275–300). Springer International Publishing. https://doi.org/10.1007/978-3-319-62206-4_9

Christopher, A. S., McCormick, D., Woolhandler, S., Himmelstein, D. U., Bor, D. H., & Wilper, A. P. (2016). Access to Care and Chronic Disease Outcomes Among Medicaid-Insured Persons Versus the Uninsured. *American Journal of Public Health*, *106*(1), 63–69. https://doi.org/10.2105/AJPH.2015.302925

Church, R. L., & Davis, R. R. (1974). The maximal covering location problem. *Papers in Regional Science*, *32*(1), 101–118.

City of Phoenix. (2010). *Tree and Shade Master Plan*. https://www.phoenix.gov/parkssite/Documents/T and A 2010.pdf

Clarke, L. W., Jenerette, G. D., & Bain, D. J. (2015). Urban legacies and soil management affect the concentration and speciation of trace metals in Los Angeles community garden soils. *Environmental Pollution*, *197*, 1–12. https://doi.org/10.1016/j.envpol.2014.11.015

Cleveland, D. A., Phares, N., Nightingale, K. D., Weatherby, R. L., Radis, W., Ballard, J., Campagna, M., Kurtz, D., Livingston, K., Riechers, G., & Wilkins, K. (2017). The potential for urban household vegetable gardens to reduce greenhouse gas emissions. *Landscape and Urban Planning*, *157*, 365–374. https://doi.org/10.1016/j.landurbplan.2016.07.008

Clinton, N., Stuhlmacher, M., Miles, A., Uludere Aragon, N., Wagner, M., Georgescu, M., Herwig, C., & Gong, P. (2018). A Global Geospatial Ecosystem Services Estimate of Urban Agriculture. *Earth's Future*, *6*(1), 40–60. https://doi.org/10.1002/2017EF000536

Cohen, N., & Reynolds, K. (2014). Urban Agriculture Policy Making in New York's "New Political Spaces": Strategizing for a Participatory and Representative System. *Journal of Planning Education and Research*, *34*(2), 221–234. https://doi.org/10.1177/0739456X14526453

Colasanti, K. A., & Hamm, M. W. (2010). Assessing the local food supply capacity of Detroit, Michigan. *Journal of Agriculture, Food Systems, and Community*

Development, 1(12), 41–58. https://doi.org/10.5304/jafscd.2010.012.002

Colby, S. L., & Ortman, J. M. (2014). Projections of the Size and Composition of the U.S. Population: 2014 to 2060 US Census Bureau. In *Current Population Reports*. https://census.gov/content/dam/Census/library/publications/2015/demo/p25-1143.pdf

Coleman-Jensen, A., Rabbitt, M. P., Gregory, C., & Singh, A. (2019). Household Food Security in the United States in 2018. In *ERR-270* (Issue September). U.S. Department of Agriculture, Economic Research Service. https://www.ers.usda.gov/publications/pub-details/?pubid=94848

Community Gardeners of Maricopa County. (2017). *PHX Community Garden list as 4-26-17*. https://communitygardenersmc.org/resources/

Companion, M. (2016). Lessons from "The Bucket Brigade": In J. C. Dawson & A. Morales (Eds.), *Cities of Farmers* (pp. 126–140). University of Iowa Press. https://doi.org/10.2307/j.ctt20q23dv.13

Congalton, R. G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment, 37*(1), 35–46. https://doi.org/10.1016/0034-4257(91)90048-B

Connors, J. P., Galletti, C. S., & Chow, W. T. L. (2013). Landscape configuration and urban heat island effects: assessing the relationship between landscape characteristics and land surface temperature in Phoenix, Arizona. *Landscape Ecology*, *28*(2), 271–283. https://doi.org/10.1007/s10980-012-9833-1

D'Amour, C. B., Reitsma, F., Baiocchi, G., Barthel, S., Güneralp, B., Erb, K. H., Haberl, H., Creutzig, F., & Seto, K. C. (2017). Future urban land expansion and implications for global croplands. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(34), 8939–8944. https://doi.org/10.1073/pnas.1606036114

Davies, A. L., Bryce, R., & Redpath, S. M. (2013). Use of multicriteria decision analysis to address conservation conflicts. *Conservation Biology*, *27*(5), 936–944. https://doi.org/10.1111/cobi.12090

Denver Urban Gardens. (2012). *Growing community gardens: A Denver urban gardens' best practices handbook for creating and sustaining community gardens*. http://www.nccgp.org/images/uploads/resource_files/Best_Practices_for_Community_Gardens_-_Denver_Urban_Gardens.pdf

Diaz, J. M., Webb, S. T., Warner, L. A., & Monaghan, P. (2018). Barriers to community garden success: Demonstrating framework for expert consensus to inform policy and practice. *Urban Forestry and Urban Greening, 31*(March), 197–203. https://doi.org/10.1016/j.ufug.2018.02.014

Dobson, J. E. (1979). A Regional Screening Procedure for Land Use Suitability Analysis. *Geographical Review*, *69*(2), 224. https://doi.org/10.2307/214965

Douglas, I. (2012). Urban ecology and urban ecosystems: Understanding the links to human health and well-being. *Current Opinion in Environmental Sustainability*, *4*(4), 385–392. https://doi.org/10.1016/j.cosust.2012.07.005

Drake, L., & Lawson, L. (2015a). Best Practices in Community Garden Management to Address Participation, Water Access, and Outreach. *Extension Journal, Inc*, *53*(6), 1–15. http://www.joe.org/joe/2015december/a3.php

Drake, L., & Lawson, L. J. (2014). Validating verdancy or vacancy? The relationship of community gardens and vacant lands in the U.S. *Cities*, *40*, 133–142. https://doi.org/10.1016/j.cities.2013.07.008

Drake, L., & Lawson, L. J. (2015b). Results of a US and Canada community garden survey: shared challenges in garden management amid diverse geographical and organizational contexts. *Agriculture and Human Values*, *32*(2), 241–254. https://doi.org/10.1007/s10460-014-9558-7

Drake, L., Ravit, B., & Lawson, L. (2016). Developing a Vacant Property Inventory through Productive Partnerships : A University, NGO, and Municipal Planning Collaboration in Trenton, New Jersey. *Cities and the Environment (CATE)*, *8*(2), 6. http://digitalcommons.lmu.edu/cate/vol8/iss2/6/

Draus, P. J., Roddy, J., & McDuffie, A. (2014). ‘We don’t have no neighbourhood’: Advanced marginality and urban agriculture in Detroit. *Urban Studies*, *51*(12), 2523–2538. https://doi.org/10.1177/0042098013506044

Dutko, P., Ver Ploeg, M., & Farrigan, T. (2012). *Characteristics and influentialfactors of food deserts (No. 1477-2017-3995)* (Issue 140). https://www.ers.usda.gov/publications/pub-details/?pubid=45017

Eanes, F., & Ventura, S. J. (2015). Inventorying Land Availability and Suitability for Community Gardens in Madison, Wisconsin. *Cities and the Environment (CATE)*, *8*(2), 2. http://digitalcommons.lmu.edu/cate/vol8/iss2/2

Egendorf, S. P., Cheng, Z., Deeb, M., Flores, V., Paltseva, A., Walsh, D., Groffman, P., & Mielke, H. W. (2018). Constructed soils for mitigating lead (Pb) exposure and promoting urban community gardening: The New York City Clean Soil Bank pilot study. *Landscape and Urban Planning*, *175*(November 2017), 184–194. https://doi.org/10.1016/j.landurbplan.2018.03.012

Egerer, M. H., Lin, B. B., Threlfall, C. G., & Kendal, D. (2019). Temperature variability influences urban garden plant richness and gardener water use behavior, but not planting decisions. *Science of the Total Environment*, *646*, 111–120.

https://doi.org/10.1016/j.scitotenv.2018.07.270

Egli, V., Oliver, M., & Tautolo, E.-S. S. (2016). The development of a model of community garden benefits to wellbeing. *Preventive Medicine Reports*, *3*, 348–352. https://doi.org/10.1016/j.pmedr.2016.04.005

Eilertsen, G., Unger, J., & Mantiuk, R. K. (2016). Evaluation of Tone Mapping Operators for HDR Video. In *High Dynamic Range Video: From Acquisition to Display and Applications*. Elsevier Inc. https://doi.org/10.1016/B978-0-08-100412-8.00007-3

Engemann, K., Pedersen, C. B., Arge, L., Tsirogiannis, C., Mortensen, P. B., & Svenning, J.-C. (2019). Residential green space in childhood is associated with lower risk of psychiatric disorders from adolescence into adulthood. *Proceedings of the National Academy of Sciences*, 201807504. https://doi.org/10.1073/pnas.1807504116

EPA (U.S. Environmental Protection Agency). (2008). *Reducing urban heat islands: Compendium of strategies.* https://www.epa.gov/heat-islands

Estoque, R. C., Murayama, Y., & Myint, S. W. (2017). Effects of landscape composition and pattern on land surface temperature: An urban heat island study in the megacities of Southeast Asia. *Science of the Total Environment*, *577,* 349–359. https://doi.org/10.1016/j.scitotenv.2016.10.195

Faber, D., & McDonough Kimelberg, S. (2014). Sustainable urban development and environmental gentrification: The paradox confronting the US environmental justice movement. *Uprooting Urban America: Multidisciplinary Perspectives on Race, Class & Gentrification. New York: Peter Lang Publishers,* 77–92.

Firth, C., Maye, D., & Pearson, D. (2011). Developing "community" in community gardens. *Local Environment*, *16*(6), 555–568. https://doi.org/10.1080/13549839.2011.586025

Fischer, K. (2011). *Foundations of Location Analysis* (Vol. 155). https://doi.org/10.1007/978-1-4419-7572-0

Forman, R. T. T. (2014). *Urban ecology: science of cities*. Cambridge University Press.

Fraser, A. M., Chester, M. V, Eisenman, D., Hondula, D. M., Pincetl, S. S., English, P., & Bondank, E. (2017). Household accessibility to heat refuges: Residential air conditioning, public cooled space, and walkability. *Environment and Planning B: Urban Analytics and City Science*, *44*(6), 1036–1055. https://doi.org/10.1177/0265813516657342

Galletti, C. S., Li, X., & Connors, J. P. (2019). Establishing the relationship between urban land-cover configuration and night time land-surface temperature using spatial regression. *International Journal of Remote Sensing*, 1–23. https://doi.org/10.1080/01431161.2019.1594432

Garvin, E., Branas, C., Keddem, S., Sellman, J., & Cannuscio, C. (2013). More than just an eyesore: Local insights and solutions on vacant land and urban health. *Journal of Urban Health*, *90*(3), 412–426. https://doi.org/10.1007/s11524-012-9782-7

Georgescu, M., Morefield, P. E., Bierwagen, B. G., & Weaver, C. P. (2014). Urban adaptation can roll back warming of emerging megapolitan regions. *Proceedings of the National Academy of Sciences*, *111*(8), 2909–2914. https://doi.org/10.1073/pnas.1322280111

Getis, A., & Ord, J. K. (2010). The Analysis of Spatial Association by Use of Distance Statistics. *Geographical Analysis*, *24*(3), 189–206. https://doi.org/10.1111/j.1538-4632.1992.tb00261.x

Ghose, R., & Pettygrove, M. (2014). Actors and networks in urban community garden development. *Geoforum*, *53*, 93–103. https://doi.org/10.1016/j.geoforum.2014.02.009

Gill, S. . E., Handley, J. . F., Ennos, A. . R., Pauleit, S., Ennos, R., Pauleit, S., Ennos, A. . R., & Pauleit, S. (2007). Adapting cities for climate change: the role of the green infrastructure. *Built Environment*, *33*(1), 115–133. https://doi.org/10.2148/benv.33.1.115

Gober, P., Brazel, A., Quay, R., Myint, S., Grossman-Clarke, S., Miller, A., & Rossi, S. (2009). Using Watered Landscapes to Manipulate Urban Heat Island Effects: How Much Water Will It Take to Cool Phoenix? *Journal of the American Planning Association*, *76*(1), 109–121. https://doi.org/10.1080/01944360903433113

Gober, P., & Burns, E. K. (2002). The Size and Shape of Phoenix's Urban Fringe. *Journal of Planning Education and Research*, *21*(4), 379–390. https://doi.org/10.1177/0739456X0202100403

Goddard, M. A., Dougill, A. J., & Benton, T. G. (2010). Scaling up from gardens: biodiversity conservation in urban environments. *Trends in Ecology and Evolution*, *25*(2), 90–98. https://doi.org/10.1016/j.tree.2009.07.016

Goddard, M. A., Dougill, A. J., & Benton, T. G. (2013). Why garden for wildlife? Social and ecological drivers, Motivations and barriers for biodiversity management in residential landscapes. *Ecological Economics*, *86*, 258–273. https://doi.org/10.1016/j.ecolecon.2012.07.016

Godschalk, D. R. (2004). Land use planning challenges: Coping with conflicts in visions of sustainable development and livable communities. *Journal of the American Planning Association*, *70*(1), 5–13. https://doi.org/10.1080/01944360408976334

Good, E. J. (2016). An in situ-based analysis of the relationship between land surface "skin" and screen-level air temperatures. *Journal of Geophysical Research: Atmospheres*, *121*(15), 8801–8819. https://doi.org/10.1002/2016JD025318

Gordon, C., Purciel-Hill, M., Ghai, N. R., Kaufman, L., Graham, R., & Van Wye, G. (2011). Measuring food deserts in New York City's low-income neighborhoods. *Health and Place*, *17*(2), 696–700. https://doi.org/10.1016/j.healthplace.2010.12.012

Grewal, S. S., & Grewal, P. S. (2012). Can cities become self-reliant in food? *Cities*, *29*(1), 1–11. https://doi.org/10.1016/j.cities.2011.06.003

Grier, K., Hill, J. L., Reese, F., Covington, C., Bennette, F., Macauley, L., & Zoellner, J. (2015). Feasibility of an experiential community garden and nutrition programme for youth living in public housing. *Public Health Nutrition*, *18*(15), 2759–2769. https://doi.org/10.1017/S1368980015000087

Grimm, N. B., Baker, L. J., & Hope, D. (2003). An Ecosystem Approach to Understanding Cities: Familiar Foundations and Uncharted Frontiers. In *Understanding Urban Ecosystems* (pp. 95–114). Springer-Verlag. https://doi.org/10.1007/0-387-22615-X_7

Grimm, N. B., Redman, C. L., Boone, C. G., Childers, D. L., Harlan, S. L., & Turner, B. L. (2013). *Viewing the Urban Socio-ecological System Through a Sustainability Lens: Lessons and Prospects from the Central Arizona–Phoenix LTER Programme BT - Long Term Socio-Ecological Research: Studies in Society-Nature Interactions Across Spatial and Temporal Sc* (S. J. Singh, H. Haberl, M. Chertow, M. Mirtl, & M. Schmid (eds.); pp. 217–246). Springer Netherlands. https://doi.org/10.1007/978-94-007-1177-8_10

Guhathakurta, S., & Gober, P. (2007). The Impact of the Phoenix Urban Heat Island on Residential Water Use. *Journal of the American Planning Association*, *73*(3), 317–329. https://doi.org/10.1080/01944360708977980

Guhathakurta, S., & Gober, P. (2010). Residential land use, the Urban heat island, and water use in phoenix: A path analysis. *Journal of Planning Education and Research*, *30*(1), 40–51. https://doi.org/10.1177/0739456X10374187

Guitart, D., Pickering, C., & Byrne, J. (2012). Past results and future directions in urban community gardens research. *Urban Forestry and Urban Greening*, *11*(4), 364–373. https://doi.org/10.1016/j.ufug.2012.06.007

Haase, D., Larondelle, N., Andersson, E., Artmann, M., Borgström, S., Breuste, J., Gomez-Baggethun, E., Gren, Å., Hamstead, Z., Hansen, R., Kabisch, N., Kremer, P., Langemeyer, J., Rall, E. L., McPhearson, T., Pauleit, S., Qureshi, S., Schwarz, N., Voigt, A., … Elmqvist, T. (2014). A quantitative review of urban ecosystem service assessments: Concepts, models, and implementation. *Ambio*, *43*(4), 413–

433. https://doi.org/10.1007/s13280-014-0504-0

Hanaček, K., & Rodríguez-Labajos, B. (2018). Impacts of land-use and management changes on cultural agroecosystem services and environmental conflicts—A global review. *Global Environmental Change*, *50*(September 2017), 41–59. https://doi.org/10.1016/j.gloenvcha.2018.02.016

Hansen, R., & Pauleit, S. (2014). From multifunctionality to multiple ecosystem services? A conceptual framework for multifunctionality in green infrastructure planning for Urban Areas. *Ambio*, *43*(4), 516–529. https://doi.org/10.1007/s13280-014-0510-2

Harlan, S. L., Brazel, A. J., Jenerette, G. D., Jones, N. S., Larsen, L., Prashad, L., & Stefanov, W. L. (2007). *In the shade of affluence: the inequitable distribution of the urban heat island* (pp. 173–202). Emerald Group Publishing Limited. https://doi.org/10.1016/S0196-1152(07)15005-5

Harlan, S. L., Declet-Barreto, J. H., Stefanov, W. L., & Petitti, D. B. (2013). Neighborhood Effects on Heat Deaths: Social and Environmental Predictors of Vulnerability in Maricopa County, Arizona. *Environmental Health Perspectives, 121*(2), 197–204. https://doi.org/10.1289/ehp.1104625

Hartig, T., Kaiser, F. G., & Strumse, E. (2007). Psychological restoration in nature as a source of motivation for ecological behaviour. *Environmental Conservation*, *34*(4), 291–299. https://doi.org/10.1017/S0376892907004250

Hasse, D. (2014). How is Urban Land Use Unique? In A. Reenberg & K. C. Seto (Eds.), *Rethinking Global Land Use in an Urban Era* (pp. 299–311). MIT Press.

Haurin, D. R., Herbert, C. E., & Rosenthal, S. S. (2007). Homeownership Gaps Among Low-Income and Minority Households. *Cityscape*, *9*(2), 5–51. http://www.jstor.org/stable/20868618

Heckert, M., & Mennis, J. (2012). The economic impact of greening urban vacant land: A spatial difference-in-differences analysis. *Environment and Planning A*, *44*(12), 3010–3027. https://doi.org/10.1068/a4595

Heckert, M., & Rosan, C. D. (2016). Developing a green infrastructure equity index to promote equity planning. *Urban Forestry and Urban Greening*, *19*, 263–270. https://doi.org/10.1016/j.ufug.2015.12.011

Hedquist, B. C., & Brazel, A. J. (2014). Seasonal variability of temperatures and outdoor human comfort inPhoenix, Arizona, U.S.A. *Building and Environment*, *72*, 377–388. https://doi.org/10.1016/j.buildenv.2013.11.018

Heim, C. E. (2001). Leapfrogging, Urban Sprawl, and Growth Management: Phoenix, 1950-2000. *American Journal of Economics and Sociology*, *60*(1), 245–283. https://doi.org/10.1111/1536-7150.00063

Heinimann, A., Mertz, O., Frolking, S., Christensen, A. E., Hurni, K., Sedano, F., Chini, L. P., Sahajpal, R., Hansen, M., & Hurtt, G. (2017). *A global view of shifting cultivation : Recent , current , and future extent*. 1–21.

Heris, M. P., Middel, A., & Muller, B. (2020). Impacts of form and design policies on urban microclimate: Assessment of zoning and design guideline choices in urban redevelopment projects. *Landscape and Urban Planning*, *202*(May), 103870. https://doi.org/10.1016/j.landurbplan.2020.103870

Hersperger, A. M., Oliveira, E., Pagliarin, S., Palka, G., Verburg, P., Bolliger, J., & Grădinaru, S. (2018). Urban land-use change: The role of strategic spatial planning. *Global Environmental Change*, *51*(May), 32–42. https://doi.org/10.1016/j.gloenvcha.2018.05.001

Hilliard, J. (2017, February 3). PHX Renews Community Garden to Close in Phoenix - Here's Why. *Phoenix New Times*, 11–13. https://www.phoenixnewtimes.com/arts/why-phx-renews-community-garden-is-closing-in-midtown-phoenix-9051615

Hollander, J. B. (2011). *Sunburnt cities: The great recession, depopulation and urban planning in the American sunbelt.* Routledge.

Holmes, C., Hall, S. J., Heavenrich, H., & Shock, E. (2018). *Trace metal content of community garden soils and plants in metropolitan Phoenix, AZ* (Issue June). https://halllab.asu.edu/wp-content/uploads/2018/10/PhxCommunityGardenMetals_June-2018.pdf

Hondula, D. M., Georgescu, M., & Balling, R. C. (2014). Challenges associated with projecting urbanization-induced heat-related mortality. *Science of the Total Environment*, *490*, 538–544. https://doi.org/10.1016/j.scitotenv.2014.04.130

Hope, D., Gries, C., Zhu, W., Fagan, W. F., Redman, C. L., Grimm, N. B., Nelson, A. L., Martin, C., & Kinzig, A. (2008). Socioeconomics Drive Urban Plant Diversity. In J. M. Marzluff, E. Shulenberger, W. Endlicher, M. Alberti, G. Bradley, C. Ryan, U. Simon, & C. ZumBrunnen (Eds.), *Urban Ecology: An International Perspective on the Interaction Between Humans and Nature* (pp. 339–347). Springer US. https://doi.org/10.1007/978-0-387-73412-5_21

Horst, M. (2008). *Growing Green: An Inventory of Public Lands Suitable for Community Gardens in Seattle, Washington*. http://works.bepress.com/megan-horst/4/

Huang, G., Zhou, W., & Cadenasso, M. L. (2011). Is everyone hot in the city? Spatial pattern of land surface temperatures, land cover and neighborhood socioeconomic characteristics in Baltimore, MD. *Journal of Environmental Management*, *92*(7), 1753–1759. https://doi.org/10.1016/j.jenvman.2011.02.006

Hunt, J. C. R., Aktas, Y. D., Mahalov, A., Moustaoui, M., Salamanca, F., & Georgescu, M. (2017). Climate change and growing megacities: hazards and vulnerability. *Proceedings of the Institution of Civil Engineers - Engineering Sustainability, 171*(6), 314–326. https://doi.org/10.1680/jensu.16.00068

Imhoff, M. L., Zhang, P., Wolfe, R. E., & Bounoua, L. (2010). Remote sensing of the urban heat island effect across biomes in the continental USA. *Remote Sensing of Environment*, *114*(3), 504–513. https://doi.org/10.1016/j.rse.2009.10.008

Ishtiaque, A., Shrestha, M., & Chhetri, N. (2017). Rapid urban growth in the kathmandu valley, nepal: Monitoring land use land cover dynamics of a himalayan city with landsat imageries. *Environments - MDPI*, *4*(4), 1–16. https://doi.org/10.3390/environments4040072

Iwaniec, D. M., Cook, E. M., Davidson, M. J., Berbés-Blázquez, M., & Grimm, N. B. (2020). Integrating existing climate adaptation planning into future visions: A strategic scenario for the central Arizona–Phoenix region. *Landscape and Urban Planning, 200*(April), 103820. https://doi.org/10.1016/j.landurbplan.2020.103820

Jenerette, G. D., Harlan, S. L., Buyantuev, A., Stefanov, W. L., Declet-Barreto, J., Ruddell, B. L., Myint, S. W., Kaplan, S., & Li, X. (2016). Micro-scale urban surface temperatures are related to land-cover features and residential heat related health impacts in Phoenix, AZ USA. *Landscape Ecology*, *31*(4), 745–760. https://doi.org/10.1007/s10980-015-0284-3

Jenerette, G. D., Harlan, S. L., Stefanov, W. L., & Martin, C. A. (2011). Ecosystem services and urban heat riskscape moderation: Water, green spaces, and social inequality in Phoenix, USA. *Ecological Applications*, *21*(7), 2637–2651. https://doi.org/10.1890/10-1493.1

Jermé, E. S., & Wakefield, S. (2013). Growing a just garden: Environmental justice and the development of a community garden policy for Hamilton, Ontario. *Planning Theory and Practice*, *14*(3), 295–314. https://doi.org/10.1080/14649357.2013.812743

Jerome, G. (2017). Defining community-scale green infrastructure. *Landscape Research*, *42*(2), 223–229. https://doi.org/10.1080/01426397.2016.1229463

Jetter, K. M., & Cassady, D. L. (2006). The availability and cost of healthier food alternatives. *American Journal of Preventive Medicine*, *30*(1), 38–44. https://doi.org/10.1016/j.amepre.2005.08.039

Kaethler, T. M. (2006). *Growing Space: The Potential for Urban Agriculture in the City* *of Vancouver*. http://community-wealth.org/sites/clone.community-wealth.org/files/downloads/report-kaethler.pdf

Kamarianakis, Y., Li, X., Turner, B. L., & Brazel, A. J. (2019). On the effects of landscape configuration on summer diurnal temperatures in urban residential areas: application in Phoenix, AZ. *Frontiers of Earth Science, 13*(3), 445–463. https://doi.org/10.1007/s11707-017-0678-4

Kane, K., Connors, J. P., & Galletti, C. S. (2014). Beyond fragmentation at the fringe: A path-dependent, high-resolution analysis of urban land cover in Phoenix, Arizona. *Applied Geography*, *52*, 123–134. https://doi.org/10.1016/j.apgeog.2014.05.002

Kaplan, S. (2020, July 8). How America's hottest city will survive climate change. *Washington Post*. https://www.washingtonpost.com/graphics/2020/climate-solutions/phoenix-climate-change-heat/

Karge, T. (2018). Placemaking and urban gardening: Himmelbeet case study in Berlin. *Journal of Place Management and Development*, *11*(2), 208–222. https://doi.org/10.1108/JPMD-10-2017-0109

Karuri-Sebina, G., Haegeman, K.-H., & Ratanawaraha, A. (2016). Urban futures: anticipating a world of cities. *Foresight*, *18*(5), 449–453. https://doi.org/10.1108/FS-07-2016-0037

Kaye, J. P., Groffman, P. M., Grimm, N. B., Baker, L. A., & Pouyat, R. V. (2006). A distinct urban biogeochemistry? *Trends in Ecology and Evolution*, *21*(4), 192–199. https://doi.org/10.1016/j.tree.2005.12.006

Keridwen, C. (2019, February 13). How Phoenix Is Working to Beat Urban Heat. *Scientific American*. https://www.scientificamerican.com/article/how-phoenix-is-working-to-beat-urban-heat/

Kessler, R. (2013). Urban Gardening: Managing the Risks of Contaminated Soil. *Environmental Health Perspectives*, *121*(11–12), 326–333. https://doi.org/10.1289/ehp.121-A326

Khandelwal, A. K., Balling, R. C., Goldblatt, R., Clinton, N., Tellman, B., Cheng, W.-H., Serrano-Candela, F., Stuhlmacher, M. F., Wang, C., Georgescu, M., & Hanson, G. (2017). Using Landsat and nighttime lights for supervised pixel-based image classification of urban land cover. *Remote Sensing of Environment*, *205*(December 2017), 253–275. https://doi.org/10.1016/j.rse.2017.11.026

Kotejoshyer, R., Zhang, Y., Flum, M., Fleishman, J., & Punnett, L. (2019). Prospective evaluation of fidelity, impact and sustainability of participatory workplace health teams in skilled nursing facilities. *International Journal of Environmental Research and Public Health*, *16*(9). https://doi.org/10.3390/ijerph16091494

Kremer, P., & DeLiberty, T. L. (2011). Local food practices and growing potential: Mapping the case of Philadelphia. *Applied Geography*, *31*(4), 1252–1261. https://doi.org/10.1016/j.apgeog.2011.01.007

Kremer, P., Hamstead, Z. A., & McPhearson, T. (2016). The value of urban ecosystem services in New York City: A spatially explicit multicriteria analysis of landscape scale valuation scenarios. *Environmental Science & Policy, 62,* 57–68. https://doi.org/10.1016/j.envsci.2016.04.012

Kuang, J., Yamaguchi, H., Liu, C., Johnson, G. M., & Fairchild, M. D. (2007). Evaluating HDR rendering algorithms. *ACM Transactions on Applied Perception, 4*(2), 9. https://doi.org/10.1145/1265957.1265958

Lambin, E. F., & Meyfroidt, P. (2010). Land use transitions: Socio-ecological feedback versus socio-economic change. *Land Use Policy, 27*(2), 108–118. https://doi.org/10.1016/j.landusepol.2009.09.003

Langegger, S. (2013). Emergent public space: Sustaining chicano culture in North Denver. *Cities*, *35,* 26–32. https://doi.org/10.1016/j.cities.2013.04.013

Langemeyer, J., Madrid-Lopez, C., Mendoza Beltran, A., & Villalba Mendez, G. (2021). Urban agriculture — A necessary pathway towards urban resilience and global sustainability? *Landscape and Urban Planning*, *210*, 104055. https://doi.org/10.1016/j.landurbplan.2021.104055

Langemeyer, J., Wedgwood, D., McPhearson, T., Baró, F., Madsen, A. L., & Barton, D. N. (2020). Creating urban green infrastructure where it is needed – A spatial ecosystem service-based decision analysis of green roofs in Barcelona. *Science of the Total Environment*, *707*, 135487. https://doi.org/10.1016/j.scitotenv.2019.135487

Łaszkiewicz, E., Kronenberg, J., & Marcińczak, S. (2018). Attached to or bound to a place? The impact of green space availability on residential duration: The environmental justice perspective. *Ecosystem Services*, *30,* 309–317. https://doi.org/10.1016/j.ecoser.2017.10.002

Leiter, R., Hinds, J. B., Larsen, C., Debay, A., & Walker, D. (2016). *Urban Agriculture Suitability Analysis Model*.

Li, Xiaoma, Zhou, W., & Ouyang, Z. (2013). Relationship between land surface temperature and spatial pattern of greenspace: What are the effects of spatial resolution? *Landscape and Urban Planning*, *114*, 1–8. https://doi.org/10.1016/j.landurbplan.2013.02.005

Li, Xiaoxiao, Kamarianakis, Y., Ouyang, Y., Turner II, B. L., & Brazel, A. (2017). On the association between land system architecture and land surface temperatures:

Evidence from a Desert Metropolis—Phoenix, Arizona, U.S.A. *Landscape and Urban Planning*, *163*, 107–120. https://doi.org/10.1016/j.landurbplan.2017.02.009

Li, Xiaoxiao, Li, W., Middel, A., Harlan, S. L. L., Brazel, A. J. J., & Turner, B. L. L. (2016). Remote sensing of the surface urban heat island and land architecture in Phoenix, Arizona: Combined effects of land composition and configuration and cadastral–demographic–economic factors. *Remote Sensing of Environment, 174*, 233–243. https://doi.org/10.1016/j.rse.2015.12.022

Li, Xiaoxiao, Myint, S. W., Zhang, Y., Galletti, C., Zhang, X., & Turner, B. L. (2014). Object-based land-cover classification for metropolitan Phoenix, Arizona, using aerial photography. *International Journal of Applied Earth Observation and Geoinformation*, *33*(1), 321–330. https://doi.org/10.1016/j.jag.2014.04.018

Li, Xiaoxiao, & Shao, G. (2013). Object-based urban vegetation mapping with high-resolution aerial photography as a single data source. *International Journal of Remote Sensing*, *34*(3), 771–789. https://doi.org/10.1080/01431161.2012.714508

Li, Xueping, Zhao, Z., Zhu, X., & Wyatt, T. (2011). Covering models and optimization techniques for emergency response facility location and planning: A review. *Mathematical Methods of Operations Research*, *74*(3), 281–310. https://doi.org/10.1007/s00186-011-0363-4

Lin, B. B., Egerer, M. H., Liere, H., Jha, S., Bichier, P., & Philpott, S. M. (2018). Local- and landscape-scale land cover affects microclimate and water use in urban gardens. *Science of the Total Environment*, *610–611*, 570–575. https://doi.org/10.1016/j.scitotenv.2017.08.091

Lin, B. B., Philpott, S. M., Jha, S., & Liere, H. (2017). Urban Agriculture as a Productive Green Infrastructure for Environmental and Social Well-Being. In P. Y. Tan & C. Y. Jim (Eds.), *Greening Cities*. Springer Singapore. https://doi.org/10.1007/978-981-10-4113-6

Lin, T., Gibson, V., Cui, S., Yu, C. P., Chen, S., Ye, Z., & Zhu, Y. G. (2014). Managing urban nutrient biogeochemistry for sustainable urbanization. *Environmental Pollution*, *192*, 244–250. https://doi.org/10.1016/j.envpol.2014.03.038

Litt, J. S., Soobader, M. J., Turbin, M. S., Hale, J. W., Buchenau, M., & Marshall, J. A. (2011). The influence of social involvement, neighborhood aesthetics, and community garden participation on fruit and vegetable consumption. *American Journal of Public Health*, *101*(8), 1466–1473. https://doi.org/10.2105/AJPH.2010.300111

Lottrup, L., Grahn, P., & Stigsdotter, U. K. (2013). Workplace greenery and perceived level of stress: Benefits of access to a green outdoor environment at the workplace. *Landscape and Urban Planning*, *110*(1), 5–11.

https://doi.org/10.1016/j.landurbplan.2012.09.002

Lovell, S. T. (2010). Multifunctional urban agriculture for sustainable land use planning in the United States. *Sustainability*, *2*(8), 2499–2522. https://doi.org/10.3390/su2082499

Lovell, S. T., & Taylor, J. R. (2013). Supplying urban ecosystem services through multifunctional green infrastructure in the United States. *Landscape Ecology*, *28*(8), 1447–1463. https://doi.org/10.1007/s10980-013-9912-y

Lucan, S. C., & Chambers, E. C. (2013). Better Measurement Needed to Move Food-Environment Research Forward. *Obesity*, *21*(1), 2. https://doi.org/10.1002/oby.20006

Lwasa, S., Mugagga, F., Wahab, B., Simon, D., Connors, J., & Griffith, C. (2014). Urban and peri-urban agriculture and forestry: Transcending poverty alleviation to climate change mitigation and adaptation. *Urban Climate*, *7*, 92–106. https://doi.org/10.1016/j.uclim.2013.10.007

Mack, E. A., Tong, D., & Credit, K. (2017). Gardening in the desert: a spatial optimization approach to locating gardens in rapidly expanding urban environments. *International Journal of Health Geographics*, *16*(1), 37. https://doi.org/10.1186/s12942-017-0110-z

MacRae, R., Gallant, E., Patel, S., Michalak, M., Bunch, M., & Schaffner, S. (2010). Could Toronto provide 10% of its fresh vegetable requirements from within its own boundaries? Matching consumption requirements with growing spaces. *Journal of Agriculture, Food Systems, and Community Development*, *1*(2), 105–127. https://doi.org/10.5304/jafscd.2010.012.008

MAG (Maricopa Association of Governments). (2014). *Maricopa Co. Parks Dataset*. https://www.azmag.gov/Programs/Maps-and-Data

MAG (Maricopa Association of Governments). (2017). *The Building Landmark Inventory*. https://www.azmag.gov/Programs/Maps-and-Data

MAG (Maricopa Association of Governments). (2019). *Bikeways in Maricopa and Pinal Cos., AZ, 2019*. https://www.azmag.gov/Programs/Maps-and-Data

Malczewski, J. (1999). *GIS and multicriteria decision analysis*. John Wiley.

Malloy, C. (2020, April 2). Growing Up — Urban Farms Have the Potential to Transform Phoenix. *Phoenix New Times*. https://www.phoenixnewtimes.com/content/printView/11462682

McBride, M. B., Shayler, H. A., Spliethoff, H. M., Mitchell, R. G., Marquez-Bravo, L.

G., Ferenz, G. S., Russell-Anelli, J. M., Casey, L., & Bachman, S. (2014). Concentrations of lead, cadmium and barium in urban garden-grown vegetables: The impact of soil variables. *Environmental Pollution*, *194*, 254–261. https://doi.org/10.1016/j.envpol.2014.07.036

McClintock, N. (2012). Assessing soil lead contamination at multiple scales in Oakland, California: Implications for urban agriculture and environmental justice. *Applied Geography*, *35*(1–2), 460–473. https://doi.org/10.1016/j.apgeog.2012.10.001

McClintock, N. (2018). Cultivating (a) Sustainability Capital: Urban Agriculture, Ecogentrification, and the Uneven Valorization of Social Reproduction. *Annals of the American Association of Geographers*, *108*(2), 579–590. https://doi.org/10.1080/24694452.2017.1365582

McClintock, N., & Cooper, J. (2010). *Cultivating the Commons An Assessment of the Potential for Urban Agriculture on Public Land in Oakland, California*. http://pdxscholar.library.pdx.edu/usp_fac

McClintock, N., Cooper, J., & Khandeshi, S. (2013). Assessing the potential contribution of vacant land to urban vegetable production and consumption in Oakland, California. *Landscape and Urban Planning*, *111*(1), 46–58. https://doi.org/10.1016/j.landurbplan.2012.12.009

McHarg, I. (1969). *Design with nature*. American Museum of Natural History.

McMichael, A. J., Wilkinson, P., Kovats, R. S., Pattenden, S., Hajat, S., Armstrong, B., Vajanapoom, N., Niciu, E. M., Mahomed, H., Kingkeow, C., Kosnik, M., O'Neill, M. S., Romieu, I., Ramirez-Aguilar, M., Barreto, M. L., Gouveia, N., & Nikiforov, B. (2008). International study of temperature, heat and urban mortality: The "ISOTHURM" project. *International Journal of Epidemiology*, *37*(5), 1121–1131. https://doi.org/10.1093/ije/dyn086

McPhearson, T., Pickett, S. T. A., Grimm, N. B., Niemelä, J., Alberti, M., Elmqvist, T., Weber, C., Haase, D., Breuste, J., & Qureshi, S. (2016). Advancing Urban Ecology toward a Science of Cities. *BioScience*, *66*(3), 198–212. https://doi.org/10.1093/biosci/biw002

MCTAO (Maricopa County Tax Assessor's Office). (2017). *Maricopa Co. Cadastral Dataset*. https://lib.asu.edu/geo

Meenar, M. R. (2017). Assessing the spatial connection between Urban agriculture and equity. *Built Environment*, *43*(3), 364–375. https://doi.org/10.2148/benv.43.3.364

Meerow, S. (2017). *The Contested Nature of Urban Resilience: Meaning and Models for Green Infrastructure and Climate Change Adaptation Planning* (Vol. 6).

Meerow, S. (2020). The politics of multifunctional green infrastructure planning in New York City. *Cities*, *100*(January), 102621. https://doi.org/10.1016/j.cities.2020.102621

Meerow, S., & Newell, J. P. (2017). Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit. *Landscape and Urban Planning*, *159*, 62–75. https://doi.org/10.1016/j.landurbplan.2016.10.005

Mendas, A., & Delali, A. (2012). Integration of MultiCriteria Decision Analysis in GIS to develop land suitability for agriculture: Application to durum wheat cultivation in the region of Mleta in Algeria. *Computers and Electronics in Agriculture*, *83*, 117–126. https://doi.org/10.1016/j.compag.2012.02.003

Mendes, W., Balmer, K., Kaethler, T., & Rhoads, A. (2008). Using Land Inventories to Plan for Urban Agriculture: Experiences From Portland and Vancouver. *Journal of the American Planning Association*, *74*(4), 435–449. https://doi.org/10.1080/01944360802354923

Meyfroidt, P., Roy Chowdhury, R., de Bremond, A., Ellis, E. C., Erb, K. H., Filatova, T., Garrett, R. D., Grove, J. M., Heinimann, A., Kuemmerle, T., Kull, C. A., Lambin, E. F., Landon, Y., le Polain de Waroux, Y., Messerli, P., Müller, D., Nielsen, J., Peterson, G. D., Rodriguez García, V., … Verburg, P. H. (2018). Middle-range theories of land system change. *Global Environmental Change*, *53*(September), 52–67. https://doi.org/10.1016/j.gloenvcha.2018.08.006

Miller, W. M. (2015). UK allotments and urban food initiatives: (limited?) potential for reducing inequalities. *Local Environment*, *20*(10), 1194–1214. https://doi.org/10.1080/13549839.2015.1035239

Munroe, D. K., Crandall, M. S., Colocousis, C., Bell, K. P., & Morzillo, A. T. (2019). Reciprocal relationships between forest management and regional landscape structures: applying concepts from land system science to private forest management. *Journal of Land Use Science*, *14*(2), 155–172. https://doi.org/10.1080/1747423X.2019.1607914

Munroe, D. K., & McSweeney, K. (2019). Addressing Root Drivers of Land-Climate Dynamics. *One Earth*, *1*(2), 181–184. https://doi.org/10.1016/j.oneear.2019.10.001

Murray, A. T. (2020). Sustainability and Resilience Through Micro-scale Decisions for Change. In Z. Chen, W. M. Bowen, & D. Whittington (Eds.), *Development Studies in Regional Science: Essays in Honor of Kingsley E. Haynes* (pp. 43–57). Springer. https://doi.org/10.1007/978-981-15-1435-7_4

Murray, A. T., Tong, D., & Kim, K. (2010). Enhancing classic coverage location models. *International Regional Science Review*, *33*(2), 115–133. https://doi.org/10.1177/0160017609340149

Myint, S. W., Zheng, B., Talen, E., Fan, C., Kaplan, S., Middel, A., Smith, M., Huang, H. ping, & Brazel, A. (2015). Does the spatial arrangement of urban landscape matter? examples of urban warming and cooling in phoenix and las vegas. *Ecosystem Health and Sustainability*, *1*(4), 1–15. https://doi.org/10.1890/EHS14-0028.1

Nalmpantis, D., Roukouni, A., Genitsaris, E., Stamelou, A., & Naniopoulos, A. (2019). Evaluation of innovative ideas for Public Transport proposed by citizens using Multi-Criteria Decision Analysis (MCDA). *European Transport Research Review*, *11*(1). https://doi.org/10.1186/s12544-019-0356-6

Native Health. (2020). *NATIVE HEALTH Indigenous Wellness Gardens*. https://www.nativehealthphoenix.org/services/community-health-and-wellness/gardens/

Newell, J. P., Foster, A., Borgman, M., & Meerow, S. (2020). Urban Agriculture as ecosystem services: Scaling-up in Detroit and beyond. *Manuscript in Review*. https://doi.org/10.1017/CBO9781107415324.004

Newman, G. D., Bowman, A. O. M., Jung Lee, R., & Kim, B. (2016). A current inventory of vacant urban land in America. *Journal of Urban Design*, *21*(3), 302–319. https://doi.org/10.1080/13574809.2016.1167589

Nicholls, E., Ely, A., Birkin, L., Basu, P., & Goulson, D. (2020). The contribution of small-scale food production in urban areas to the sustainable development goals: a review and case study. *Sustainability Science*, *April*. https://doi.org/10.1007/s11625-020-00792-z

Niemelä, J., Saarela, S. R., Söderman, T., Kopperoinen, L., Yli-Pelkonen, V., Väre, S., & Kotze, D. J. (2010). Using the ecosystem services approach for better planning and conservation of urban green spaces: A Finland case study. *Biodiversity and Conservation*, *19*(11), 3225–3243. https://doi.org/10.1007/s10531-010-9888-8

Niinemets, Ü., & Peñuelas, J. (2008). Gardening and urban landscaping: significant players in global change. *Trends in Plant Science*, *13*(2), 60–65. https://doi.org/10.1016/j.tplants.2007.11.009

Northam, R. M. (1971). Vacant Urban Land in the American City. *Land Economics*, *47*(4), 345–355. https://doi.org/10.2307/3145071

Noy, C. (2008). Sampling knowledge: The hermeneutics of snowball sampling in qualitative research. *International Journal of Social Research Methodology*, *11*(4), 327–344. https://doi.org/10.1080/13645570701401305

Nyerges, T. L., & Jankowski, P. (2010). *Regional and urban GIS: a decision support approach*. The Guilford Press.

Ogden, C. L., Lamb, M. M., Carroll, M. D., & Flegal, K. M. (2010). *Obesity and socioeconomic status in adults: United States, 2005-2008.* (Vol. 127, Issue 50). https://www.cdc.gov/nchs/data/databriefs/db50.pdf

Okvat, H. A., & Zautra, A. J. (2011). Community Gardening: A Parsimonious Path to Individual, Community, and Environmental Resilience. *American Journal of Community Psychology*, *47*(3–4), 374–387. https://doi.org/10.1007/s10464-010-9404-z

Oliveira, S., Andrade, H., & Vaz, T. (2011). The cooling effect of green spaces as a contribution to the mitigation of urban heat: A case study in Lisbon. *Building and Environment*, *46*(11), 2186–2194. https://doi.org/10.1016/j.buildenv.2011.04.034

Ornelas, I. J., Deschenie, D., Jim, J., Bishop, S., Lombard, K., & Beresford, S. A. A. (2017). Yéego Gardening! A Community Garden Intervention to Promote Health on the Navajo Nation. *Progress in Community Health Partnerships: Research, Education, and Action*, *11*(4), 417–425. https://doi.org/10.1353/cpr.2017.0049

Oshan, T. M., Smith, J. P., & Fotheringham, A. S. (2020). Targeting the spatial context of obesity determinants via multiscale geographically weighted regression. *International Journal of Health Geographics*, *19*(1), 11. https://doi.org/10.1186/s12942-020-00204-6

Paker, Y., Yom-Tov, Y., Alon-Mozes, T., & Barnea, A. (2014). The effect of plant richness and urban garden structure on bird species richness, diversity and community structure. *Landscape and Urban Planning*, *122*, 186–195. https://doi.org/10.1016/j.landurbplan.2013.10.005

Parece, T. E., Serrano, E. L., & Campbell, J. B. (2017). Strategically Siting Urban Agriculture: A Socioeconomic Analysis of Roanoke, Virginia. *The Professional Geographer*, *69*(1), 45–58. https://doi.org/10.1080/00330124.2016.1157496

Park, R. E., Burges, E. W., & McKenzie, R. D. (1967). *The City*. U of Chicago.

Pearsall, H., Gachuz, S., Rodriguez Sosa, M., Schmook, B., van der Wal, H., & Gracia, M. A. (2017). Urban Community Garden Agrodiversity and Cultural Identity in Philadelphia, Pennsylvania, U.S. *Geographical Review*, *107*(3), 476–495. https://doi.org/10.1111/j.1931-0846.2016.12202.x

Pearsall, H., Lucas, S., & Lenhardt, J. (2014). The contested nature of vacant land in Philadelphia and approaches for resolving competing objectives for redevelopment. *Cities*, *40*, 163–174. https://doi.org/10.1016/j.cities.2013.04.008

Pejchar, L., Reed, S. E., Bixler, P., Ex, L., & Mockrin, M. H. (2015). Consequences of Residential development for biodiversity and human well-being. *Frontiers in Ecology and the Environment*, *13*(3), 146–153. https://doi.org/10.1890/140227

Petrovic, N., Simpson, T., Orlove, B., & Dowd-Uribe, B. (2019). Environmental and social dimensions of community gardens in East Harlem. *Landscape and Urban Planning*, *183*(October 2017), 36–49. https://doi.org/10.1016/J.LANDURBPLAN.2018.10.009

Portman, M. E., Shabtay-Yanai, A., & Zanzuri, A. (2016). Incorporation of Socio-Economic Features’ Ranking in Multicriteria Analysis Based on Ecosystem Services for Marine Protected Area Planning. *PLoS ONE*, *11*(5), 1–17. https://doi.org/10.1371/journal.pone.0154473

Poulsen, M. N., Neff, R. A., & Winch, P. J. (2017). The multifunctionality of urban farming: perceived benefits for neighbourhood improvement. *Local Environment, 22*(11), 1411–1427. https://doi.org/10.1080/13549839.2017.1357686

Raja, S., Changxing Ma, & Yadav, P. (2008). Beyond Food Deserts: Measuring and Mapping Racial Disparities in Neighborhood Food Environments. *Journal of Planning Education and Research*, *27*(4), 469–482. https://doi.org/10.1177/0739456X08317461

Ranger, S., Kenter, J. O., Bryce, R., Cumming, G., Dapling, T., Lawes, E., & Richardson, P. B. (2016). Forming shared values in conservation management: An interpretive-deliberative-democratic approach to including community voices. *Ecosystem Services*, *21*(September), 344–357. https://doi.org/10.1016/j.ecoser.2016.09.016

Reenberg, A., & Seto, K. C. (2014). *Rethinking Global Land Use in an Urban Era* (K. C. Seto & A. Reenberg (eds.)). MIT Press. http://www.jstor.org/stable/j.ctt9qf5p8

Reid, C. E., O’Neill, M. S., Gronlund, C. J., Brines, S. J., Brown, D. G., Diez-Roux, A. V., & Schwartz, J. (2009). Mapping community determinants of heat vulnerability. *Environmental Health Perspectives*, *117*(11), 1730–1736. https://doi.org/10.1289/ehp.0900683

Rhone, A., Ver Ploeg, M., Williams, R., & Breneman, V. (2019). *Understanding Low-Income and Low- Access Census Tracts Across the Nation : Subnational and Subpopulation Estimates of Access to Healthy Food (No. 1476-2019-1856)* (Issue May).

Robinson-O’Brien, R., Story, M., & Heim, S. (2009). Impact of garden-based youth nutrition intervention programs: a review. *Journal of the American Dietetic Association*, *109*(2), 273–280. https://doi.org/10.1016/j.jada.2008.10.051

Rogers, C. M., & Hiner, C. C. (2016). Siting Urban Agriculture as a Green Infrastructure Strategy for Land Use Planning in Austin, TX. *Challenges in Sustainability, 4*(1). https://doi.org/10.12924/cis2016.04010039

Romero-Lankao, P., McPhearson, T., & Davidson, D. J. (2017). The food-energy-water nexus and urban complexity. *Nature Climate Change*, *7*(4), 233–235. https://doi.org/10.1038/nclimate3260

Rosan, C. D., & Pearsall, H. (2017). *Growing a sustainable city?: The question of urban agriculture*. University of Toronto Press.

Russo, A., Escobedo, F. J., Cirella, G. T., & Zerbe, S. (2017). Edible green infrastructure: An approach and review of provisioning ecosystem services and disservices in urban environments. *Agriculture, Ecosystems and Environment*, *242*(March), 53–66. https://doi.org/10.1016/j.agee.2017.03.026

Saaroni, H., Ben-Dor, E., Bitan, A., & Potchter, O. (2000). Spatial distribution and microscale characteristics of the urban heat island in Tel-Aviv, Israel. *Landscape and Urban Planning*, *48*(1–2), 1–18. https://doi.org/10.1016/S0169-2046(99)00075-4

Sadler, R. C. (2016). Integrating expert knowledge in a GIS to optimize siting decisions for small-scale healthy food retail interventions. *International Journal of Health Geographics*, *15*(1), 1–13. https://doi.org/10.1186/s12942-016-0048-6

Safransky, S. (2014). Greening the urban frontier: Race, property, and resettlement in Detroit. *Geoforum*, *56*, 237–248. https://doi.org/10.1016/j.geoforum.2014.06.003

Saha, M., & Eckelman, M. J. (2017). Growing fresh fruits and vegetables in an urban landscape: A geospatial assessment of ground level and rooftop urban agriculture potential in Boston, USA. *Landscape and Urban Planning*, *165*(August 2016), 130–141. https://doi.org/10.1016/j.landurbplan.2017.04.015

Sampson, R. J. (2017). Urban sustainability in an age of enduring inequalities: Advancing theory and ecometrics for the 21st-century city. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(34), 8957–8962. https://doi.org/10.1073/pnas.1614433114

Santamouris, M., Cartalis, C., Synnefa, A., & Kolokotsa, D. (2015). On the impact of urban heat island and global warming on the power demand and electricity consumption of buildings—A review. *Energy & Buildings*, *98*, 119–124. https://doi.org/10.1016/j.enbuild.2014.09.052

Sbicca, J. (2019). Urban Agriculture, Revalorization, and Green Gentrification in Denver, Colorado. In *The Politics of Land* (Vol. 24, pp. 149–170). https://doi.org/10.1108/S0895-993520190000026011

Schukoske, J. E. (2000). Community development through gardening: State and local policies transforming urban open space. *New York University Journal of Legislation and Public Policy*, *3*(2), 351–392. https://doi.org/10.2139/ssrn.1426079

Segal, L. M., Rayburn, J., & Beck, S. E. (2017). *The State of Obesity 2017*. https://stateofobesity.org/files/stateofobesity2017.pdf

Seto, K. C., Fragkias, M., Güneralp, B., & Reilly, M. K. (2011). A Meta-Analysis of Global Urban Land Expansion. *PLoS ONE*, *6*(8), e23777. https://doi.org/10.1371/journal.pone.0023777

Seto, K. C., Golden, J. S., Alberti, M., & Turner, B. L. (2017). Sustainability in an urbanizing planet. *Proceedings of the National Academy of Sciences*, *114*(34), 8935–8938. https://doi.org/10.1073/pnas.1606037114

Seto, K. C., Guneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences*, *109*(40), 16083–16088. https://doi.org/10.1073/pnas.1211658109

Shannon, J. (2014). Food deserts: Governing obesity in the neoliberal city. *Progress in Human Geography*, *38*(2), 248–266. https://doi.org/10.1177/0309132513484378

Shaw, H. J. (2006). Food deserts: towards the development of a classification. *Geografiska Annaler: Series B, Human Geography*, *88*(2), 231–247. https://doi.org/10.1111/j.0435-3684.2006.00217.x

Smith, J. P., Li, X., & Turner, B. L. (2017). Lots for greening: Identification of metropolitan vacant land and its potential use for cooling and agriculture in Phoenix, AZ, USA. *Applied Geography*, *85*, 139–151. https://doi.org/10.1016/j.apgeog.2017.06.005

Smith, J. P., Meerow, S., & Turner, B. L. (2021). Planning urban community gardens strategically through multicriteria decision analysis. *Urban Forestry & Urban Greening*, *58*, 126897. https://doi.org/10.1016/j.ufug.2020.126897

Sommers, B. D., Gawande, A. A., & Baicker, K. (2017). Health Insurance Coverage and Health — What the Recent Evidence Tells Us. *New England Journal of Medicine*, *377*(6), 586–593. https://doi.org/10.1056/NEJMsb1706645

South, E. C., Hohl, B. C., Kondo, M. C., MacDonald, J. M., & Branas, C. C. (2018). Effect of Greening Vacant Land on Mental Health of Community-Dwelling Adults. *JAMA Network Open*, *1*(3), e180298. https://doi.org/10.1001/jamanetworkopen.2018.0298

Spronken-Smith, R. A., & Oke, T. R. (1998). The thermal regime of urban parks in two cities with different summer climates. *International Journal of Remote Sensing*, *19*(11), 2085–2104. https://doi.org/10.1080/014311698214884

Staub, D., Colby, S. E., Olfert, M. D., Kattelmann, K., Zhou, W., Horacek, T. M., Greene, G. W., Radosavljevic, I., Franzen-Castle, L., & Mathews, A. E. (2019). A Multi-Year Examination of Gardening Experience and Fruit and Vegetable Intake During College. *Nutrients*, *11*(9), 2088. https://doi.org/10.3390/nu11092088

Stokes, E. C., & Seto, K. C. (2016). Climate change and urban land systems: bridging the gaps between urbanism and land science. *Journal of Land Use Science, 11*(6), 698–708. https://doi.org/10.1080/1747423X.2016.1241316

Stuhlmacher, M., Andrade, R., Turner, B. L., Frazier, A., & Li, W. (2020). Environmental Outcomes of Urban Land System Change: Comparing Riparian Design Approaches in the Phoenix Metropolitan Area. *Land Use Policy*, *99*(July 2019), 104615. https://doi.org/10.1016/j.landusepol.2020.104615

Taylor, J. R., & Lovell, S. T. (2012). Mapping public and private spaces of urban agriculture in Chicago through the analysis of high-resolution aerial images in Google Earth. *Landscape and Urban Planning*, *108*(1), 57–70. https://doi.org/10.1016/j.landurbplan.2012.08.001

Thomas, B. J. (2010). Food deserts and the sociology of space: Distance to food retailers and food insecurity in an Urban American neighborhood. *World Academy of Science, Engineering and Technology*, *67*(7), 19–28.

Tong, D., Crosson, C., Zhong, Q., & Zhang, Y. (2020). Optimize urban food production to address food deserts in regions with restricted water access. *Landscape and Urban Planning*, *202*(June), 103859. https://doi.org/10.1016/j.landurbplan.2020.103859

Tong, D., & Murray, A. T. (2012). Spatial Optimization in Geography. *Annals of the Association of American Geographers*, *102*(6), 1290–1309. https://doi.org/10.1080/00045608.2012.685044

Tong, D., Ren, F., & Mack, J. (2012). Locating farmers' markets with an incorporation of spatio-temporal variation. *Socio-Economic Planning Sciences*, *46*(2), 149–156. https://doi.org/10.1016/j.seps.2011.07.002

Tresch, S., Moretti, M., Le Bayon, R. C., Mäder, P., Zanetta, A., Frey, D., & Fliessbach, A. (2018). A gardener's influence on urban soil quality. *Frontiers in Environmental Science*, *6*(MAY). https://doi.org/10.3389/fenvs.2018.00025

Trust for Public Land. (2020). *The Heat Is On: A Trust for Public Land Special Report*. https://www.tpl.org/the-heat-is-on

Turner, B. (2011). Embodied connections: Sustainability, food systems and community gardens. *Local Environment*, *16*(6), 509–522. https://doi.org/10.1080/13549839.2011.569537

Turner, B. L. (2014). Land System Science: Land Systems, Sustainability and Land System Architecture. In *2014 Global Land Project Open Science Meeting*. https://www.youtube.com/watch?v=v5dd3BJHHDk

Turner, B. L. (2016). Land system architecture for urban sustainability: new directions for land system science illustrated by application to the urban heat island problem. *Journal of Land Use Science*, *11*(6), 689–697. https://doi.org/10.1080/1747423X.2016.1241315

Turner, B. L., Lambin, E. F., & Reenberg, A. (2007). The emergence of land change science for global environmental change and sustainability. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(52), 20666–20671. https://doi.org/10.1073/pnas.0704119104

Turner, B. L., Lambin, E., & Verburg, P. H. (2021). From Land-Use/Land-Cover to Land System Science. *Ambio, (forthcoming)*.

Turner, B. L., Meyfroidt, P., Kuemmerle, T., Müller, D., & Roy Chowdhury, R. (2020). Framing the search for a theory of land use. *Journal of Land Use Science*, *15*(4), 489–508. https://doi.org/10.1080/1747423X.2020.1811792

Twiss, J., Dickinson, J., Duma, S., Kleinman, T., Paulsen, H., & Rilveria, L. (2003). Community Gardens: Lessons Learned from California Healthy Cities and Communities. *American Journal of Public Health*, *93*(9), 1435–1438. https://doi.org/10.2105/AJPH.93.9.1435

U.S. Census Bureau. (2019). *2013-2017 American Community Survey 5-Year Estimates*. http://factfinder.census.gov

Uludere Aragon, N., Stuhlmacher, M., Smith, J. P., Clinton, N., & Georgescu, M. (2019). Urban agriculture's bounty: contributions to Phoenix's sustainability goals. *Environmental Research Letters*, *14*(10), 105001. https://doi.org/10.1088/1748-9326/ab428f

United Nations Population Division. (2018). *World Urbanization Prospects: 2018 Revision*.

USDA (U.S. Department of Agriculture). (2016). *Urban Agriculture Tool Kit*. https://www.nal.usda.gov/afsic/urban-agriculture

USDA (U.S. Department of Agriculture). (2017a). *Food Access Research Atlas Documentation*. https://www.ers.usda.gov/data-products/food-access-research-atlas/documentation/#changes

USDA (U.S. Department of Agriculture). (2017b). *Urban Agriculture*. https://www.nal.usda.gov/afsic/urban-agriculture

USDA (US Department of Agriculture). (2017a). *1-m NAIP Imagery*. https://gis.apfo.usda.gov/arcgis/rest/services/NAIP

USDA (US Department of Agriculture). (2017b). *2015 USDA Food Access Research Atlas*. https://www.ers.usda.gov/data-products/food-access-research-atlas/download-the-data/

USGS (US Geological Survey). (2019). *LANDSAT 8 Provisional Land Surface Temperature Map*. https://earthexplorer.usgs.gov

Uy, P. D., & Nakagoshi, N. (2008). Application of land suitability analysis and landscape ecology to urban greenspace planning in Hanoi, Vietnam. *Urban Forestry and Urban Greening*, *7*(1), 25–40. https://doi.org/10.1016/j.ufug.2007.09.002

Valley Metro. (2019a). *Valley Metro Bus Stops*. http://geocenter-valleymetro.opendata.arcgis.com

Valley Metro. (2019b). *Valley Metro Light Rail Stations*. http://geocenter-valleymetro.opendata.arcgis.com

Ver Ploeg, M., Breneman, V., Dutko, P., Williams, R., Snyder, S., Dicken, C., & Kaufman, P. (2012). Access to Affordable and Nutritious Food: Updated Estimates of Distance to Supermarkets Using 2010 Data. *USDA Economic Research Service - ERR143*. http://www.ers.usda.gov/publications/err-economic-research-report/err143.aspx#.Ut7xXZGtu-k

Voicu, I., & Been, V. (2008). The Effect of Community Gardens on Neighboring Property Values. *Real Estate Economics*, *36*(2), 241–283. https://doi.org/10.1111/j.1540-6229.2008.00213.x

Walker, R. E., Keane, C. R., & Burke, J. G. (2010). Disparities and access to healthy food in the United States: A review of food deserts literature. *Health & Place*, *16*(5), 876–884. https://doi.org/10.1016/j.healthplace.2010.04.013

Warming, M., Hansen, M. G., Holm, P. E., Magid, J., Hansen, T. H., & Trapp, S. (2015). Does intake of trace elements through urban gardening in Copenhagen pose a risk to human health? *Environmental Pollution*, *202*, 17–23. https://doi.org/10.1016/j.envpol.2015.03.011

Wei, R., Liu, X., Mu, Y., Wang, L., Golub, A., & Farber, S. (2017). Evaluating public transit services for operational efficiency and access equity. *Journal of Transport Geography*, *65*(October), 70–79. https://doi.org/10.1016/j.jtrangeo.2017.10.010

Wentz, E. A., Rode, S., Li, X., Tellman, E. M., & Turner, B. L. (2016). Impact of Homeowner Association (HOA) landscaping guidelines on residential water use. *Water Resources Research*, *52*(5), 3373–3386.

https://doi.org/10.1002/2015WR018238

Wesener, A., Fox-Kämper, R., Sondermann, M., & Münderlein, D. (2020). Placemaking in Action: Factors That Support or Obstruct the Development of Urban Community Gardens. *Sustainability*, *12*(2), 657. https://doi.org/10.3390/su12020657

Wolch, J., Byrne, J., & Newell, J. P. (2014). Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough.' *Landscape and Urban Planning*, *125*, 234–244. https://doi.org/10.1016/j.landurbplan.2014.01.017

Wright, M., Watkins, L., Hondula, D., Kurtz, L., Chakalian, P., Harlan, S., & Declet-Barreto, J. (2019). Social and Heat Vulnerability Indices in Phoenix, Arizona. *Environmental Data Initiative*. https://doi.org/https://doi.org/10.6073/pasta/177f6b35d9c7607a31c03c02d0e569a7

Wrigley, N., Warm, D., & Margetts, B. (2003). Deprivation, Diet, and Food-Retail Access: Findings from the Leeds 'Food Deserts'' Study.' *Environment and Planning A*, *35*(1), 151–188. https://doi.org/10.1068/a35150

Wu, J. (2010). Urban sustainability: An inevitable goal of landscape research. *Landscape Ecology*, *25*(1), 1–4. https://doi.org/10.1007/s10980-009-9444-7

Wu, J. (2013). Landscape sustainability science: Ecosystem services and human well-being in changing landscapes. *Landscape Ecology*, *28*(6), 999–1023. https://doi.org/10.1007/s10980-013-9894-9

Yang, Y., & Diez-Roux, A. V. (2012). Walking distance by trip purpose and population subgroups. *American Journal of Preventive Medicine*, *43*(1), 11–19. https://doi.org/10.1016/j.amepre.2012.03.015

Zhang, Y., Murray, A. T., & Turner, B. L. L. (2017). Optimizing green space locations to reduce daytime and nighttime urban heat island effects in Phoenix, Arizona. *Landscape and Urban Planning*, *165*, 162–171. https://doi.org/10.1016/j.landurbplan.2017.04.009

Zhou, W., Huang, G., & Cadenasso, M. L. (2011). Does spatial configuration matter? Understanding the effects of land cover pattern on land surface temperature in urban landscapes. *Landscape and Urban Planning*, *102*(1), 54–63. https://doi.org/10.1016/j.landurbplan.2011.03.009

Zhuo, X., Boone, C. G., & Shock, E. L. (2012). Soil lead distribution and environmental justice in the phoenix metropolitan region. *Environmental Justice*, *5*(4), 206–213. https://doi.org/10.1089/env.2011.0041

APPENDIX A

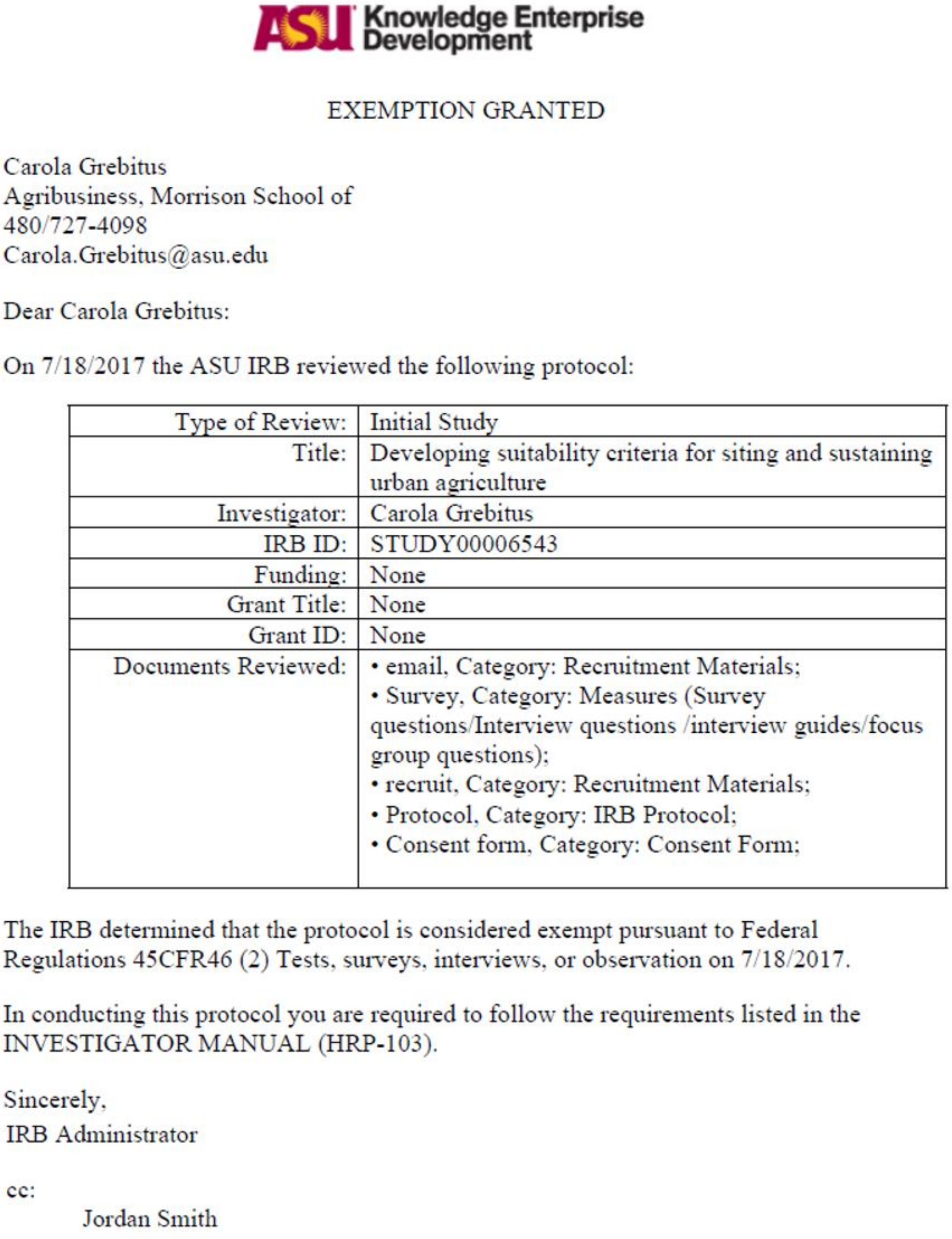
PERMISSIONS FROM CO-AUTHORS

All co-authors have consented to the use of the three papers for the dissertation. The names of the co-authors corresponding to each chapter are listed below.

- CHAPTER 2: Xiaoxiao Li, B.L. Turner II
- CHAPTER 3: Sara Meerow, B.L. Turner II
- CHAPTER 4: Yujia Zhang, Daoqin Tong, B.L. Turner II

APPENDIX B

INSTITUTIONAL REVIEW BOARD APPROVAL



ASU Knowledge Enterprise Development

EXEMPTION GRANTED

Carola Grebitus
Agribusiness, Morrison School of
480/727-4098
Carola.Grebitus@asu.edu

Dear Carola Grebitus:

On 7/18/2017 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Developing suitability criteria for siting and sustaining urban agriculture
Investigator:	Carola Grebitus
IRB ID:	STUDY00006543
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• email, Category: Recruitment Materials; • Survey, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • recruit, Category: Recruitment Materials; • Protocol, Category: IRB Protocol; • Consent form, Category: Consent Form;

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (2) Tests, surveys, interviews, or observation on 7/18/2017.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,
IRB Administrator

cc:
Jordan Smith

APPENDIX C

CHAPTER 3: SUPPLEMENTAL MATERIAL

C.1 Stakeholder Information

C.1.1 Additional Stakeholder Information

The community garden siting criteria survey was developed over the summer of 2017 in consultation with eight experts associated with the City of Phoenix, local community gardening organizations, local nonprofit groups, and Arizona State University. The prime objective of the survey was to ascertain stakeholder priorities concerning a diversity of siting criteria through both ranking and rating exercises. Participants were first asked to rate criteria for a given category (i.e., Social Characteristics or Physical Setting) on a five-point scale with 5 being most important and 1 being least important. Respondents then ranked those same criteria in order of importance. After this was done for both categories, stakeholders were then asked to rank the totality of criteria comprehensively (i.e. the Comprehensive category). Because of the number of criteria, and concerns related to survey duration, the decision was made to not include a pair-wise comparison to the survey.[17]

The survey was administered via the Qualtrics online survey platform and was open from August 17, 2017, to September 15, 2017, and was distributed via snowball sampling. Instructions and a link to the survey were emailed to multiple local community garden organizers/non-profit representatives to share among their membership and to the Arizona State University Sustainable Cities Network listserv. Participants self-reported their expertise as it relates to urban community gardening (Table B1.), and zip codes were used to ensure that participants were local to the greater Phoenix metro-area. Of the 62 respondents, only 37 completed the survey in its entirety. The responses from those 37 stakeholders were the basis of the criteria weights used in the indices.

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[17] The inclusion of an addition pair-wise comparison analysis would have resulted in 196 comparisons for participants to evaluate, in addition to the criteria ranking and rating exercises and additional socio-demographic questions at the end of the survey. While the simpler rating method is potentially less precise than pairwise comparisons, there is evidence that the results of the two methods are often correlated (Eilertsen et al., 2016; Kuang et al., 2007; Meerow & Newell, 2017). Criteria ratings were kept in the survey for comparison against the ranking results. Bivariate Pearson Correlations between the rating and raking values for the Social Characteristics and Physical Setting categories are 0.949 and 0.990, respectively ($p \leq 0.01$), suggesting that the two are highly comparable.

Table C1. Survey Respondents

Question	Respondents	Percentage
How would you describe your area of expertise as it relates to urban gardens, urban agriculture, etc. (Pick which applies best.)		
Policy/Planning/Government	16	43.24%
Community Leader	2	5.41%
Academic	1	2.70%
Non-Profit/Non-Governmental Org	5	13.51%
Experienced Volunteer or Gardener	11	29.73%
Other	2	5.41%
How many years of experience do you have in the area of urban gardens or urban agriculture?		
Under 1	3	8.11%
1-2	6	16.22%
3-4	3	8.11%
5-6	8	21.62%
7-8	4	10.81%
9-10	5	13.51%
11 or more	8	21.62%
In addition to being an expert, do you and/or anyone in your household actively participate in an urban garden?		
Yes	11	29.73%
No	16	43.24%
Used to but no longer	10	27.03%
What is your employment status?		
Employed full time	29	78.38%
Employed part time	3	8.11%
Unemployed looking for work	0	0.00%
Unemployed not looking for work	0	0.00%
Retired	5	13.51%
Student	0	0.00%
Disabled	0	0.00%
What is your approximate household income? *		
Less than $10,000	0	0.00%

$10,000 - $29,999	1	2.86%
$30,000 - $49,999	5	14.29%
$50,000 - $69,999	6	17.14%
$70,000 - $89,999	6	17.14%
$90,000 - $109,999	4	11.43%
$110,000 - $129,999	3	8.57%
$130,000 - $149,999	1	2.86%
More than $150,000	8	22.86%
What is your highest level of education?		
Less than high school	0	0.00%
High school graduate	1	2.70%
Some college	6	16.22%
2-year degree	2	5.41%
4-year degree	11	29.73%
Graduate/Professional degree	15	40.54%
What is your gender?		
Male	18	48.65%
Female	19	51.35%
Other	0	0.00%
How old are you?		
18 - 24	0	0.00%
25 - 34	3	8.11%
35 - 44	7	18.92%
45 - 54	12	32.43%
55 - 64	9	24.32%
65 - 74	5	13.51%
75 and Older	1	2.70%

n = 37

**Income (n = 34)*

C.1.2 Stakeholder Survey

Community Garden Suitability Criteria Survey

Hello!

Researchers from Arizona State University are seeking individuals to volunteer for a short, anonymous online survey to help evaluate the importance of various criteria when considering potential community garden locations. The results of this survey will then be incorporated in a dissertation study that aims to create a rating scale to help better evaluate the suitability of potential locations for future community garden projects.

You must be 18 years or older to participate.
To access the study please click on the link below.

https://tinyurl.com/ASUcommunitygardensurvey

The survey is open until September 15, 2017, and should take about 15 to 20 minutes (or less) to complete. It is compatible with most mobile devices, though, it is recommended that the survey is taken on a computer.

Thank you very much,

Jordan P. Smith
Dr. Carola Grebitus
Arizona State University

Community Garden Suitability Criteria Survey

Information and Consent Sheet for Survey Participants

This study is being conducted by researchers from Arizona State University. The purpose is to identify criteria that are important to determining where to develop community gardens.

The following survey is expected to take about 15 to 20 minutes or less, and your answers will be confidential and will be only released in an aggregated format. Your name will not be collected, and your responses will be treated confidentially. You are free to withdraw from the survey at any time or leave any questions unanswered. Participation in the survey will imply consent for us to use these data in our research. These data will be used for statistical purposes only. Statistical results will be reported in research papers and a Ph.D. dissertation. In the future, the results may be used for subsequent research on urban agriculture development. There are no anticipated risks to participating in this study. You must be 18 or older to participate.

If you have any questions, comments, or suggestions about the survey or the study, please feel free to contact the investigators Jordan P. Smith (jordan.p.smith@asu.edu) and Carola Grebitus (carola.grebitus@asu.edu). If you have any questions about your rights as a participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788.

Introduction

Urban agriculture encompasses a wide array of forms. For the purposes this study, urban agriculture has been restricted to more conventional types of community garden projects. While frequently cited as a means of utilizing vacant land, not all locations are ideally suitable for community gardens, in part due to specific site conditions or location setting. Special consideration must then be given to which criteria are most important. Evaluating all these criteria in conjunction with one another can prove to be difficult, though.

You have been selected for this survey because of your knowledge of some aspects of community gardens. Your input is important in the determination of criteria essential to consider in the planning, implementing, and sustaining such projects. Few academic studies have attempted to use such criteria as a means of assessing the suitability in a quantitative sense. With your help, various criteria can be ranked, rated, and ultimately translated into variables for later use in a model to better evaluate community garden suitability.

It should be noted that the model produced through this study is ultimately not meant to replace community engagement or necessary environmental due-diligence and soil analysis. It will instead serve as a decision-making support tool which grants the user the ability to assess available sites and how they compare to one another in terms of suitability.

Study Assumptions

While community gardens can be developed in a number of different locations, this study assumes development on vacant lots/parcels with appropriate bare soil, scrub, or grass groundcover as well as roadway access. Mandatory criteria have also been taken into account: water access is assumed to be present at a given location, and the vacant parcel is not a current/former source of contamination (e.g., leaking gas station, dry cleaner) and is not within immediate proximity to any such location.

Q3

Community gardens have been shown to provide many benefits for the areas in which they are located. In the following two questions rate and rank potential community garden benefits.

Q4

How important are the following community gardening benefits?

Community gardens:

	Extremely important	Very important	Moderately important	Slightly important	Not at all important
provide a source of fresh, local produce for the community which can have nutritional benefits	○	○	○	○	○
provide additional greenspace/ community space	○	○	○	○	○
provide green cover that cools community and reduces Urban Heat Island Effect [extreme/lasting temperatures in highly developed/paved areas that can be lowered through vegetative coverage].	○	○	○	○	○
aid in the attenuation of stormwater by providing permeable groundcover	○	○	○	○	○

	Extremely important	Very important	Moderately important	Slightly important	Not at all important
can improve local air quality	○	○	○	○	○
provide opportunities for improving mental/physical health through gardening activities	○	○	○	○	○
can allow for the creation of farmer's markets/produce stands which can serve as an economic opportunity	○	○	○	○	○
provide educational opportunities for the community	○	○	○	○	○

Q5
Drag and drop the eight community gardening benefits in order of importance from 1 (most important) to 8 (least important).

1. Fresh, local produce for the community
2. Additional greenspace/community space
3. Green cover that cools community and reduces Urban Heat Island Effect
4. The attenuation of stormwater by providing permeable groundcover
5. Local air quality improvement
6. Improving mental/physical health through gardening
7. Economic opportunity through farmer's markets/produce stands
8. Educational opportunities

Q6
The next several questions consist of rating and ranking the selected potential suitability criteria. The criteria are broken into two general categories: Social Setting and Physical Setting. Again, it is assumed that all candidate sites are *existing* vacant parcels that have water and roadway access and are not located on or in the immediate vicinity of known environmental hazards.

Q7
How important are the following Social Setting criteria when planning, implementing, and sustaining community gardens?
Community gardens should be sited in/near:

	Extremely important	Very important	Moderately important	Slightly important	Not at all important
Low socioeconomic communities (Household income less than or equal to the poverty level-	○	○	○	○	○

	Extremely important	Very important	Moderately important	Slightly important	Not at all important
$24,600 for a family of four)					
Communities with high or majority ethnic/racial minority populations	○	○	○	○	○
Communities with populations susceptible to extreme temperatures	○	○	○	○	○
Communities with high incidences of chronic diseases (e.g., obesity, hypertension, type 2 diabetes)	○	○	○	○	○
Communities with limited green spaces (e.g., parks, soccer fields)	○	○	○	○	○
Food deserts (i.e., long distances to major grocery stores)	○	○	○	○	○
Public spaces such as municipal parks or schools	○	○	○	○	○

Q8

Drag and drop the seven Social Setting criteria in order of importance from 1 (most important) to 7 (least important).

1. Low socioeconomic communities (Household income less than or equal to the poverty level)
2. Communities with high or majority ethnic/racial minority populations
3. Communities with populations susceptible to extreme temperatures
4. Communities with high incidences of chronic diseases (e.g., obesity...)
5. Communities with limited green spaces (e.g., parks, soccer fields)
6. Food deserts
7. Public spaces such as municipal parks or schools

Q9

How important are the following Physical Setting criteria when planning, implementing, and sustaining community gardens? Community gardens should be sited in/near:

	Extremely important	Very important	Moderately important	Slightly important	Not at all important
Densely populated areas	○	○	○	○	○
Residential neighborhoods near where people live	○	○	○	○	○
Centralized commercial areas where lots of people visit and work	○	○	○	○	○
Areas that are more prone to stormwater runoff	○	○	○	○	○
Areas that experience extreme temperatures due to the Urban Heat Island effect	○	○	○	○	○
Bikeable areas	○	○	○	○	○
Locations near public transportation stops/stations, including bus and light rail	○	○	○	○	○
Vacant parcels with bare groundcover	○	○	○	○	○
Vacant parcels with scrub/shrub vegetated groundcover	○	○	○	○	○
Vacant parcels with mesic groundcover. (In the context of Phoenix, AZ, mesic vegetation includes green grass and trees, often not indigenous to the desert.)	○	○	○	○	○

Q10
Drag and drop the ten Physical Setting criteria in order of importance from 1 (most important) to 10 (least important).

1. Densely populated areas
2. Residential neighborhoods near where people live
3. Centralized commercial areas where lots of people visit and work
4. Areas that are more prone to stormwater runoff
5. Areas that experience extreme temperatures due to the Urban Heat Island effect
6. Bikeable areas
7. Locations near public transportation stops/stations, including bus and light rail
8. Vacant parcels with bare groundcover
9. Vacant parcels with scrub/shrub vegetated groundcover
10. Vacant parcels with mesic groundcover

Q11
Drag and drop *all* of the Social and Physical criteria presented in this survey in order of importance from 1 (most important) to 17 (least important).

1. Low income communities
2. High or majority ethnic/racial minority populated communities
3. Populations susceptible to extreme temperatures
4. Communities with high incidences of chronic diseases
5. Areas with limited green spaces
6. Food deserts
7. Near public spaces such as municipal parks or schools
8. Densely populated areas
9. Residential neighborhoods
10. Centralized commercial areas
11. Areas that are more prone to stormwater runoff
12. Strong Urban Heat Island areas
13. Bikeable areas
14. Locations near public transportation stops/stations
15. Vacant parcels with bare groundcover
16. Vacant parcels with scrub/shrub vegetated groundcover
17. Vacant parcels with mesic groundcover.

Q12
How important do you think it is that members of a community want a proposed community garden developed in their area?

Extremely important	Very important	Moderately important	Slightly important	Not at all important

Q13
When should a community be approached during the garden development process?

- At the beginning, before any potential sites in their area have been identified.
- After potential sites have been identified in the area but have not yet been evaluated.
- After potential sites in the area have been identified and evaluated for suitability.

Q14
Do you think that community interest/willingness should ultimately determine whether a community garden is developed or not?

Yes No I don't know

Q15
Please take a moment to complete the following demographic and background questions for statistical purposes.

Q16
How many years of experience do you have in the area of community gardens or urban agriculture?

Under 1 1-2 3-4 5-6 7-8 9-10 11 or more

Q17
How would you describe your area of expertise as it relates to community gardens, urban agriculture, etc. (Pick which applies best.)

- Policy/Planning/Government
- Community Leader
- Academic
- Non-Profit/Non-Governmental Org
- Experienced Volunteer or Gardener
- Other

Q18
In addition to being an expert, do you and/or anyone in your household actively participate in a community garden?

Yes No Used to but no longer

Q19
Using the slider, approximately how many miles must you/your household member travel to visit the community garden?

Distance (Miles) 00.5 1 1.5 2 2.5 3 3.5 4 4.5 5 > 5 miles

Q20
What mode of transportation do you/your household member use to travel to the community garden? (Select all that apply)

Household Automobile
Rideshare Service or Taxi
Bicycle
Mass Transit or Community Shuttle
Walking or Mobility Aid (e.g., wheelchair, scooter)
A friend/neighbor/non-household relation provides transportation

Q21
Did you provide initial input into construction of this survey?

Yes
No
Maybe/I do not remember

Q22
What is your employment status?

Employed full time
Employed part time
Unemployed looking for work
Unemployed not looking for work
Retired
Student
Disabled

Q23
What is your approximate household income?

Less than $10,000
$10,000 - $29,999
$30,000 - $49,999
$50,000 - $69,999
$70,000 - $89,999
$90,000 - $109,999
$110,000 - $129,999
$130,000 - $149,999
More than $150,000

Q24
What is your highest level of education?

Less than high school
High school graduate
Some college
2-year degree
4-year degree
Graduate/Professional degree
Doctorate

Q25
What is your gender?

Male
Female
Other

Q26
What is your age?
18 - 24 25 - 34 35 - 44 45 - 54 55 - 64 65 - 74 75 or Older

Q27
Please enter your five digit zip code.

Q28
Do you have any comments?

Table C.1.3 Stakeholder Survey Results (By Respondent)

	Community Garden Benefits- Likert Rating (Scale: 1 - 5)							
	Q4_FRESH_VEG	Q4_GREENSPACE	Q4_UHI	Q4_SW	Q4_AIRQ	Q4_HEALTH	Q4_MARKET	Q4_EDU
Participant	CG_BENE - provide a source of fresh produce for the community	CG_BENE - provide additional greenspace/community space	CG_BENE - Urban Heat Island Effect Cooling.	CG_BENE - Stormwater	CG_BENE - can improve local air quality	CG_BENE - mental/physical health improvement	CG_BENE - farmer's markets as an economic opportunity	CG_BENE - educational opportunities
1	3	5	5	4	3	4	5	5
2	4	4	4	3	4	4	3	4
3	5	5	5	4	4	4	5	4
4	5	5	4	4	4	5	5	5
5	3	1	2	1	2	2	5	4
6	4	3	4	3	3	4	4	4
7	4	2	2	4	4	5	4	4
8	4	5	5	2	3	3	4	4
9	5	4	4	3	5	5	4	4
10	3	4	2	2	2	5	3	3
11	2	2	2	1	2	3	1	3
12	4	4	3	2	2	4	4	3
13	5	5	5	5	5	5	5	5
14	5	5	5	5	5	4	4	5
15	5	4	4	3	4	5	3	5
16	5	5	5	5	5	4	4	4
17	2	5	5	5	3	5	2	4
18	4	5	4	3	3	5	3	5
19	5	4	3	2	2	3	4	5
20	5	4	5	5	5	4	5	4
21	4	4	4	4	3	4	3	4
22	4	4	3	2	3	3	3	4
23	5	5	5	5	5	5	5	5
24	5	5	5	5	5	5	5	5
25	3	4	4	3	3	3	4	4
26	5	5	5	2	5	5	5	5
27	4	3	2	2	2	5	4	5
28	5	4	5	4	4	5	4	5
29	4	5	4	3	4	5	3	5
30	4	4	3	3	4	5	3	5
31	5	5	4	4	5	5	4	5
32	4	5	5	4	5	5	4	4
33	4	2	4	4	4	4	3	2
34	4	4	4	3	4	5	4	4
35	4	5	5	4	4	5	2	4
36	5	4	5	4	4	4	5	4
37	4	3	2	4	2	2	3	3
Rating Averages	🟢 **4.189**	🟢 **4.108**	🟡 **3.973**	🔴 **3.405**	🔴 **3.676**	🟢 **4.270**	🟡 **3.811**	🟢 **4.243**
Rank								

Note: Ratings are on Likert scale 5= most important. 1 = least important; Dots represent higher to lower ratings related to the group of questions
Q19_1 and Q20 had very low response rates. Perhaps the slider was too difficult to use

n = 37 Participants who filled out all of the Ranking and Rating Sections. Raw data n = 62

	arden Benefits Ranking (1 - 8)						
	Q5_2	**Q5_3**	**Q5_4**	**Q5_5**	**Q5_6**	**Q5_7**	**Q5_8**
Participant	CG_BENE_RANK - Additional greenspace/community space	CG_BENE_RANK - Green cover that cools community and reduces Urban Heat Island	CG_BENE_RANK - The attenuation of stormwater by providing permeable groundcover	CG_BENE_RANK - Local air quality improvement	CG_BENE_RANK - Improving mental/physical health through gardening	CG_BENE_RANK - Economic opportunity through farmer's markets/produce stands	CG_BENE_RANK - Educational opportunities
1	1	4	7	8	2	5	3
2	7	3	6	8	2	5	4
3	4	2	5	7	6	3	8
4	5	7	8	6	2	4	3
5	2	5	8	7	3	1	4
6	4	6	8	7	2	5	1
7	5	8	7	6	1	4	3
8	2	1	7	8	6	3	5
9	4	5	7	3	1	8	6
10	2	4	5	6	1	8	3
11	3	4	6	7	5	8	2
12	6	5	8	7	4	3	1
13	3	8	6	7	4	5	2
14	3	2	4	7	8	6	5
15	4	5	7	6	2	8	3
16	5	2	4	8	6	3	7
17	1	3	2	6	5	7	4
18	2	3	8	7	1	6	4
19	4	5	8	7	6	1	3
20	8	1	3	2	7	6	5
21	2	6	4	8	3	7	5
22	3	5	7	8	4	6	1
23	1	6	4	5	7	8	2
24	1	3	7	8	4	5	6
25	5	1	3	6	4	7	2
26	2	3	8	5	1	6	7
27	5	6	8	7	2	3	1
28	5	4	6	7	3	8	1
29	4	5	8	6	2	7	1
30	2	5	8	7	1	6	3
31	4	3	8	6	2	5	7
32	1	8	7	6	2	5	3
33	7	4	6	3	2	5	8
34	4	8	7	6	1	3	5
35	2	1	4	7	6	8	3
36	3	2	6	5	4	8	7
37	2	8	3	6	7	5	4
Rating Averages							
Rank	**2**	**5**	**7**	**8**	**3**	**6**	**4**

	Community Garden Social Criteria - Likert Rating (Scale: 1 - 5)						
	Q7_LOW_SES	Q7_RACE_MINOR	Q7_HTEMP_COMM	Q7_SICK_COMM	Q7_NO_GREEN	Q7_FD_DESERT	Q7_NEAR_PUBSP
Participant	SOC_CRIT - Low socioeconomic communities (Household income less than or equal to	SOC_CRIT - Communities with high or majority ethnic/racial minority populations	SOC_CRIT - Communities with populations susceptible to extreme temperatures	SOC_CRIT - Communities with high incidences of chronic diseases (e.g., obesity, hypertension, type 2 diabetes)	SOC_CRIT - Communities with limited green spaces (e.g., parks, soccer fields)	SOC_CRIT - Food deserts (i.e., long distances to major grocery stores)	SOC_CRIT - Public spaces such as municipal parks or schools
1	2	2	3	3	4	3	4
2	5	3	3	5	4	5	3
3	5	5	5	5	5	5	4
4	5	3	4	5	5	5	4
5	4	4	1	2	2	5	2
6	3	3	2	4	2	5	5
7	4	4	1	4	4	4	4
8	4	2	1	4	5	5	5
9	5	4	4	5	4	5	3
10	2	2	2	2	4	1	4
11	1	1	1	1	1	1	2
12	3	2	2	2	3	3	4
13	3	3	3	3	3	3	3
14	5	5	4	5	4	4	3
15	4	3	1	1	4	4	3
16	4	5	5	5	4	5	5
17	1	1	3	3	5	5	5
18	3	3	4	5	4	4	4
19	5	3	3	5	3	5	5
20	5	5	5	5	4	5	4
21	4	4	3	5	4	5	4
22	4	4	4	4	4	3	2
23	5	3	5	5	5	5	5
24	5	4	4	4	5	5	5
25	4	3	3	4	3	3	3
26	1	1	4	4	4	4	4
27	4	3	1	3	4	3	3
28	5	3	4	5	4	5	4
29	3	3	3	3	4	2	3
30	5	4	4	5	5	5	4
31	5	3	4	4	4	5	4
32	5	5	5	5	5	5	5
33	5	3	3	5	3	5	3
34	5	4	4	4	4	5	4
35	5	4	5	5	5	4	5
36	3	3	5	4	5	4	4
37	3	3	2	3	3	2	4
Rating Averages	🟢 3.892	🔴 3.243	🔴 3.243	🟢 3.946	🟢 3.919	🟢 4.108	🟢 3.838
Rank							

Participant	Community Garden Social Criteria - Ranking (1 -7)						
	Q8_1	**Q8_2**	**Q8_3**	**Q8_4**	**Q8_5**	**Q8_6**	**Q8_7**
	SOC_CRIT_RANK - Low socioeconomic communities (Household income less than or equal	SOC_CRIT_RANK - Communities with high or majority ethnic/racial minority	SOC_CRIT_RANK - Communities with populations susceptible to extreme	SOC_CRIT_RANK - Communities with high incidences of chronic diseases (e.g.,	SOC_CRIT_RANK - Communities with limited green spaces (e.g., parks, soccer fields)	SOC_CRIT_RANK - Food deserts	SOC_CRIT_RANK - Public spaces such as municipal parks or schools
1	4	6	3	5	1	7	2
2	3	7	4	2	5	1	6
3	2	4	6	3	5	1	7
4	3	7	6	2	5	1	4
5	2	5	7	3	4	1	6
6	3	4	7	2	6	1	5
7	2	4	7	1	6	3	5
8	3	6	7	4	5	1	2
9	1	2	6	3	5	4	7
10	3	5	4	6	1	7	2
11	6	2	5	3	4	7	1
12	5	7	6	4	1	2	3
13	5	6	4	7	3	1	2
14	3	2	5	4	6	1	7
15	4	5	7	6	2	1	3
16	7	4	3	1	6	2	5
17	6	7	4	5	2	3	1
18	5	6	2	1	4	3	7
19	1	3	7	2	6	4	5
20	2	6	1	4	7	3	5
21	2	1	7	4	6	3	5
22	2	5	6	4	1	3	7
23	3	7	6	5	2	4	1
24	3	7	6	2	4	1	5
25	3	2	4	1	6	7	5
26	7	6	4	1	2	3	5
27	1	2	7	6	4	5	3
28	2	7	5	3	4	1	6
29	4	5	7	3	1	6	2
30	2	6	7	3	5	1	4
31	7	5	6	4	2	1	3
32	3	5	7	6	2	4	1
33	2	4	7	3	5	1	6
34	4	3	7	2	5	1	6
35	5	4	6	3	2	7	1
36	5	7	3	6	2	1	4
37	3	6	5	2	4	7	1
Rating Averages							
Rank	**3**	**6**	**7**	**2**	**4**	**1**	**5**

Participant	Community Garden Physical Environment Criteria - Likert Rating (Scale: 1 - 5)									
	Q9_DENSE_PO PHYS_CRIT - Densely populated areas	Q9_NEAR_RESI PHYS_CRIT - Residential neighborhoods near where people live	Q9_NEAR_BUSI PHYS_CRIT - Centralized commercial areas where lots of people visit and work	Q9_SW_PRONE PHYS_CRIT - Areas that are more prone to stormwater runoff	Q9_UHI_PRONE PHYS_CRIT - Areas that experience extreme temperatures due to the Urban Heat Island effect	Q9_BIKEABLE PHYS_CRIT - Bikeable areas	Q9_MASS_TRANS PHYS_CRIT - Locations near public transportation stops/stations, including bus and light rail	Q9_VAC_BAR PHYS_CRIT - Vacant parcels with bare groundcover	Q9_VAC_SCR PHYS_CRIT - Vacant parcels with scrub/shrub vegetated groundcover	Q9_VAC_MESIC PHYS_CRIT - Vacant parcels with mesic groundcover. (In the context of Phoenix, AZ, mesic vegetation includes green grass and
1	5	5	5	3	4	5	5	1	1	1
2	4	5	4	3	3	4	3	3	3	2
3	4	5	3	2	4	4	5	2	2	1
4	3	5	3	3	3	5	4	3	3	3
5	3	5	2	1	1	1	2	5	1	1
6	3	3	3	3	3	3	2	4	4	4
7	3	4	4	1	2	3	4	1	1	4
8	5	5	3	1	1	4	5	5	3	3
9	5	5	3	3	4	5	2	4	4	3
10	3	5	3	1	2	1	3	1	4	2
11	4	5	4	2	2	4	4	4	3	3
12	4	4	3	2	1	3	4	3	3	3
13	3	3	3	3	3	3	3	3	3	3
14	3	4	2	3	3	3	4	5	4	3
15	3	5	2	4	3	3	3	5	2	2
16	5	5	5	5	5	4	5	4	4	4
17	3	5	4	5	4	5	4	4	4	1
18	4	4	3	3	4	4	4	5	3	4
19	5	5	3	2	2	2	2	4	4	3
20	4	5	4	5	5	5	3	5	4	3
21	4	5	4	3	3	4	4	3	3	4
22	4	4	2	2	3	3	3	3	1	1
23	5	5	1	3	5	5	2	3	3	3
24	5	4	4	3	5	5	4	4	2	4
25	3	4	3	3	4	4	3	4	4	3
26	1	4	4	4	4	4	5	3	5	1
27	4	5	3	2	2	3	4	1	2	2
28	4	5	3	4	5	5	4	3	3	5
29	3	5	2	3	3	4	4	4	4	2
30	5	4	4	2	3	4	5	4	4	4
31	5	5	5	3	5	4	3	3	3	5
32	5	5	2	2	2	5	5	4	4	2
33	5	5	5	4	2	2	5	2	2	2
34	4	5	4	4	4	5	5	4	3	3
35	4	4	3	4	4	2	4	5	2	2
36	4	3	4	3	4	3	3	5	3	5
37	1	3	1	2	1	3	2	1	1	5
Rating Averages	● **3.838**	● **4.514**	● **3.243**	● **2.865**	● **3.189**	● **3.676**	● **3.676**	● **3.432**	● **2.946**	● **2.865**
Rank										

	Community Garden Physical Environment Criteria - Ranking (1 - 10)									
	Q10_1	**Q10_2**	**Q10_3**	**Q10_4**	**Q10_5**	**Q10_6**	**Q10_7**	**Q10_8**	**Q10_9**	**Q10_10**
Participant	PHYS_CRIT_RANK - Densely populated areas	PHYS_CRIT_RANK - Residential neighborhoods near where people live	PHYS_CRIT_RANK - Centralized commercial areas where lots of people visit and work	PHYS_CRIT_RANK - Areas that are more prone to stormwater runoff	PHYS_CRIT_RANK - Areas that experience extreme temperatures due to the Urban Heat Island effect	PHYS_CRIT_RANK - Bikeable areas	PHYS_CRIT_RANK - Locations near public transportation stops/stations, including bus and light rail	PHYS_CRIT_RANK - Vacant parcels with bare groundcover	PHYS_CRIT_RANK - Vacant parcels with scrub/shrub vegetated groundcover	PHYS_CRIT_RANK - Vacant parcels with mesic groundcover
1	1	3	2	7	6	4	5	9	8	10
2	9	4	3	8	10	1	6	7	2	5
3	6	2	7	9	4	3	1	8	5	10
4	8	1	9	10	7	3	2	4	5	6
5	5	1	7	10	4	6	8	9	2	3
6	7	9	6	5	10	8	4	1	2	3
7	2	1	3	4	7	6	5	8	9	10
8	4	1	6	9	10	5	2	3	7	8
9	2	1	10	8	7	4	9	3	5	6
10	2	1	8	9	7	10	3	6	4	5
11	3	4	6	9	2	8	7	1	5	10
12	3	5	9	10	6	7	8	4	1	2
13	9	1	4	2	8	3	10	7	6	5
14	3	8	10	1	9	5	7	2	4	6
15	6	1	4	3	5	7	8	2	9	10
16	3	7	2	6	1	5	4	8	10	9
17	6	1	5	3	10	2	4	7	9	8
18	4	7	3	8	1	6	5	2	10	9
19	1	2	5	10	8	3	6	4	7	9
20	9	6	8	2	1	4	5	3	7	10
21	2	1	4	9	10	6	5	7	8	3
22	2	1	4	7	8	3	5	6	9	10
23	2	1	10	3	4	8	9	6	7	5
24	4	3	9	8	7	2	5	1	10	6
25	2	4	9	8	10	1	6	7	3	5
26	7	1	6	3	4	2	5	9	8	10
27	1	3	4	8	7	5	2	10	9	6
28	7	1	10	6	5	3	4	9	8	2
29	4	2	8	10	7	5	6	3	1	9
30	5	4	3	10	9	2	1	8	7	6
31	6	1	10	5	7	8	4	9	2	3
32	3	1	8	10	9	4	7	2	5	6
33	1	3	2	5	6	10	4	7	9	8
34	8	3	6	5	2	4	7	1	10	9
35	2	4	8	5	6	7	3	1	9	10
36	6	9	4	8	3	7	5	2	10	1
37	5	2	6	4	10	1	3	9	7	8
Rating Averages										
Rank	**2**	**1**	**6**	**9**	**7**	**3**	**4**	**5**	**8**	**10**

	Community Garden All Criteria - Ranking (1 - 17)																
	Q11_1	Q11_2	Q11_3	Q11_4	Q11_5	Q11_6	Q11_7	Q11_8	Q11_9	Q11_10	Q11_11	Q11_12	Q11_13	Q11_14	Q11_15	Q11_16	Q11_17
Participant	ALL_CRIT_RANK - Low income communities	ALL_CRIT_RANK - High or majority ethnic/racial minority populated communities	ALL_CRIT_RANK - Populations susceptible to extreme temperatures	ALL_CRIT_RANK - Communities with high incidences of chronic diseases	ALL_CRIT_RANK - Areas with limited green spaces	ALL_CRIT_RANK - Food deserts	ALL_CRIT_RANK - Near public spaces such as municipal parks or schools	ALL_CRIT_RANK - Densely populated areas	ALL_CRIT_RANK - Residential neighborhoods	ALL_CRIT_RANK - Centralized commercial areas	ALL_CRIT_RANK - Areas that are more prone to stormwater runoff	ALL_CRIT_RANK - Strong Urban Heat Island areas	ALL_CRIT_RANK - Bikeable areas	ALL_CRIT_RANK - Locations near public transportation stops/stations	ALL_CRIT_RANK - Vacant parcels with bare groundcover	ALL_CRIT_RANK - Vacant parcels with scrub/shrub vegetated groundcover	ALL_CRIT_RANK - Vacant parcels with mesic groundcover.
1	11	14	8	10	6	12	7	1	2	3	13	9	5	4	15	17	16
2	3	14	17	2	8	1	9	5	16	15	10	12	6	4	13	7	11
3	2	5	3	4	13	1	12	8	9	11	14	10	7	6	17	15	16
4	4	17	6	3	11	1	12	15	2	16	14	5	7	13	9	10	8
5	5	4	17	7	6	2	9	1	14	13	16	15	10	12	8	11	3
6	7	8	9	6	5	1	10	16	12	11	13	15	14	17	2	3	4
7	3	4	12	2	11	7	1	5	6	17	10	13	9	8	14	15	16
8	2	15	17	8	10	4	9	6	1	12	16	11	5	7	3	13	14
9	2	5	8	6	10	3	13	4	1	17	15	7	9	16	11	12	14
10	7	16	11	13	3	14	4	6	2	15	5	12	17	8	1	9	10
11	16	15	14	11	8	7	2	13	3	1	10	9	6	5	4	12	17
12	5	16	6	12	1	13	3	4	7	14	17	11	8	9	2	15	10
13	12	9	7	14	5	1	2	16	6	15	4	10	3	17	11	8	13
14	3	1	16	2	14	5	9	13	8	17	15	7	6	11	4	12	10
15	7	13	15	14	6	1	5	10	2	11	4	9	8	12	3	16	17
16	11	14	5	6	2	1	8	12	4	3	13	9	7	10	17	15	16
17	15	17	9	11	1	10	2	6	3	7	4	5	14	8	12	16	13
18	11	17	5	1	9	2	16	12	13	8	6	3	10	7	4	15	14
19	1	4	11	5	7	13	6	2	3	16	17	15	14	10	8	9	12
20	8	9	2	4	12	5	13	11	10	14	3	1	6	7	15	16	17
21	1	2	13	3	11	5	17	8	4	9	16	15	7	6	10	12	14
22	5	8	11	6	4	3	12	1	2	14	7	15	10	13	9	17	16
23	2	16	9	8	6	5	4	3	1	17	7	10	14	15	12	13	11
24	7	3	8	4	1	6	12	14	2	15	17	10	9	11	5	16	13
25	1	10	17	12	5	14	6	13	8	11	3	4	9	15	16	7	2
26	17	16	14	2	11	12	7	10	4	13	15	9	6	3	8	1	5
27	2	8	12	11	9	7	5	1	4	10	14	13	6	3	17	15	16
28	2	16	11	9	6	1	13	7	3	17	12	8	4	5	15	14	10
29	9	11	13	14	5	10	8	1	2	17	16	12	6	7	3	4	15
30	4	10	9	8	14	1	12	5	3	2	15	13	6	7	17	11	16
31	6	2	7	17	10	9	5	4	1	11	13	8	14	16	12	15	3
32	10	11	13	12	4	2	9	3	1	14	17	15	16	8	5	6	7
33	2	10	16	3	7	1	15	6	5	4	11	9	17	8	12	14	13
34	17	7	8	3	13	1	14	12	5	11	6	2	4	10	9	16	15
35	10	1	12	7	5	14	3	11	2	16	8	6	13	9	4	15	17
36	16	12	7	17	2	1	5	6	9	8	11	4	13	10	3	15	14
37	8	14	11	2	6	9	1	12	4	10	5	13	3	7	15	16	17
Rating Averages																	
Rank	**3**	**12**	**13**	**5**	**4**	**2**	**7**	**6**	**1**	**15**	**14**	**11**	**8**	**9**	**10**	**16**	**17**

Participant	Community Garden General User Willingness (See Proceeding Sheet)		
	Q12 COMM_WANT_CG - How important do you think it is that a community wants a proposed community garden to be developed?	**Q13** COMM_APPROACH - When should a community be approached during the garden development process?	**Q14** COMM_WILLING - Do you think that community interest/willingness should ultimately determine whether a community garden is developed or not?
1	5	1	1
2	5	1	1
3	3	1	1
4	5	1	1
5	5	1	1
6	5	1	1
7	5	1	1
8	5	1	1
9	5	1	1
10	2	2	2
11	4	1	2
12	4	1	1
13	5	1	1
14	5	1	1
15	5	1	1
16	5	1	1
17	5	3	1
18	5	2	3
19	5	2	1
20	5	3	1
21	5	3	1
22	5	2	1
23	5	1	1
24	4	2	1
25	4	1	2
26	4	1	1
27	5	1	1
28	4	1	1
29	5	3	1
30	5	1	1
31	5	1	1
32	5	1	1
33	5	2	1
34	4	3	1
35	5	1	1
36	5	3	1
37	4	2	1
Rating Averages			
Rank			

Expert-Specific Demographics and Other Qual. Questions (See Proceeding Sheet)

Q16	**Q17**	**Q18**	**Q19_1**	**Q20**	**Q21**	**Q22**	**Q23**	**Q24**	**Q25**	**Q26**	**Q27**
YRS_CG_EXP - How many years of experience do you have in the area of community	EXPERT_SPECIAL - How would you describe your area of expertise as it relates to community gardens, urban	DOES_EXPERT_CG - do you and/or anyone in your household actively participate in a community garden?	CG_DIST - Distance (Miles)	TRANSPORT	PRIOR_INPUT	EMPLOY_STAT - What is your employment status?	HHI_LVL	EDU_LVL	GENDER	AGE	ZIP_CODE
5	6	3	1.12	1	3	1	5	6	1	4	85201
2	1	1			2	1		6	2	4	85282
2	1	1			2	1	5	6	2	4	85003
6	5	2			2	5	5	3	2	6	85250
7	1	1			2	2	3	3	1	7	85339
7	4	3	0.1	5	3	1	4	6	1	6	85645
4	1	2			2	1	7	5	2	7	85012
7	3	2			2	1		6	2	6	85040
7	1	1			3	5	7	6	1	7	85225
2	4	3		1	2	5	5	6	1	6	85015
5	5	1			3	1	4	4	2	5	85323
7	5	2			2	1	4	3	1	5	85023
6	2	3	1	1	3	1	3	2	1	5	86303
6	5	3	0.45	3,5	2	5	3	7	1	7	85712
1	1	2			2	1	8	6	1	5	85282
4	1	2			2	1		6	2	5	85012
4	1	2			2	1	9	6	2	5	85029
3	1	2			2	1	4	5	2	3	85206
4	5	1			1	1	9	6	2	5	85308
2	6	2			2	1	5	5	1	4	85014
5	5	1			2	1	9	3	1	6	85268
4	5	3	0.3	1,3,5	2	1	7	7	2	5	85006
4	1	1			2	1	9	6	1	4	85379
4	1	1			2	1	4	5	2	4	85142
2	2	2			2	1	5	4	1	5	85350
7	5	3	1.51	1,3	2	2	9	5	2	6	85323
7	5	3		1	2	5	2	6	1	8	85701
5	5	2			2	1	6	3	2	6	85308
4	1	2			2	1	9	5	2	5	85338
6	4	3	4.99	1	2	1	9	5	1	6	85259
7	5	3		1	2	2	3	3	2	7	85042
6	4	1			2	1	4	5	2	5	85392
2	1	2			2	1	9	5	2	3	85016
1	1	2			2	1	6	6	1	6	85331
3	1	2			2	1	6	6	1	3	85202
1	1	2			2	1	6	5	2	5	85013
3	4	1			2	1	3	5	1	4	85283

All Stakeholder Comments (By Respondent #)

5 Water and city Zonning are the biggest factors and staff to run gardens 8 out 10 do not get to be 2 Years old Die from lack of interest ..... and money to run...$$$$ long term land use, start up cost and yearly costs

6 "I take exception to utilizing community gardens as an economic generator for low income folks, this is done based on the farmers market method. Once you figure in transportation costs and labor (which should be worth something). most farmers market sales loose money.
Arizona community gardens take a lot of time and energy. but the other concern is chemical pollution from car exhaust, soil contamination and water run off.
Even knowing these dangers I do eat my own product. I stopped selling excess product some years ago and prefer to donate to a local nonprofit and take the tax breaks as a way to make money and pay for the food I grow fro myself and my family."

8 Education about what can be grown when in the location is extremely important.

10 Missing things like therapy, involvement by private sector, water source

11 the site is important but what will decide if the garden is successful is the management of operations. It is difficult to maintain a garden when you have a handful of volunteers, year after year. the burden is too much.

13 Some of the questions don't loan themselves to give an accurate representation of feedback for the categories in concern. Even though it might be more data to sieve through, if there was a comments section next to each category being looked at say, the minorities section, a more elaborate discussion of that criteria could ensue. Just ranking the category in terms of level of importance, leaves one feeling like its placement is relative when in actuality, we all live in communities made up differently based on industry, income, infrastructure, etc. Educating our young is our main focus. The ethnicity is an advantage to you in Tucson as it looks at food and its place in culture which is huge. For us here in Prescott, because we are monotone in our culture, its place doesn't have the same impact but wherever you go, children will always respond to this form of education.

14 Gotta have community support or it's just a garden, not a community garden!!

16 "I wish you also looked into local government support AND challenges in locating a community garden. Such issues may include water use, selling produce near/outside the

community garden, and cultural differences when working together in a community garden. Good Luck with your project. "

17 People are typically enthusiastic about a community garden, but aren't around when it comes to the funding and working in the sunshine. Unless 100 show up for an interest meeting, help with another garden until the interest is there. Unless the local municipality supports it as well, likelihood of success is low. Everyone loves the thought of a community garden but few realize the magnitude of the undertaking, especially in the desert. Also, if you're close to the desert mountains, forget it. You'll have fat and sassy rabbits.

22 I think community gardens belong in all communities that want them. It is important for the community to have a desire for and interest in the garden or it won't be sustained - that and tenure on the land are the two most important factors I have seen in longevity of community gardens.

24 Thank you for gathering such important data for our community!

28 Community gardens need participation from educators or professionals...help the community to help themselves.

32 In my experience, the number one factor to consider for the establishment of a community garden is community interest and involvement. I have seen too many community garden projects start and fail due to organizations assuming that they know what is best for a population or community and starting a project only to have it fail. There is no such thing as a community garden without community. And "community" must involve those people who live closest to the site. Not everyone wants to garden. And lots of people in lower income areas don't speak the "public health" lingo or embrace the ideas that seem fashionable right now.

33 In successful community gardens, development is driven by the community members. When community gardens are established without broad buy-in and participation of community members, they soon fizzle. Getting a lot of people to say they are interested in a garden and would get a plot if such a garden existed is one thing, but getting those people to actually take time from their day to do as they've said is another. That is understandable (and something we can all relate to). My point, though, is that the latter doesn't count as buy-in and participation. It's more productive to offer help and guidance and money to a passionate group that drives the creation of a garden tailored to the needs

and customs and desires of their own community, and it more often results in a sustainable community garden, which is what we're after. Building it won't make people come.

34 Thank you for the opportunity. This has been a concept that has been discussed in this community for several years with different proposals.

36 I would really like to see a community garden (or ten) in Phoenix's urban core. I would like both green space for recreation and onsite farmer's markets with edible food produced.

C.2 Siting Criteria And Indicators

Spatially represented siting criteria indicators were developed using ArcMap 10.6. Shapefiles for census tracts and block groups, the Census-delineated urban boundary of the Phoenix metropolitan area were obtained through the ASU Map and Geospatial Hub (https://lib.asu.edu/geo). The 2017 VPPG inventory was developed by Uludere Aragon and associates (2019). VPPGs were assigned GEOID attribute fields based on their respective census tract and block group, and all shapefiles and images used were re-projected to the North American Datum 1983.

C.2.1 Normalization of Criteria Indicators

All criteria indicator values were normalized using a linear scale transformation:

$$x'_{ij} = \frac{x_{ij} - x_j^{min}}{x_j^{max} - x_j^{min}} \qquad (1)$$

or

$$x'_{ij} = \frac{x_j^{max} - x_{ij}}{x_j^{max} - x_j^{min}} \qquad (2)$$

where x'_{ij} is the normalized value of a given indicator, x_{ij} is the initial indicator value, and x_j^{min} and x_j^{max} are the minimum and maximum values for that indicator, respectively (Malczewski, 1999). Equation 1 was applied in cases when a high pre-normalized value was considered higher potential/priority (e.g., a high population density), and Equation 2 was applied when a low pre-normalized value was considered higher potential/priority (e.g., park-poor neighborhoods).

C.2.3 Criteria Indicators

Food Deserts

Food deserts perhaps represent the most self-evident siting criterion; though, the conceptualization and representation of these regions can vary. Generally, food deserts are considered to be regions with minimal or no options to access fresh foods, often attributed to the absence of major grocery stores (Beaulac et al., 2009; Dutko et al., 2012; Walker et al., 2010). Arguments against food deserts largely stem from the contention that physical distance to a food retailer is not as real a barrier to access as lack of funds, as well as the opportunity cost associated with preparing meals (Shannon, 2014; Thomas, 2010). Furthermore, recent research conducted by the USDA continues to suggest that many food-insecure households may live in communities with higher grocery store access than more affluent suburban households (Rhone et al., 2019), further complicating the agency’s narrative. Critiques notwithstanding, the concept remains popular in planning and community garden literature (Albright, 2020; Mack et al., 2017), and its inclusion as a criterion was paramount to stakeholders.

The food desert criterion was represented as the share of the census tract population who are classified as both low-income and residing more than 1 mile from a supermarket or large grocery store (USDA, 2017b). This metric was employed in part due to the widespread coverage and readily available data of USDA Food Atlas and coupled with the fact that it is the formal definition adopted by the City of Phoenix (Albright, 2020; Uludere, 2019). Low access tracts are those in which > 33% (or at least 500 residents) live more than one mine from a major food retailer. A census tract is considered low-income if the poverty rate exceeds 20%, or median family income ≤ 80% of the state-wide (or metro) value. VPPGs were joined to the low-income/low-access share values of the tract in which they are located.

Community Health

Community health is related to the overall concept of food deserts in that lack of nutritious food options may lead to less healthy purchasing/eating behaviors (Allcott et al., 2017). However, comorbidities like hypertension and obesity (both of which may be linked to diet [Segal et al., 2017]) are not exclusive to only food deserts or—more reliably—low socioeconomic status (Ogden et al., 2010). For instance, while obesity rates vary across the Phoenix metro-area, many of the region's most affluent suburbs have census tracts with obesity rates exceeding 20% (Oshan et al., 2020).

Increased access to produce from community gardens has been shown to improved nutritional outcomes for participating households including reductions body mass index and overall eating habits (Alaimo et al., 2008; Castro et al., 2013; Twiss et al., 2003). Additionally, community gardening is linked to lower stress rates which benefits residents' health and mental well-being from childhood through adulthood (Branas et al., 2018; Engemann et al., 2019; South et al., 2018). Owing to these and other potential health benefits, community health was strongly emphasized as a criterion by stakeholders.

Representing the criterion, however, is difficult. As noted in Section 3.5, insurance represents a coarse metric at best. Access publicly available health data (e.g., obesity) that was not aggregated at the city or county-level proved problematic. Data on obesity generated by the 500 Cities Project (https://www.cdc.gov/500cities/index.htm) were used by Oshan et al. (2020) in their Phoenix metro-area study; however, the researchers restricted their analysis to the 10 metro cities covered by the dataset. In reality, large regions of the Phoenix Metropolitan Statistical Area were not covered by the CDC data. Despite its limitations, particularly in capturing health conditions in wealthier areas, the community health criterion was represented as the share of the census tract's uninsured, non-institutionalized civilian population (U.S. Census Bureau, 2019). Uninsured status has been shown to correlate highly with many comorbidities (e.g., hypertension and obesity), which improved nutrition can mitigate (Christopher et al., 2016; Sommers et al., 2017). VPPGs were joined to the uninsured share values of the tract in which they are located.

Lower-Income Neighborhoods

Multiple stakeholders made a point to distinguish between the concepts of food deserts and food insecurity. For many food-insecure households, healthy food access may be largely a function of cost, both in terms of financial expenditures and the time necessary to buy and prepare raw produce (Allcott et al., 2017; Shannon, 2014), rather than the physical distance to a major grocery store (Lucan & Chambers, 2013; Rhone et al., 2019). It is therefore unsurprising that food insecurity in the USA is highly correlated with income (Rhone et al., 2019; Coleman-Jensen, 2019). Owing to this, as well as other factors like the preponderance of vacant lots in lower-income areas (Newman et al., 2016; Uludere Aragon et al., 2019), many community garden projects are actively sited in lower-income neighborhoods (e.g., Rosan & Pearsal. 2017). Simply siting community gardens in lower-income neighborhoods, however, is not a panacea for food insecurity and buy-in from the local community in critical to their success (Draus et al., 2014). Thus, the inclusion of this criterion further underscores the need for equitable community engagement throughout the planning process.

The lower-income community criterion was represented as the population share of residents within a census tract living at or below the poverty level (U.S. Census Bureau, 2019). VPPGs were joined to the poverty share values of the tract in which they are located.

Park-Poor Neighborhoods

Lack of access to greenspaces represents a major source of environmental inequity in may urban areas (Heckert & Rosan, 2016). Aside from the variety of ecosystem services provided by vegetated areas (e.g., stormwater runoff reduction and urban heat island mitigation [Meerow & Newell, 2017; Trust for Public Land, 2020]), the mere presence of green space in a neighborhood is shown to strengthen children's connection to the natural world and promote more environmentally conscious behavior (Hartig et al., 2007). Furthermore, gardens can serve as spaces for socialization and foster neighbor-to-neighbor interaction (Petrovic et al., 2019). Increasingly, planners are factoring in the role that community gardens can play as part of a multi-pronged approach to increasing green cover while simultaneously enhancing urban food systems (Albright, 2020; Wolch et al., 2014).

The park poverty criterion was represented as the number of publicly accessible parks (including but not limited to municipal parks, regional parks, and sports parks) either inside of or within a 10-minute walk (780 meters) (Bohannon & Williams Andrews, 2011) of a census block group's boundary. Using the buffer function in ArcMap, 780-meter buffers were drawn around each of the 532 parks within the study area (MAG, 2014). Census block groups were spatially joined with the parks' buffers to create a block group coverage shapefile. VPPGs were joined to the block group in which they are located.

Community Space Proximity

Community gardens as social spaces may benefit from proximity to community spaces (e.g., religious institutions, community centers, public libraries, and senior centers) where individuals congregate and which may already support community garden organizations (Bleasdale, 2015; Drake & Lawson, 2015a; Ghose & Pettygrove, 2014). Additionally, nearby community spaces may themselves benefit from the presence of a community garden, in some instances accepting surplus produce as donations (Drake & Lawson, 2015b).

The community space proximity criterion was represented as a 10-minute walking distance from a publicly accessible park; a public, private, or charter school; a community center; a senior center; a public library; or a religious institution (e.g., temple, church, mosque) (ADE, 2018; MAG, 2014, 2017; MCTAO, 2017). Religious institutions were identified from the 2017 Maricopa County cadastral dataset based on the primary use codes (PUCs) for "worship facilities." A buffer of 780 meters representing a 10-minute walk was drawn around each park and school using the buffer function in ArcMap. VPPGs that intersected at least one buffer were assigned a value of 1.

Minority Neighborhoods

Community gardening has been shown to have support among minority communities, both in terms of fostering cultural identity through foods and customs as well as through developing a sense of place, especially in areas undergoing transition (Balmer et al., 2005; Birky & Strom, 2013; Langegger, 2013). For instance, ongoing projects have been launched to help Native American communities retain foods traditionally cultivated by the tribe and combat deep-rooted dietary and health challenges within the community (Native Health, 2020; Ornelas et al., 2017). Additionally, even after excluding poverty-level households, minority households in the study area consistently earn less than the local annual median income compared to Caucasian residents (U.S. Census Bureau, 2019). This condition is coupled with a documented gap (even when accounting for income) in homeownership rates between Caucasians and non-Caucasians (Haurin et al., 2007), resulting in disparities regarding to capacity to engage in household gardens.

The racial/ethnic minority neighborhood criterion was represented as the share of the census tract's population who are not white, non-Hispanic individuals (U.S. Census Bureau, 2019). VPPGs were joined to the minority population share values of the tract in which they are located.

Heat Vulnerable Neighborhoods

Heat vulnerability represents a major public health challenge for the Phoenix metro-area. Prolonged exposure to elevated temperatures can result in illnesses like heat exhaustion and heat stroke and may even be fatal (McMichael et al., 2008). Heat vulnerable populations include not only lower-income and minority households but also the elderly and individuals who live alone (Harlan et al., 2013). Lack of access to air conditioning or public cooling centers is also a major contributor to heat vulnerability. Within the Phoenix region, 5% of households in the region are without a form of residential cooling (Fraser et al., 2017). Even when air conditioning is present, it may be used sparingly (or not at all) due to cost or unreliable functionality (Harlan et al., 2013).

The heat vulnerability criterion was represented through the creation of a census tract-level Heat Vulnerability Index (HVI) using methods originally developed by Reid and associates (2009) and adapted for the Phoenix area by Harlan and colleagues (2013). The following variables were included in the HVI: % minority, % Latino immigrants, % below the Federal poverty line, % no high school diploma, % senior citizens (≥ 65 years of age), % of senior citizens who live alone, % of individuals who live alone, % with no central air conditioning, tract normalized difference vegetation index (NDVI) mean, tract NDVI standard deviation (Fraser et al., 2017; U.S. Census Bureau, 2019; USDA, 2017b). NDVI was calculated on a 2017 one-meter National Agriculture Image Program (NAIP) image of the study area using ERDAS. Using the zonal statistics function in ArcMap, the mean NDVI and standard deviation for each Census Tract were calculated.

To calculate the HVI, a principal component analysis (PCA) was conducted on the variables using SPSS. The analysis included a Kaiser normalization and varimax rotation. A total of three components were extracted, and the directionality of the loadings was checked based on known positive indicators (e.g., poverty) and negative indicators (e.g., vegetation cover). The component scores were then summed to create HVI scores for each tract. For a detailed description of the methodology we followed, see Wright and colleagues (2019). VPPGs were joined to the tract in which they are located.

Residential Proximity

The inclusion of residential proximity was heavily emphasized by stakeholders as a key siting criterion. In many cases, community gardens are developed with the intent of being an integral part of residents' lives as places for socialization and strengthening a sense of community (Bleasdale, 2015; Poulsen et al., 2017; Rosan & Pearsall, 2017). While there is a need for additional research to determine if there is a direct correlation between residential proximity and garden success, their development has been linked to increased property values (Voicu & Been, 2008) and the reversal of urban blight (Bowman & Pagano, 2004; Branas et al. 2018; Garvin et al, 2013).

The residential proximity criterion was represented using a 100-meter distance threshold. Residential parcels were extracted from the 2017 Maricopa County cadastral dataset based on their PUC (MCTAO, 2017). Residential PUC categories included single-family homes, apartments, condominiums, mobile home/RV parks, nursing homes, townhouses, multi-family homes, and "residences on large lots." A total of 1,275,745 parcels were extracted from the dataset and merged into one contiguous polygon. A 100-meter buffer was drawn around the polygon. VPPGs that intersected the buffer were assigned a value of 1.

Population Density

It is important for a population of aspirant gardeners be available to support any community garden, and, commonly, finding a sufficient pool of participants to sustain a garden (both in its nascency and later years) can be difficult (Bleasdale, 2015; Diaz et al., 2018). Additionally, as many urban food initiatives aim to help the largest populations possible, it stands to reason that the benefits of community gardens would be felt the most in areas with large populations of residents (Kaethler, 2006). However, because of the sometimes-significant variation in census tract size across the study area, the population density was used in place of the population of individuals living within a tract.

The population density criterion was represented by census tract population density (U.S. Census Bureau, 2019). To diminish the influence of an outlying, densely populated tracts in downtown Phoenix that heavily influenced the linear scale score, the square root of the population density was taken and subsequently normalized. VPPGs were joined to the population density values of the tract in which they are located.

Commercial Proximity

Commercial proximity was cited by several stakeholders as an important siting factor as many ongoing urban revitalization and food system initiatives, and cities have begun to examine the role of urban/community gardens in commercial areas (Albright, 2020; Wolch et al., 2014). This is coupled with research showing that community gardens can reduce workers' stress and promote team building (Kotejoshyer et al., 2019; Lottrup et al., 2013). Proximity to commercial areas may also accommodate commuters. A study by Tong et al. (2012) found that in, many cases, trips to farmers' markets did not originate from home but the patron's place of work or as part of combined trips conducted while running errands. More research is needed concerning community gardens specifically, but these trip-planning habits may also hold for gardeners and—if there is a farmer's market associated with the garden—customers.

The commercial proximity criterion was represented using a 100-meter distance threshold. Commercial parcels were extracted from the 2017 Maricopa County cadastral dataset based on their PUC (MCTAO, 2017). Commercial PUC categories included convenience stores, strip malls, supermarkets, mixed-use retail/office, department stores, shopping centers, office buildings, and banks/loan offices. A total of 18,582 parcels were extracted from the dataset and merged into a contiguous polygon. A 100-meter buffer was drawn around the polygon. VPPGs that intersected the buffer were assigned a value of 1.

Extreme Temperature Areas

Elevated land surface temperature (LST) as a result of the urban heat island effect poses enormous challenges for the Phoenix metro-area (Brazel et al., 2007; Harlan et al., 2013). The effect, resulting from the proliferation of impervious pavement and built structures, is felt across the study area but can vary greatly depending on neighborhood conditions (Connors et al., 2013; Harlan et al., 2007). While certain populations are more susceptible to the effects of the urban heat island effect (i.e., heat vulnerability), the phenomenon still results in decreased thermal comfort and increased utility expenditures across the board (Fraser et al., 2017; Guhathakurta et al., 2007; Wentz et al., 2016). Furthermore, status quo development, coupled with overall increasing temperatures as a result of climate change, will only exacerbate the issue in the coming years and makes it a top priority for municipal governments across the region (Hunt et al., 2017). Both modeling and empirical research have indicated, however, that even microscale changes to the landscape (e.g., the addition of green cover) can have both a localized and cumulative cooling effect (Oliveira et al., 2011; Zhang et al., 2017). As such, green spaces like community gardens do hold the potential to mitigate extreme temperatures as one other their multiple co-benefits (Ackerman et al., 2014).

The extreme temperature (i.e., heat) criterion was represented by census block group mean land surface temperature (LST). LST for the study area was derived using August 16, 2017, 30-m Landsat Provisional Surface Temperature images produced by the USGS (USGS, 2019). LST imagery was converted from its original Kelvin format into Celsius using the raster band arithmetic function in ArcMap. The mean LST of each census block group was then calculated using the zonal statistics function. Tracts with higher mean LST values represent areas that are a higher priority for VPPG development. VPPGs were joined to the mean LST value for the block group in which they are

Stormwater Runoff

Green infrastructure is typically conceptualized primarily as a means of mitigating excess stormwater runoff (e.g., Meerow & Newell, 2017). However, one of the co-benefits associated with community gardens (albeit not one of the primary ones) is the addition of pervious groundcover holds the potential to absorb rainfall and ultimately reduce stormwater runoff (Hansen & Pauleit, 2014; Lovell, 2010). Like the additive contribution of small green spaces with regard to elevated temperatures, increases in permeable spaces like community gardens can potentially have both a localized and cumulative impact on stormwater runoff (Akerman, 2012).

The stormwater runoff criterion was represented by the percent coverage of impervious surface per census block group. Impervious surface for each block group was derived using a 2010 1-meter National Agriculture Imagery Program (NAIP) land cover map for the study area (Li et al., 2014). In ArcMap, the classes for "pavement" and “building” were extracted from the image. To calculate the impervious surface area, the number of 1-m pixels of both classes were summed for each census block group using the zonal statistics function. Percent coverage was then determined by dividing the impervious surface area by the total block group area. VPPGs were joined to the impervious surface value for the block group in which they are located.

Mass Transit Accessibility & Bikeability

While Phoenix, like many Sun Belt metros, is heavily car-centric, ridership on the region’s mass transit system remains sizeable (i.e., 64 million riders in 2019) (https://www.valleymetro.org/ridership-reports). This especially holds for lower-income households within the urban core who are more likely to have lower rates of car ownership than households in the suburbs (U.S. Census Bureau, 2019). Transportation to community gardens is a challenge for individuals without an automobile, especially if that garden is beyond a walking distance (Balmer et al., 2005; Parece et al., 2017). It is, therefore, crucial to ensure ease of access to community gardens via mass transit, particularly in areas considered to be disadvantaged.

The same also applies for bikeability. In the Phoenix metro-area, biking is a necessity for some and a choice for others. Recognizing this, it is important to plan community gardens within a reasonable distance of dedicated bike infrastructure (Denver Urban Gardens, 2012; Kaethler, 2006). Additionally, it supports ongoing within the study area to improve bike infrastructure and promote cycling as an alternative form of transportation (https://www.phoenix.gov/streetssite/Pages/Bicycle-Master-Plan.aspx).

Transit infrastructure access for the mass transit accessibility criterion was represented using a 10-minute walking threshold (780 meters) from either a bus or light rail stop/station (Valley Metro, 2019a, 2019b). VPPGs that were located within the buffer were assigned a value of 1. Transit infrastructure access for the bikeability criterion was represented using a 100-meter distance threshold from bike lanes, bikeways, and bike paths (MAG, 2019). Using the buffer function in ArcMap, 100-meter buffers were drawn around each segment of dedicated bike infrastructure within the study area. VPPGs that were located within the buffer were assigned a value of 1.

Vacant Parcel Groundcover

Vacant parcels with buildings and other impervious surfaces are costly to convert to garden space, although other factors, in the end, may overcome this cost (USDA, 2016). While all of the VPPGs included in the 2017 inventory have groundcover conducive to cultivation (Uludere Aragon et al., 2019), there is still cost (both monetary and temporal) which type of groundcover (i.e., bare, scrub, or mesic). Rather than disregard a distinction in groundcover or restrict our VPPG inventory to just bare parcels, the criteria were presented for the stakeholders to evaluate.

VPPG groundcover was determined using attributes determined in the initial dataset developed by Uludere Aragon and associates (2019). Parcel groundcover was classified using methods developed by Smith and colleagues (2017) wherein cadastral data is combined with high-resolution remotely sensed imagery. Using 1-meter 2017 NAIP imagery (USDA, 2017b), a supervised classification was conducted on several hundred "training" samples in ERDAS to establish different land use classes. Using isolated band 3 and post-PCA band 2 spectral data, the zonal statistics function in ArcMap was employed to calculate the mean and standard deviation of each band for each VPPG. Finally, a discriminate analysis was conducted to classify the remaining VPPG. For a full description of the methods used, refer to Smith and associates (2017). In the MCDA, the groundcover classes were separated into three different criteria, all assigned a value of 1 or 0 accordingly.

C.3 Complete Comprehensive Criteria Ranking Results

Ranking	Residential Proximity	Food Deserts	Lower Income Communities	Park Poor Communities	Community Health	Population Density
Mean	2.97	3.41	4.46	3.81	4.05	4.87
STDEV	2.2	1.65	1.67	1.81	2.03	1.76
Ranking Order	1	2	3	4	5	6
	Community Space Proximity	Bikeability	Mass Transit Accessibility	Bare Groundcover	Extreme Temperature Areas	Minority Communities
Mean	5.43	8.87	9.30	9.32	9.57	10.11
STDEV	1.62	3.96	3.88	5.13	3.88	5.13
Ranking Order	7	8	9	10	11	12
	Heat Vulnerable Communities	Stormwater Runoff	Commercial Proximity	Scrub/Shrub Vegetated Groundcover	Mesic Groundcover	
Mean	10.51	11.14	11.78	12.24	12.30	
STDEV	4.03	4.63	4.58	4.12	4.38	
Ranking Order	13	14	15	16	17	

C.4 Sensitivity Analysis

To test for weight sensitivity, each index was modified using equally weighted criteria, and the results were compared to the study's stakeholder-derived, baseline values (Malczewski, 1999). All three indices displayed differing degrees of sensitivity to the adjusted weights when compared to the stakeholder-derived values (Table B2).

In the Modified Social Characteristics Index, 4136 (70%) VPPGs' siting scores increased by ≥ 5 points. Only 20 parcels decreased by ≤ 3. The average score was 43.2—higher than the baseline's 37.1. Scores increased primarily in the middle range between 40 to 60 (Table B2). Middle-to-higher scores were more distributed across the metro-area when compared to the baseline index, particularly for parcels located in tracts with lower food desert values but with higher values in the other social criteria (e.g., high-minority neighborhoods). This is not surprising given the location-specific nature of food deserts; whereas, many of the other social variables are more prevalent across the study area.

The modified Physical Setting Index scores increased ≥ 5 points in 838 (14.2%) VPPGs and decreased ≥ 5 in 2,359 (43.0%), with a mean score to 45.2—less than the baseline's 47.8. Scores especially decreased in the 60 to 69 range. The overall decline is most likely attributable to the diminished power of the residential proximity criterion which served to lower VPPG siting scores in non-residential areas. Under the equally weighted scheme, factors like local infrastructure (e.g., metro stops) and physical conditions (e.g., LST) have greater influence and can depress scores otherwise boosted by residential proximity in the baseline index. This trend is observed across the metro-area.

The change in the modified Comprehensive Index was mixed, increasing ≥ 5 points in 715 (12.1%) VPPGs and decreasing ≥ 5 points in 1,139 (19.3%). The mean siting score was 46.8—only slightly larger than the baseline's 46.5. Siting scores generally increased within the urban core and decreased in more affluent suburbs, as well on the urban fringe. This is likely attributable to the weakening of the top two criteria (residential proximity and food deserts, respectively). Just as in the modified Physical Setting Index, the boost received by residential proximity is reduced significantly for VPPGs across the metro-area. Additionally, as observed in the modified Social Characteristics Index, the diminished power of the food deserts allows for other less geographically-restricted, social criteria to have greater influence. The higher weighting of the other criteria in the Comprehensive Index and the prevalence of social criteria within those criteria (aside from the physical criteria residential proximity and population density) means that the Modified Comprehensive Index favors locations similar to those observed under the Modified Social Characteristics Index.

The baseline MCDA was also applied among the 76 extant community gardens in the metro-area, of which only 30 are located in designated food deserts (CGMC, 2017; Mack et al., 2017). The mean siting scores for the Social Characteristics, Physical Setting, and Comprehensive indices were 45.6, 72.2, and 52.5, respectively. The social criteria score is not surprising given the 46 gardens, almost all suburban in location, are not located in food deserts. This suggests that adding a neighborhood demand metric for food desert residents could ensure that gardens are sited in areas where residents want them.

Table C2. The results of the sensitivity analyses. “Baseline VPPGs” are those resulting from the original, stakeholder-derived weights, and “Modified VPPGs” are those produced by the equally-weighted scenario.

Siting Score	Social Characteristics Index			Physical Setting Index			Comprehensive Index		
	Baseline VPPGs	Modified VPPGs	% Change	Baseline VPPGs	Modified VPPGs	% Change	Baseline VPPGs	Modified VPPGs	% Change
90 - 100	0	0	0.00%	17	25	0.10%	0	0	0.00%
80 - 89	13	12	0.00%	285	139	-2.50%	27	1	-0.40%
70 - 79	60	163	1.70%	430	521	1.50%	123	137	0.20%
60 - 69	276	590	5.30%	1,094	355	-12.50%	582	795	3.60%
50 - 59	487	961	8.00%	976	1458	8.20%	1,705	1,745	0.70%
40 - 49	1,224	1,464	4.10%	1,307	1,310	0.10%	2,317	1,553	-12.90%
30 - 39	2,344	1,876	-7.90%	830	696	-2.30%	189	1,168	16.60%
20 - 29	1,332	825	-8.60%	285	1110	14.00%	777	387	-6.60%
10 -19	172	17	-2.60%	407	226	-3.10%	188	122	-1.10%
< 10	0	0	0.00%	277	68	-3.50%	0	0	0.00%
Mean Score	37.1	43.2	-	47.8	45.2	-	46.5	46.8	-
Median Score	35	41	-	48	42	-	48	48	-
Score STDEV	12.0	12.9	-	19.5	17.6	-	12.9	12.3	-

* The percent change in scores under the modified index when compared to the baseline values of the 5,908 VPPGs.

APPENDIX D

CHAPTER 4: SUPPLEMENTAL MATERIAL

The index used to establish the siting potential of VPPG i (S_i) for the CGCM was developed using methods and data outlined by Smith et al.'s *Planning Urban Community Gardens Strategically through Multicriteria Decision Analysis* (2020). For a comprehensive explanation of the application of multicriteria decision analysis, the siting criteria, and the construction of the index, please refer to their study.

Their assessment developed a series of siting indices to assign a siting score to add another level of geographic context to where a VPPG is located and its potential as a prospective community garden location. They derived siting criteria and weights based on stakeholder feedback elicited from a targeted survey. They then developed spatial indicators for each criterion and determined criteria weights using a rank-sum procedure (Eq. C1):

$$w_j = \frac{n-r_j+1}{\sum_{k=1}^{n}(n-r_k+1)} \tag{C1}$$

where w_j is the weight of criterion j (all weights sum to 1), n is the number of criteria included in the index, and r_j is the rank of criterion j derived from the survey data (Nyerges & Jankowski, 2010).

Siting criteria were selected based on a comprehensive ranking exercise wherein 17 criteria were presented to survey respondents. While they used seven criteria, our modified siting index utilized the top five physical siting criteria related to the built environment and geographic context of a VPPG's location. Criteria indicators were developed using ArcMap 10.6 and were normalized using a linear scale transformation (Eqs. C2 & C3):

$$x'_{ij} = \frac{x_{ij}-x_j^{min}}{x_j^{max}-x_j^{min}} \tag{C2}$$

or

$$x'_{ij} = \frac{x_j^{max}-x_{ij}}{x_j^{max}-x_j^{min}} \tag{C3}$$

where x'_{ij} is the normalized indicator value, x_{ij} is the initial indicator value, and x_j^{min} and x_j^{max} are the minimum and maximum indicator values for the set, respectively (Malczewski, 1999). Indicator values were then applied to each VPPG. A *brief* explanation of the rationale for the criterion's inclusion and the spatial indicators developed to represent it is included below. Quoted text describing the derivation of the criteria are all from Smith et al.'s Appendix C. For the CGCM, the siting score for each VPPG was calculated using a linear combination and was then adjusted for the parcel's area (A_i) as described in Section 4 of the main text. Figure C1 shows the frequency of the final adjusted siting scores (S_i^*) used in the CGCM.

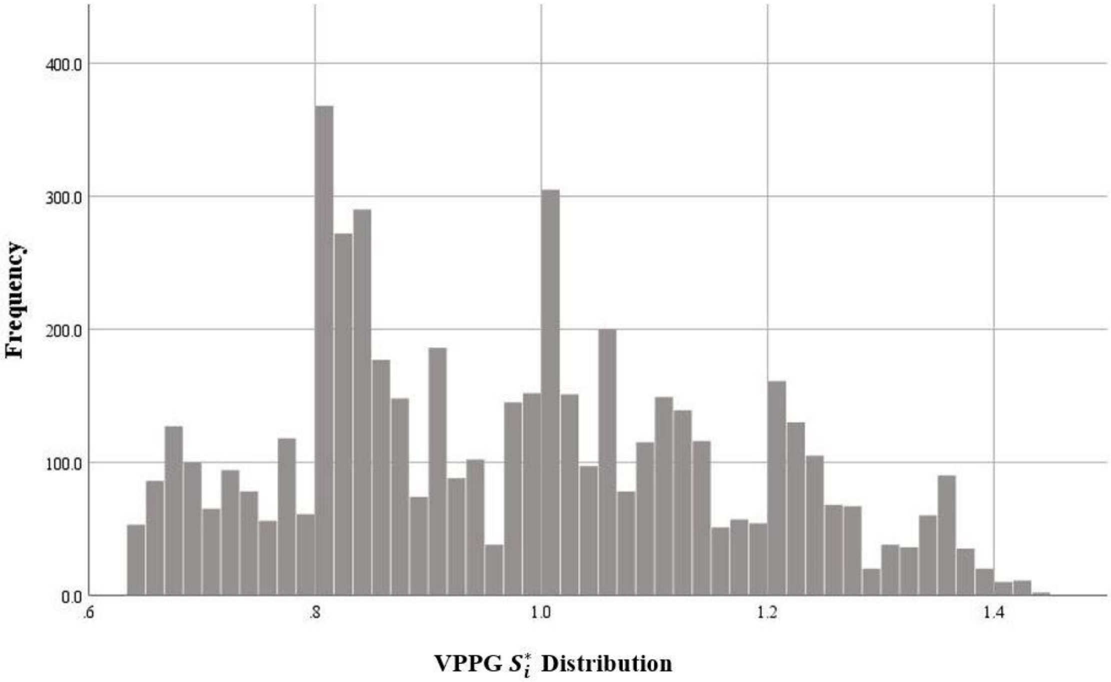

Figure C1. Adjusted Siting Score Distribution

Criteria and Indicators

1. Residential Area Proximity

When integrated into a neighborhood, community gardens hold the potential to become an integral part of the social fabric, promoting a sense of community and providing places for socialization (Poulsen et al., 2017; Rosan & Pearsall, 2017). "*The residential proximity criterion was represented using a 100-meter distance threshold. Residential parcels were extracted from the 2017 Maricopa County cadastral dataset based on their PUC (MCTAO, 2017)*[…] [and were] *merged into one contiguous polygon. A 100-meter buffer was drawn around the polygon. VPPGs that intersected the buffer were assigned a value of 1.*" (Appendix C, pgs. 18-19).

2. Census Tract Population Density

Siting community gardens in more densely populated tracts means that their co-benefits accrue locally in areas where they may potentially help the most people (Kaethler, 2006). It also improves the chances of there being a critical mass of individuals to support the garden (Bleasdale, 2015; Diaz et al., 2018). As per Smith et al., *"The population density criterion was represented by census tract population density (U.S. Census Bureau, 2019). To diminish the influence of an outlying, densely populated tracts in downtown Phoenix* *that heavily influenced the linear scale score, the square root of the population density was taken and subsequently normalized. VPPGs were joined to the population density values of the tract in which they are located."* (Appendix C, pg. 18).

3. Community Space Proximity

Community gardens frequently serve as spaces for socialization and may benefit by being sited nearby community spaces where residents already gather (Bleasdale, 2015; Ghose & Pettygrove, 2014). As per Smith et al., *"The community space proximity criterion was represented as a 10-minute walking distance from a publicly accessible park; a public, private, or charter school; a community center; a senior center; a public library; or a religious institution (e.g., temple, church, mosque) (ADE, 2018; MAG, 2014, 2017; MCTAO, 2017)*[…] *A buffer of 780 meters representing a 10-minute walk was drawn around each park and school using the buffer function in ArcMap. VPPGs that intersected at least one buffer were assigned a value of 1."* (Appendix C, pgs. 15-16).

4. Bikeability

It is recommended that community gardens be sited in bikeable areas as it is not uncommon for residents to use bicycles for transport in urban and suburban areas, either out of necessity or recreation (Denver Urban Gardens, 2012; Kaethler, 2006). *"…*[The] *bikeability criterion was represented using a 100-meter distance threshold from bike lanes, bikeways, and bike paths (MAG, 2019). Using the buffer function in ArcMap, 100-meter buffers were drawn around each segment of dedicated bike infrastructure within the study area. VPPGs that were located within the buffer were assigned a value of 1."* (Appendix C, pgs. 22-23).

5. Mass Transit Access

For households either without a car or with a car in frequent use to access a community garden that is too far to walk to, mass transit may be a necessity (Balmer et al., 2005; Parece et al., 2017). *"…*[The] *mass transit accessibility criterion was represented using a 10-minute walking threshold (780 meters) from either a bus or light rail stop/station (Valley Metro, 2019a, 2019b). VPPGs that were located within the buffer were assigned a value of 1."* (Appendix C, pgs. 22-23).