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RESEARCH ARTICLE

The governance of community gardens as commons and its role in the socio-ecological outcomes of gardening in Austin, Texas, USA

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Abstract

Community gardens represent vacant lots in urban areas with public or private land ownership that community members use primarily for urban agriculture. This research studies community gardens in Austin, Texas (USA), with the focus on: (1) approaches taken to govern community gardens and (2) socio-ecological outcomes of gardening associated with the implemented models of governance. Social outcomes are represented by the level of gardeners' satisfaction and perceptions of their success. Environmental outcomes represent ecological services provided by gardens as green spaces and expressed through net primary productivity (NPP), which measures carbon sequestration. This paper argues that these types of outcomes in community gardens are codependent and affect each other, and the governance approach determines what forms this interdependence takes. This study employs Ostrom's socio-ecological systems (SES) framework that reflects both social and natural aspects of community gardening and explains the connection between the governance approaches, gardeners' perception of their success, and changes in carbon sequestration. This paper uses a mixed-methods approach with key informant interviews with managers of community gardens yielding both qualitative and quantitative data. Remote sensing analysis is applied to calculate the amount of biomass for the carbon sequestration model using remote sensing imagery from the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) and Planet Inc. The analysis reveals that the highest measurements of the social and ecological performance in community gardens in Austin are associated with 'bottom-up' governance structures where community members are in charge of decision-making and management.

Keywords Community gardening · Carbon sequestration · Socio-ecological systems · Governance of common resources · Net primary productivity · Human perceptions

1 Community gardens as local food movements

Considering rapid global urbanization, urban food systems represent a distinct area of research, often as a response to urban poverty, food insecurity (Bedore 2010, pp.1420–1421), and negative impacts of urbanization on the environment (Kowarik 1995; McKinney 2008). Improving food environments is an important fix for the underlying structure of disinvestment and decline in communities (LeDoux et al. 2014). Local food movements strive to improve communities' environments through ecological, political, economic, and socio-cultural processes (Jarosz 2008, pp.231–232). This paper investigates community gardens as alternative local food movements with a focus on the approaches taken to govern them and socio-ecological outcomes of gardening associated with the implemented models of governance. Social outcomes are represented by the level of gardeners' satisfaction and perceptions of their success. Environmental outcomes represent ecological services provided by gardens as green spaces and expressed through the net primary productivity (NPP), which represents the difference between absorbed and released carbon dioxide and measures carbon sequestration (National Aeronautics and Space Administration 2000). The research objectives of this study are: (1) Through the qualitative analysis of key informants' interviews, examine the models of governance implemented in community gardens; (2) through the analysis of key informants' interviews, evaluate the gardeners' perceptions of their success; (3) evaluate the ecological services provided by community gardens as urban green spaces by

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calculating the amount of sequestered carbon and examine the role of human factors in these services by calculating the seasonal differences; and (4) using inferential statistics, examine the role of different models of governance in gardeners' perceptions of the success and seasonal differences in carbon sequestration through the lenses of the socio-ecological systems (SES) framework.

Community gardens represent a local initiative implemented by many communities around the world. Community gardens represent vacant lots in urban areas with public or private land ownership that community members use primarily for urban agriculture (Schukoske 2000, p.352). In the USA, community gardens often amount to short-term use of vacant land awaiting construction (Colding and Barthel 2013, p.160). Glover defines a community garden as 'an organized, grassroots initiative whereby a section of land is used to produce food or flowers or both in an urban environment for the personal use or collective benefit of its members' (Glover et al. 2005, p. 79). International research in community gardening has focused on sustainability as community gardens integrate their components with an emphasis on environmental and social dimensions. Community gardening often involves physical transformation of land, which then promotes community-identity formation and the production of place (Milbourne 2012 p.944). Many researchers have identified access to fresh food, community-building, and social inclusion as the primary motivations for those who become involved in community gardens worldwide (Baker 2004; Bodel and Anda 1996; Hanna and Oh 2000; Kurtz 2001; Turner 2011). In Melbourne, Australia, community gardens are used to engage migrants to participate in urban activities and help them assimilate in a community (Agustina et al. 2012, pp. 439–440). Participation in urban agriculture projects bring people together to work alongside each other, to communicate, to share seeds, to share harvests, to share recipes, to share knowledge, to use common resources (e.g., water), and to perform duties like composting and recycling. In Germany, community gardens are predominantly used for leisure activities (Fox-Kämper et al. 2018, p. 61). Gardening may produce a sense of accomplishment and self-actualization (Agustina et al. 2012, p. 446). In New York City, USA, urban gardens provide a space for citizens to exercise their right to the city and promote democratic values (Smith et al. 2003, pp. 206–208). In Philadelphia, USA, community gardens provide a solution to food deserts (Kremer et al. 2011). Environmental benefits of community gardening include biodiversity, microclimate regulation, filtration of atmospheric particulates, rainwater retention, noise attenuation (Bolund and Hunhammar 1999; Haase 2015; Zinia et al. 2018). For example, studies in Manchester, UK, show that urban green spaces help to decrease the temperature in cities (Gill et al. 2007, p.118).

Many studies associate community gardens with neighborhoods' 'commons'—a natural resource, a property, a practice, or a knowledge that is shared and collectively managed by a group of people for individual and communal benefit (Basu et al. 2017; Gibson-Graham et al. 2013; Teig et al. 2009). Although gardeners typically work independently on individual plots, the collective actions of community members preserve and maintain the gardens through political activism, fundraising, grant-seeking, up-keep, or garbage disposal (Petrovic et al. 2019, pp.37–39). Community gardens involve numerous participants that may represent schools, hospitals, religious institutions, local communities and members, and marginalized groups like youth, the elderly, diverse racial and ethnic groups (Pudup 2008; Saldivar-Tanaka and Krasny 2004; Teig et al. 2009). Governments and non-governmental organizations (NGOs) may also be involved as they advocate, educate, plan, and negotiate for community spaces (Eizenberg 2012a, b, pp.106–107). Ghose et al. (2014) showed that community gardens depend on the social networks to survive, function, and overcome barriers. Gardeners create ties with non-profit organizations, government agencies, and businesses to obtain materials, resolve land-use conflicts, or acquire other resources, like information and advocacy support (Baker 2004; Ghose et al. 2014; Schmelzkopf 2002; Staeheli et al. 2002).

This study analyzes the socio-ecological performance of community gardens in Austin, Texas (USA), as a function of their governance and the spatial interaction of actors with socioeconomic and environmental conditions. A community garden is a system where the gardeners, other people, and the natural world are interdependent. The governance approach determines what forms this interdependence would take. This study addresses the gap in the literature related to the role of governance approaches implemented by community gardens in their socio-ecological performance. It also argues that social and environmental aspects of community gardening coexist. Social and environmental outcomes of community gardening affect each other and result from the organized collective effort. The gardening activity cannot be performed without human effort. Social outcomes of gardening (such as the level of gardeners' satisfaction and their perceptions of garden's success) are affected by garden's productivity. In turn, human efforts contribute to ecological services provided by gardens, including carbon sequestration—the process of capturing and storing atmospheric carbon dioxide. There is a gap in the literature related to the carbon sequestration by small-scale urban green spaces, such as community gardens. This study addresses this gap by calculating the seasonal differences in community gardens' carbon sequestration. The productivity of gardening depends on the cumulative input of ecological factors (sunlight, rain, and soil), the application of seeds, tools, and fertilizer, and the human factor (volunteer efforts of community gardeners).

The efficacy of human efforts depends on how the garden's activities are organized and governed.

2 Governance of community gardens

Governance approaches can range from 'top-down' governance (in which community gardens are fully or partially managed by the municipal government or other external organizations) to 'bottom-up' approaches (in which community gardens are run by the gardeners and sometimes by external specialists who volunteer or are hired to help) (Fox-Kamper et al. 2018; McGlone et al. 1999; Nettle 2014). In practice, governance often blends these models (Nettle 2014); government agencies and gardeners share the power. McGlone et al (1999) distinguished five types of governance of community projects (including community gardens): 'top-down'—projects managed and run by professionals, 'top-down'—projects managed by professionals but run by paid workers/volunteers, 'bottom-up'—projects managed and run by local communities with the help of paid workers and professionals, 'bottom-up'—projects managed and run by local communities with informal professional support, and 'bottom-up'—projects managed and run by local communities (Table 1). Fox-Kämper et al (2018) also suggested a sixth type: 'bottom-up'—projects with political and/or administrative support for funding, land tenure, and advising. (Fox-Kämper et al. 2018, p.65). This typology of governance approaches has been used to describe governance practices in community gardens in different countries, such as Germany, Australia, New Zealand, Canada, and the USA (Fox-Kämper et al. 2018).

There have been debates regarding the most effective form of governance for community gardens (Austin et al. 2006; D'Abundo and Carden 2008; Eizenberg 2012a, b; Fox-Kämper et al. 2018; Palamar 2010; Petrovic et al. 2019; Stocker and Barnett 1998). For example, in New Zealand, local government supports urban community gardens by regulating their establishment and management (Fox-Kämper et al. 2018, p.61). However, when decision-making is run entirely by the government and external professionals, gardeners feel estranged from their gardens (Eizenberg 2012a, b, pp.112–113). Governmental and non-profit organizations can impose their own interests and goals on the gardens and, therefore, the gardeners (Ghose et al. 2014, pp.94–95). On the other hand, professional expertise and governmental support provide stability and longevity (Austin et al. 2006; Ghose et al. 2014; Follmann and Viehoff 2015; Palamar 2010). Studies have suggested that the success of community gardens depends on the levels of gardeners' participation, and these are connected to the levels of power they hold in management and decision-making (D'Abundo and Carden 2008; Howe and Wheeler 1999; Stocker and Barnett 1998). Many have advocated for a combination of

Table 1 The description of the types of the governance of community gardens (McGlone et al. 1999, pp.17–19)

Type of governance	Description
'Top-down': projects managed and run by professionals	Governmental or non-profit organizations manage and operate a garden entirely, including decision-making. Management committees have no local community representation
'Top-down': projects managed by professionals but run by paid workers/volunteers	Governmental or non-profit organizations manage a garden, including decision-making. They hire workers or seek for volunteers to run a garden. 'Gardens planned, established, or managed by paid professionals with limited community involvement' (Fox-Kämper et al.: 2018, p. 60)
'Bottom-up': projects managed and run by local communities with the help of paid workers and professionals	Community members manage and operate a garden with the help of hired workers and professionals. Decision-making is run by both local communities and paid professionals. Professional help is usually stronger during the planning and establishing stages (Fox-Kämper et al., 2018)
'Bottom-up': projects managed and run by local communities with informal support from a professional	Community members manage and operate a garden with the unpaid (unstructured) help of professional organizations, including NPOs. Professionals can offer advice, provide funding, and participate in some decision-making
'Bottom-up': projects managed and run by local communities	Community members manage and run a garden exclusively, including decision-making. Sometimes gardens can obtain external support on their own terms, including advice and funding. Usually there is no consistent funding
'Bottom-up' with political and/or administrative support, which includes funding, land tenure, and advising	Community members manage and operate a garden with the help of governmental organizations. Decision-making is run by local communities, while the government provides funding, land tenure, and/or advice

gardeners' autonomy and support from environmental-stewardship organizations (Petrovic et al. 2019). Some studies have found community garden members who indicate that not having professional coordination is a barrier to success (Fox-Kämper et al. 2018, p.101).

This study analyzes community gardens as socio-ecological systems using Ostrom's socio-ecological systems framework, because it helps to reflect both social and natural aspects of community gardening and focuses on the aspect of governance (Vogt et al. 2015). This framework proposes a conceptual model and research variables, which provides a common ground for researchers from different disciplines as well as international scholars and practitioners (McGinnis and Ostrom 2014). The SES framework seeks to understand how the rules and regulation in use, the specific biophysical characteristics of the gardens, and the attributes of the community affect the decision-making process and gardening outcomes. It is built on the assumption that individual and collective choices influence the results of collective action (McGinnis and Ostrom 2014). The SES variables that comprise the model include eight first-level core subsystems: social, economic, and political settings (S), related ecosystems (ECO), resource units (RU), a resource system (RS), a governance system (GS) and actors (A), the interactions (I) between them and the resulting outcomes (O) (Fig. 1).

These first-tier variables included multiple second- and lower-tier variables as well. (Refer to Appendix A for the descriptions of the SES variables used in this analysis.) Each community garden is a case of an (RS), consisting of individual plots or (RU). Actions provide a platform to create different socio-ecological outcomes (O) through gardening practices (I). Community gardening involves actors (A) (i.e., gardeners and other stakeholders). In some gardens, the gardeners do not participate in management or decision-making, while in others they are involved in everything. The (GS) of community gardens represent a variable in the SES framework that influences other elements. This study uses the version of the SES model proposed by Vogt et al. (2015) that includes an ecological component-related ecosystems (ECO), which affect gardening and productivity. The literature argues that incorporated ecological variables help fully understand human–environment problems described by the SES framework (Vogt et al. 2015). This research also proposes third-tier variables specific to analysis of community gardens (Appendix A).

The SES framework can be used to analyze community gardening because it considers social and ecological aspects and their interactions, includes qualitative and quantitative data, proposes a variety of sub-variables, focuses on the governance and management of natural resources, and focuses on the role of community members in the process of governance. Each community garden represents an example of a resource systems. Gardening practices represent actions through which input variables are transformed

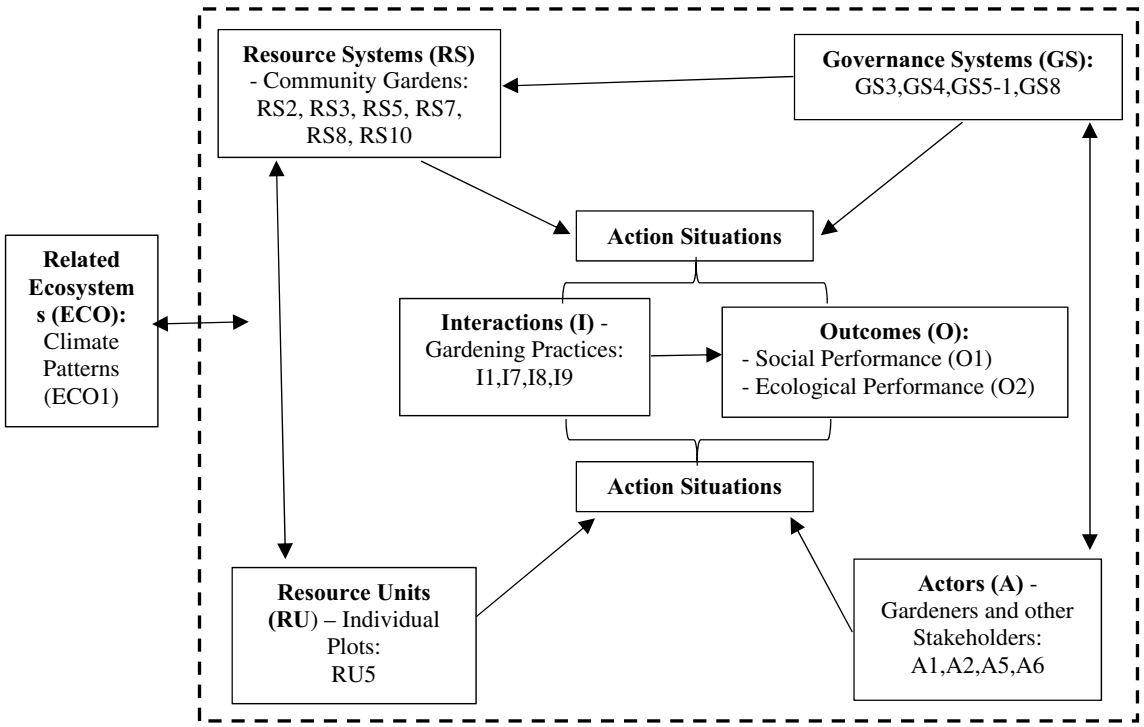

Fig. 1 The SES framework applied to the study of community gardens

into outcomes. Outcome includes both social performance and ecological performance measures. Social performance is measured by the level of satisfaction or 'success' derived from gardening. Instead of assuming the success of a garden based on the factors selected from a researcher's perspective (for example, using the number of participants or crop yield as a measure of success), this study allows gardeners to evaluate their gardens' success based on their own perspectives. This approach argues that individual and community values and perspectives are determined by the habits of, traditions of, practices among, and interrelationships within a particular group of people or community (Carolan and Hale 2016, pp.531–532). Ecological performance analyzes community gardens' success by evaluating ecosystem service production. It is represented by gardens' carbon sequestration—the amount of carbon dioxide that stays in the ecosystem and provides for the functioning of its components (Chapin III et al. 2009, p.841), measured by NPP. NPP reflects a socio-ecological interdependence of community gardening because it depends on multiple factors: climate, garden's size, and time and human effort.

This study contributes to the existing scholarship by analyzing the success of community gardens and their ecological performance as a function of their governance. It analyzes community gardens as socio-ecological systems and illustrates that social and ecological outcomes of community gardening need to be analyzed in tandem because of their intertwined nature. It also contributes to the SES conceptual model by introducing new variables specific to the community gardens' analysis and applicable to the international context.

3 Mixed-method approach to the analysis of community gardens in Austin, Texas

The study area is Austin, Texas, the eleventh most populated city of the USA, and fourth most populous in Texas (Infoplease 2014). The 2019 estimate of population, 978,908, is 23 percent more than the 2010 total (US Census Bureau 2019), making Austin the fastest-growing large city in the USA (Weissmann 2015). Austin has a humid subtropical climate (Köppen climate classification), experiencing hot summers and relatively mild winters (NOAA 'Austin Climate Summary' 2010). The climate creates a very diverse ecological and biological profile (NOAA 'Austin Climate Summary' 2010). The average annual rainfall, 34.32 inches (872 mm), is distributed fairly evenly throughout the year, though spring and fall are the wettest seasons ('U.S. Climate Data' https://www.usclimatedata.com/), making them the prime growing seasons in this region (Petersen 2001). The city of Austin is located within the gardening zone III (Texas Gardening Regions, USDA Plant Hardiness Zone Map, 2012) and is in plant-hardiness zone 8a (USDA Plant Hardiness Zone Map 2012). Temperature and precipitation patterns in Austin facilitate year-round cultivation and promote gardening.

Austin's community gardening began about 40 years ago. The Coalition of Austin Community Gardens (CAGG) was created in 2008 to support the development of community gardens in Austin and to establish a network for participants. CACG promotes the establishment of new community gardens in the greater Austin metropolitan area and monitors existing ones to foster stability and land security for existing gardens, and to help them to thrive through advocacy and gardener education opportunities (https://communitygardenaustin.org/about/). CACG cooperates with other organizations—the Sustainable Food Center and the City of Austin's Sustainable Urban Agriculture and Community Gardens program. There are fifty-one known community gardens located within the boundary of the City of Austin (CAGG Website); twenty-six of them responded to the questionnaire and agreed to participate in this analysis (Fig. 2).

This study has four research questions: (1) What types of governance approaches do community gardens in Austin use? (2) How do the members of community gardens evaluate the success of their gardens? (3) How does carbon sequestration compare between growing and non-growing seasons? (4) What is the relationship between models of governance and analyzed socio-ecological outcomes?

This research utilizes a mixed-method analysis. Qualitative data include key informant interviews, and quantitative data include satellite and climate data. The key informants (gardens' managers or other appointed individuals) from twenty-six gardens participated in the questionnaire (Appendix D) either via email or via phone. First, they received the list of questions to discuss with the members of their community garden. Second, they filled out the questionnaire and returned it via email or chose to answer the questions via phone. The key informant interviews were analyzed using content analysis and deductive coding process with the SES variables used as codes and assigned to the interview responses to determine the models of governance. The following questions were asked to determine the corresponded SES variables describing governance approaches utilized by community gardens: (1) Who owns the land on which your community garden operates? (2) How is your community garden governed? Who is responsible for the decision-making in your garden and who is involved in its management? (3) Can you describe some management techniques or strategies that you use to achieve the goals of your community garden? (4) Do you receive funding from external sources? Would you please name the sources of your funding?

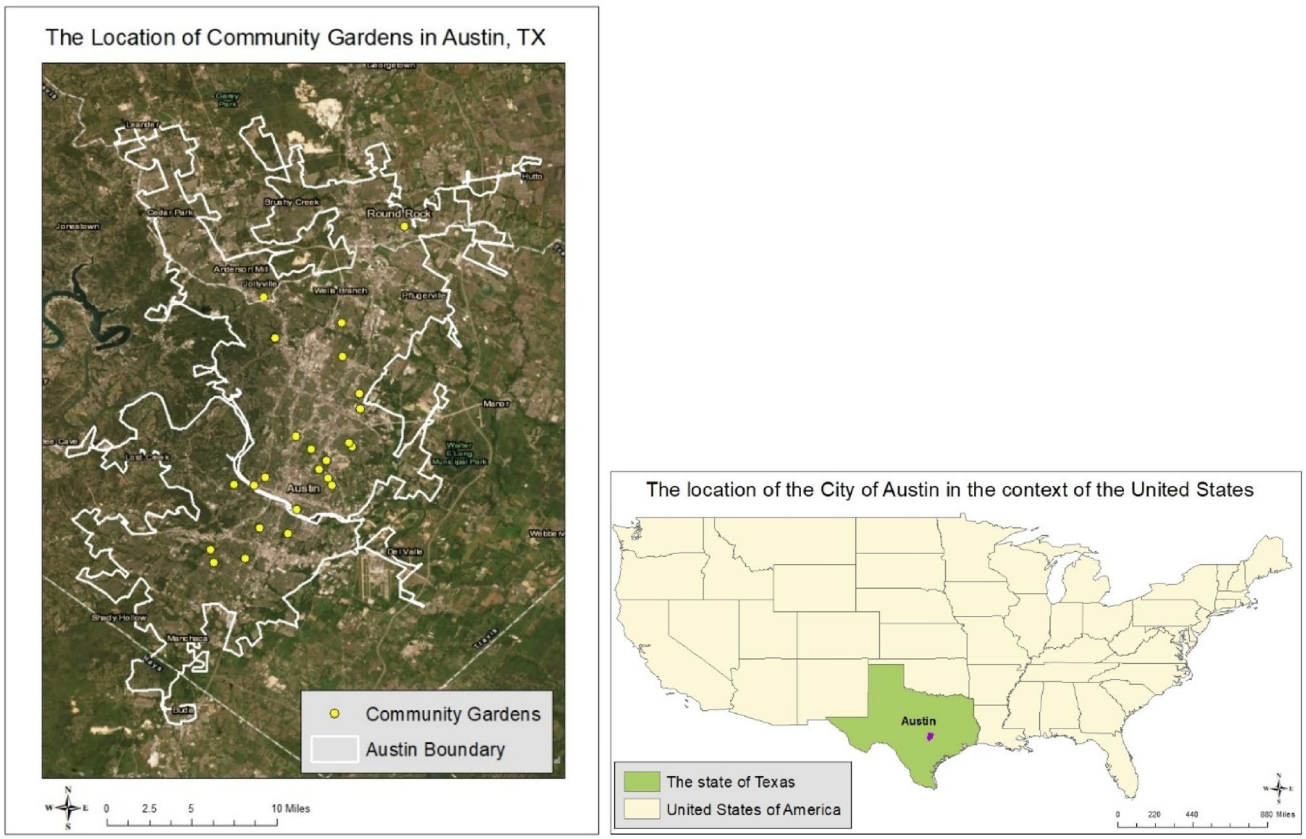

Fig. 2 Left: The locations of community gardens in Austin, Texas. Right: The location of the City of Austin in the context of the USA

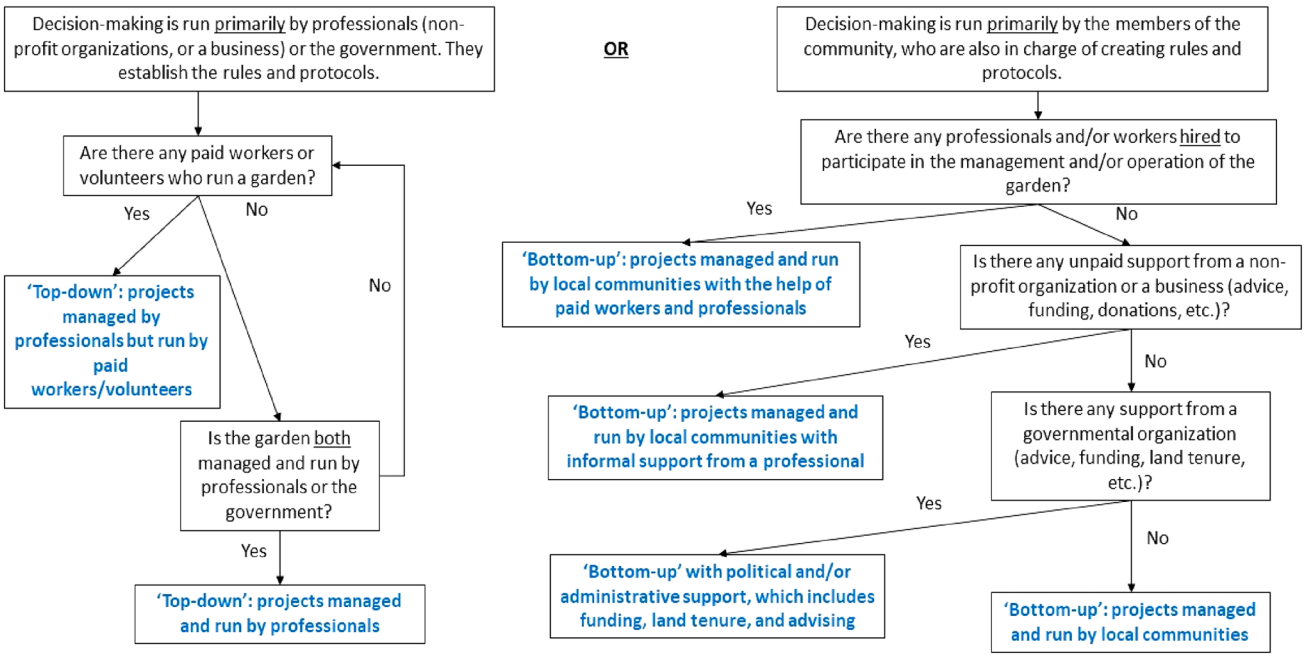

Fig. 3 Criteria to determine the model of governance

The flowchart (Fig. 3) was used to determine the model of governance. The last question on the questionnaire asked key informants to indicate their perceptions of the success by checking the appropriate box on the LIKERT scale from 'unsuccessful' to 'very successful' and aimed to answer the second research question (Appendix D).

To answer the third research question, this paper applied the CASA algorithms for evaluating carbon sequestration through NPP (Field et al. 1995; Potter et al. 1993; Tripathi et al. 2010):

$$\mathrm{NPP} = \mathrm{NDVI} * \mathrm{PAR} * \mathrm{LUE}, \quad (1)$$

where NDVI is normalized difference vegetation index (describes the relative density of vegetation for each pixel in a satellite image), PAR is photosynthetically active radiation (represents the amount of light available for photosynthesis), and LUE is light use efficiency factor (the efficacy of solar radiation utilization in fixing carbon) (Appendix C). Two sources of satellite data were used—ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) (70 m resolution) and PlanetScope imagery (3 m resolution)—to obtain variables to calculate NPP. PAR values were obtained from the Research Data Archive managed by the National Center for Atmospheric Research. NDVI values were calculated for each garden by processing remote sensing imagery in ArcGIS for Desktop Standard, version 10.4.1.

4 Results

4.1 Types of governance approaches used by community gardens in Austin

To determine governance approaches utilized by gardens, it is important to understand the distribution of power among the participants of the garden, such as who takes the leadership (the SES variable A5), who participates in the garden's organization, including decision-making and management (GS3), who implements the rules (GS5-1), and who owns the garden's land (GS4) (Fig. 1, Appendix A). Power dynamics are embedded in and analyzed through various activities related to community gardening, such as planting and harvesting (I1), activities that do not involve food production, such as self-governance, garden's maintenance, formal and informal environmental education and leisure activities (I7), networking (I8), and monitoring (I9). These SES variables served as codes for a deductive coding process to analyze interviews with key informants (Appendix A). For example, network structures (GS3) are determined through the analysis of networking activities (I8), like securing funding, promotion, donations, environmental education, distribution of surplus. Gardens' networks also include external organizations that provide financial support and information. For instance, the St. David's Foundation Community Garden in Austin receives sponsorship and advice from the economic sector.

Most of the community gardens in Austin are located on land belonging to the City of Austin. Some gardens use land belonging to churches or schools. For most community gardens in Austin, these property rights (GS4 variable) do not affect the management and the decision-making except in the case of church property. For example, the Unity Community Garden has a church liaison who the gardeners consult for decision-making. This research proposes a second-tier SES variable—GS5-1 (Rules and protocols)—which establishes the steps for implementing rules and protocols and the forms that can they take—formal or informal. It determines who is in charge of organization and management. Rules and protocols determine the criteria for membership and participation, levels of gardeners' individual responsibilities, behavioral norms, participants' rights, and obligations.

The analysis revealed three governance approaches adopted by community gardens in Austin (Table 2).

Most gardens follow the governance approach: *'bottom-up': projects managed and run by local communities with informal support from a professional*. Many gardens who follow this model collaborate with the Sustainable Food Center. It is a non-profit organization whose goal is to 'increase the amount of local food consumed by residents in Central Texas by 2035 and to cultivate a just and regenerative food system so people and the environment can thrive' (The Sustainable Food Center 2019). The Sustainable Food Center plays an important role because serves as a sponsor and adviser to many Austin's community gardens:

> The Sustainable Food Center helps the garden by carrying an insurance policy, holding the garden's funds, paying the City of Austin water bill, and providing a platform to collect dues from gardeners.—Cherry Creek Community Garden.

Other external organizations that sponsor or help community gardens in Austin include Sprouts Healthy Communities Foundation, the Rollingwood Women's Club, St. David's Foundation, Austin Park Foundation, public schools, religious institutions, and businesses. Some gardens received financial support from the local and state governmental organizations like the Austin Parks and Recreation Department, the City of Austin's Office of Sustainability, the Texas Department of Agriculture, and the Texas Farm Bureau. These gardens are managed by professionals and employ a

Table 2 Models of governance used by community gardens in Austin

	Models of governance					
	'Top-down': projects managed and run by professionals	'Top-down': projects managed by professionals but run by paid workers/ volunteers	'Bottom-up': projects managed and run by local communities with the help of paid workers and professionals	'Bottom-up': projects managed and run by local communities with informal support from a professional	'Bottom-up' with political and/or administrative support, which includes funding, land tenure, and advising	'Bottom-up': projects managed and run by local communities
Number of community gardens	0	8	0	13	0	5

Table 3 Community gardens' perceptions of their success

	Please indicate your perception of the success (your personal measure of success) of your community garden by checking the appropriate box on the scale below				
	Unsuccessful	Unsuccessful, but has a potential for improvement	Successful, but with many issues/ problems	Successful, but with a few issues/ problems	Very successful
Number of community gardens	0	0	4	10	12

'top-down' model of governance, which indicates that professional organizations have better access to the local government and able to reach for governmental support easier than community-managed gardens.

None of the interviewed community gardens in Austin hire workers to run the garden or professionals for organization and management. Gardens with 'top-down' governance structures are run by volunteers. Schools, non-profit organizations, churches, and businesses assist 'bottom-up' community gardens voluntarily. The garden's management reflects its network structure. For instance, the organizational structure of the Adelphi Acre Community Garden includes several stewardship teams: Outreach Team, Infrastructure Team, Education Team, Compost Team, Donation Team, Orchard Team, Flora Team, Oak Grove Team, Marketing and Events Team. Each team performs specific tasks and interacts with certain groups of actors, for example, the Outreach Team '*develops volunteer relationships with schools, businesses, organizations and so on, taking the garden out to the wider community and vice versa*.'; the Marketing and Events Team is '*responsible for promoting the garden to the wider community and for organizing potlucks, community events, festivals, plant sales, and other social events. [It] sells garden-branded t-shirts and water bottles*.' (the Adelphi Acre Community Garden). The organization and the management determine the efficacy of collective action performed by gardeners; this can be evaluated by both the amount of biomass produced and the sense of accomplishment and satisfaction expressed by gardens' members.

4.2 Members' perceptions of the success of community gardens

Key informants indicated their perceptions of the success of their community garden by checking the appropriate box on the LIKERT scale from 'unsuccessful' to 'very successful.' The SES variables (Appendix B) served to understand

the gardeners' perceptions through the content analysis of interviews. Four gardens indicated their levels of success as Successful, but with many issues/problems, ten gardens indicated their levels of success as 'Successful, but with a few issues/problems.' Most of the gardens (twelve) indicated their levels of success were 'Very Successful' (Table 3). No key informants considered their community gardens to be 'Unsuccessful' or 'Unsuccessful, but with a potential for improvement.'

4.3 The differences in carbon sequestration between growing and non-growing seasons

Two values of NPP were calculated for each community garden: one for a representative period of a growing season (t1) and one for a representative period of a non-growing season (t2). These representative periods were chosen based on the season based on the examination of the Austin's climate data, availability of remote sensing data, and the information provided by the local gardeners. July was chosen to represent the non-growing season; May represents the growing season. PlanetScope scenes from July 27, 2018, and May 26, 2019, were used to calculate NDVI. However, there were no images available on these dates for some of the gardens; therefore, the data for the closest available dates were acquired. The NDVI scenes were created individually for each garden. For some gardens, there was an increase in NDVI values during the growing seasons. For other gardens, NDVI values did not change, which might indicate a low gardeners' participation. The average mean NDVI value for a non-growing season was 0.42, for a growing season–0.47. The ECOSTRESS satellite images were used to derive variables to calculate LUE (Appendix C). These variables were calculated on a garden level by averaging the per-pixel values within a garden, with three to four pixels for each garden.

The results show that on July 27, 2018 (representing a non-growing season), a cumulative NPP of the community gardens in Austin was approximately 12.4 kg. During a representative period of a growing season (on May 26, 2019), the total amount of sequestered carbon was more than three times higher (40.1 kg). The lowest seasonal increase in NPP was recorded in the Good Soil Community Garden (88.06 g.). The highest seasonal increase in NPP was in the Sunshine Community Gardens (5502.08 g). The average increase in NPP was 1065.1 g (~ 1 kg). Eight out of twenty-six gardens had a seasonal increase in carbon sequestration between two representative periods of more than 1000 g (> 1 kg).

5 The role of governance in the socio-ecological outcomes of gardening

5.1 Community gardens as commons

This is the study of community gardens as commons. Scholars define commons as resources that are collectively owned and managed by communities or governments that exist for the use by and to the benefit of individuals and communities (Basu et al. 2017; Ostrom 1990). Gibson-Graham et al. (2013) discuss commons as a process, activity, or a practice that is shared by a community and can take place with any form of property: private, state owned, or open access. They distinguish several types of commons: biophysical, social, cultural, and intellectual (Gibson-Graham et al. 2013, p.130). The literature discusses community gardens as urban green commons—physical green spaces in the city that are collectively managed (Colding and Barthel, 2013, p. 159), and as biophysical commons (Basu et al. 2017; Gibson-Graham et al. 2013; Teig et al. 2009). However, the complex nature of community gardening means that other types of commons are involved. Thus, social commons associated with community gardens include networks, social inclusion, and social capital (Ponstingel 2022). For example, many gardens in Austin indicated community-building and development of friendships among their primary goals. Another research on community gardening in Germany shows that many urban gardens use communal plots instead of individual plots to foster communication and community-building (Fox-Kämper et al. 2018, pp. 60–61). Intellectual commons include information and knowledge that are created, shared, retained, and enacted through social relations and networks in the community gardens, for example, environmental education (Ponstingel 2022). Cultural commons in community gardens can include collectively created art or other physical objects that express sense of community and appreciation, values, and believes (Fig. 4).

5.2 The relationships between the governance of community gardens and perceptions of the success

The fact that different types of commons coexist in community gardens intertwines environmental and social aspects of community gardening. The argument is that social and ecological outcomes of community gardening are codependent and affect each other. The governance approach determines what forms this interdependence takes. The SES

Fig. 4 Left: Collectively created art objects at the St. David's Foundation Community Garden, Austin. Image source: https://sites.google.com/site/sdfcommunitygarden/home. Right: A sign at the Grow Together Garden at Gateway Church expressing members' religious values. Image source: https://www.facebook.com/GrowTogetherCommunityGardenOfGateway/

framework applied by this research reflects both social and natural aspects of community gardening that work in tandem to create 'socionature' in an urban area. Sustainable and organic food production was the most common primary goal of community gardens in Austin. The ability to achieve their goals influences gardeners' perceptions of their success, which represent social outcomes in this research.

Gardens that experience many issues/problems operate consistently throughout the year and have regular scheduled meetings to perform gardening chores that require collective action and to discuss organizational issues. However, all four gardens in this category experience low participation when it comes to common duties such as taking care of garden's common areas. Two of these gardens are non-profit organization that use volunteers to run the gardens, while the other two employ *'bottom-up': projects managed and run by local communities with informal support from a professional governance approach* and they mentioned a struggle with understanding the best management techniques and policies to govern the garden.

The most successful gardens have consistent (or stable) levels of participation (Fig. 5). However, more than half of the gardens interviewed experienced issues with participation in group activities, such as taking care of the garden's common areas. Though only 5 out of 26 gardens have a declining participation, most gardens struggle with members' participation in collective duties like general garden maintenance. This may affect the consistency of social

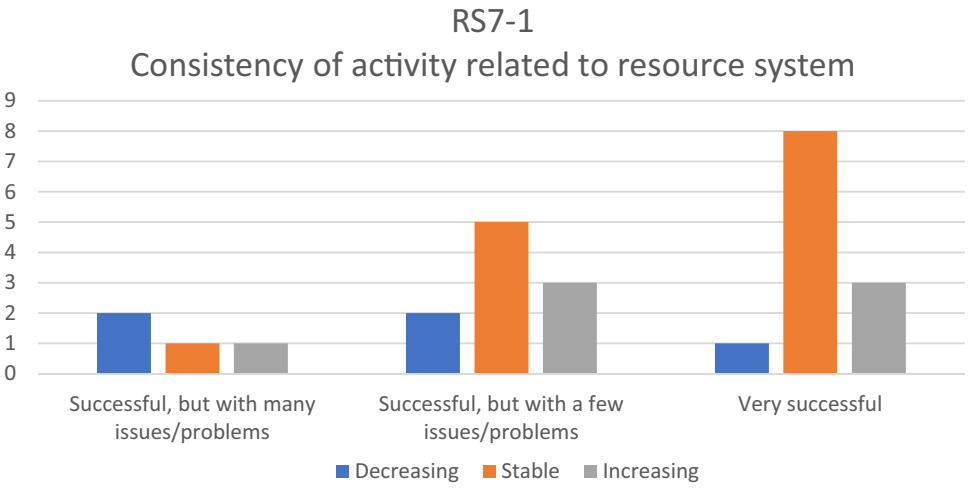

Fig. 5 Level of participation in community gardens by the perception of success

interactions, and by extension social capital. Social capital includes sense of place, social networks, trust, and reciprocity and is beneficial for individuals (Altschuler et al. 2004, p.1220). Gardens that perceive themselves to be 'successful, but with a few issues/problems' seem to struggle with organization and management the most. Some of the gardens from the 'very successful' category encounter a different problem: their capacities cannot accommodate the number of people who want to join the garden, and they have long waiting lists. The interviews with key informants show that often participation in community gardens depends on the institutional ties (to a school, a church, a non-profit organization) as well as informal social connections (to a family or a neighborhood). For example, a President of the Rollingwood Community Education Garden described how he became a member of this garden:

> I joined RWCEG largely to support an interest my son had in gardening when he was in grade school.

A garden's size and longevity, level of participation, number of gardeners, socioeconomic attributes of members, and amount of social capital affect gardeners' perceptions of their success. The oldest gardens in Austin (founded in 1978, 1979, and 1981) are perceived to be the most successful. These three gardens are also among the most populated gardens. Socioeconomic and demographic attributes also help to understand why communities have certain values. This analysis did not determine any economic attributes of the gardeners in Austin. The key informants indicated that gardens do not keep records of the income level or other economic characteristics of their members. The ethnic composition includes people of White, Asian, Black, Hispanic or Latino, and Indian ancestry. The analysis of key informant interviews did not reveal any associations between the perceptions of success and ethnic composition or age. Every garden has representatives of at least one minority ethnic group, but most of the gardens are still predominantly White and of all ages.

The gardens' areas were determined in square meters and converted to acres. These areas fall in the 200–3000 m2 range, with a few outliers (4,140 m2; 4,743 m2; 5,859 m2; 6,138 m2; and 16,911 m2). All these larger gardens indicated their perceptions of success as 'very successful.' Larger gardens are able to accommodate more garden plots, include more community members, and dedicate extra space for socializing, which contributes to higher perceptions of success. For example, one of the five largest community gardens in Austin—Adelphi Acre Community Garden—includes a playground for kids and areas dedicated for cooking lessons. It helps the garden to reach its goals of providing social gathering space and educating about safe, sustainable, and local food production.

Governance is another important factor that influences the success of community gardens. Studies have concluded that 'successful' community gardens involve collaboration between different organizations, strong social capital, and high levels of community engagement (Diaz et al. 2018; Fox-Kämper et al. 2018; Howe and Wheeler 1999; Stocker and Barnett 1998). Scholars connect positive social capital with 'bottom-up' types of governance with a community's authority to create their own rules and norms (Rydin and Pennington 2000).

Two categories of gardeners' perceptions—'successful, but with many issues/problems' and 'successful, but with a few issues/problems'—have a fairly equal distribution of 'top-down' and 'bottom-up' governance structures. No governance approach predominates in these two groups. Gardens that have many issues/problems do not employ the *'bottom-up': projects managed and run by local communities* model. This model of governance is associated with less extensive network structures, which can simplify the organization and management. Twelve community gardens in Austin perceive themselves to be 'very successful.' Three out of the twelve gardens use *the 'top-down': projects managed by professionals but run by paid workers/volunteers* model. Two gardens use the *'bottom-up': projects managed and run by local communities* model. The predominant model of governance is *'bottom-up': projects managed and run by local communities with informal support from a professional* (seven gardens use this model). This model of governance allows community members to manage and run the garden, which gives a feeling of control over the urban space and can boost gardeners' perceptions of their success and their satisfaction with gardening. At the same time, this approach aids governance by providing external expertise through extended networks. Community members are still involved in the management of their gardens, but they also receive assistance from professional organizations. Thus, gardeners create ties with non-profit organizations, government agencies, and businesses to obtain materials, resolve land-use conflicts, or acquire other resources like information and advocacy support (Schmelzkopf 2002; Baker 2004):

> We work closely with the Sustainable Food Center as our fiscal sponsor. We use a google group to communicate to gardeners on business and priorities related to the garden.—the St. David's Foundation Community Garden.

Gardeners' perceptions of their success and their sense of accomplishment also depend on whether a garden serves its purposes and achieves its goals. Analysis of interviews determined several primary purposes of community gardening in Austin: (1) sustainable, community-based agriculture and organic food production; (2) provide fresh food for low-income residents; (3) community building and social

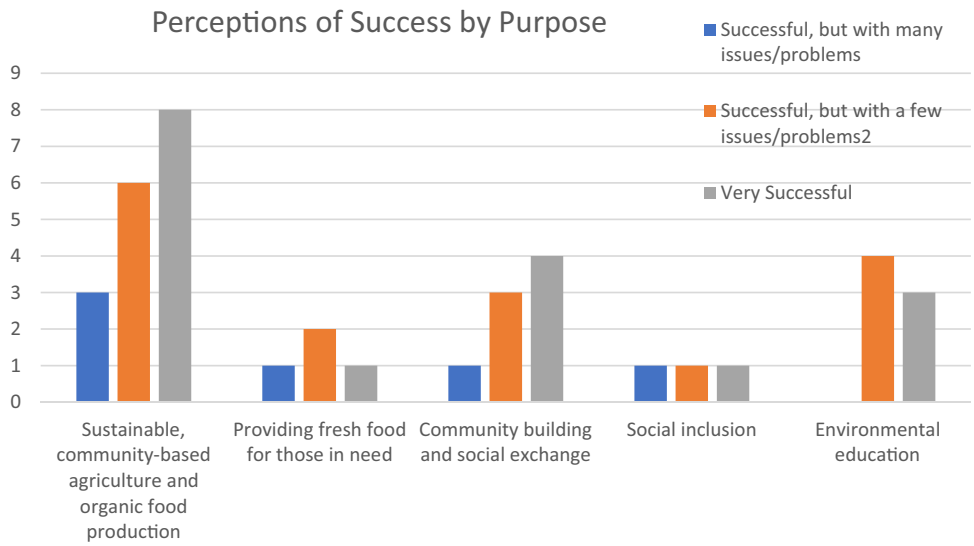

Fig. 6 Perceptions of the success of community gardens in Austin by purpose

exchange; (4) social inclusion; and (5) environmental education (Fig. 6). With the most common primary goal of community gardens in Austin regardless their governance approach being sustainable and organic food production, this paper further explores the interdependence between the gardeners' perceptions of the success and produced biomass.

5.3 The relationships between the governance of community gardens and carbon sequestration

Food production through gardening involves interaction with and transformation of nature and results in the production of biomass. The process of gardening cannot be conducted without human effort. Social outcomes of gardening are affected by garden's productivity, and ecological outcomes are affected by the amount of time and effort dedicated by the gardeners to the production of food. Three community gardens—Deep Eddy Community Garden, Festival Beach Community Garden, and Lamplight Community Garden—were the gardens with the highest perceptions of success and the highest seasonal changes in NPP. All three use a 'bottom up' governance approach (Table 4). None of the gardens that have a high seasonal change in NPP with an increase in the amount of biomass use 'top-down' governance structures. A possible explanation is that many community gardens in Austin with 'top-down' models of governance focus more on social inclusion and social exchange (for example, senior

Table 4 Models of governance and perceptions of success associated with high differences in carbon sequestration (> 1 kg) and increase in NDVI values

Community gardens in Austin, TX	Seasonal difference in NPP (g)	Model of governance	Perception of success
Deep Eddy community garden	2797.847	'bottom-up': projects managed and run by local communities	Very successful
Festival beach community garden	3553.207	'bottom-up': projects managed and run by local communities with informal support from a professional	Very successful
Lamplight community garden	2207.205	'bottom-up': projects managed and run by local communities with informal support from a professional	Very successful
Patterson park community garden	1601.347	'bottom-up': projects managed and run by local communities	Successful, but with a few issues/problems
South Austin community garden	1024.724	'bottom-up': projects managed and run by local communities with informal support from a professional	Successful, but with a few issues/problems
St. David's foundation community garden	1230.144	'bottom-up': projects managed and run by local communities with informal support from a professional	Successful, but with many issues/problems

centers) that happen through the production of food rather than on the food produced.

Increase in NPP values depends on the three factors: PAR, LUE, and NDVI (Eq. 1). The values of PAR and LUE are based on the local climate conditions, while the values of NDVI depend on both climate and human efforts. Increase in NDVI values might indicate increase in human participation, extended and more frequent working hours, and improvement in gardening skills. These aspects of community gardening are affected by how a garden is organized and managed. Six out of eight community gardens that showed a high increase in NPP (> 1 kg), also demonstrated an increase in NDVI values. This means that the changes in carbon sequestration associated with these gardens might be influenced by human factors, such as participation. Most of the gardens in this category utilize the model of governance *'bottom-up': projects managed and run by local communities with informal support from a professional*.

Most of community gardens with low seasonal changes in NPP (less than 300 g) have small areas. The lowest change in NPP between a growing and non-growing seasons was registered in the Good Soil Community Garden, which is also experiencing a decreasing participation. This garden applies a governance approach: *'top-down': projects managed by professionals but run by paid workers/volunteers* and has the smallest small area among the analyzed gardens. It also has low perceptions of its success ('successful, but with many issues/problems'). Thus, availability of space affects the amount of biomass produced. However, some of the larger gardens also had a low seasonal change in NPP and a decrease in the NDVI values (for example, Alamo Community Garden, Garden of Eatin' at South Austin Senior Activity Center, Asian American Resource Center Program Garden). Another example of the garden with one of the lowest seasonal changes in NPP is Rollingwood Community Garden. However, this garden is among the most populous gardens and has an increasing participation. Low biophysical productivity in Rollingwood Community Garden might relate to the primary purpose of this garden, which includes community building and social exchange. Therefore, the management in this garden focuses on the socializing rather than production of biomass.

The human factor is also important in carbon uptake because gardeners determine the amounts and types of biomass that is planted. Dennis and James (2016a, b) emphasize the significance of stakeholder participation in environmental stewardship of urban green spaces and its contribution to the adaptive capacity of social–ecological systems. In community gardens, environmental stewardship is carried out by the decision-makers. Based on the model of governance, the decision-makers can be the gardeners, managers, external organizations, or a local government (Fox-Kämper et al. 2018; McGlone et al. 1999, pp.17–19). The governance of the community gardens determines its efficacy in terms of participation, longevity, and ecosystem services. As a result, the model of governance that is selected affects the ecological efficacy of gardens.

5.4 Participation as a fundamental aspect of community gardening

The choice of a governance approach can be influenced by the purpose of a community garden. The relationships between primary goals and models of governance help to reveal what factors affect the governance structure (Fig. 7). The most common primary goal of community gardens in Austin regardless their governance approach is sustainable and organic food production. However, all gardens whose

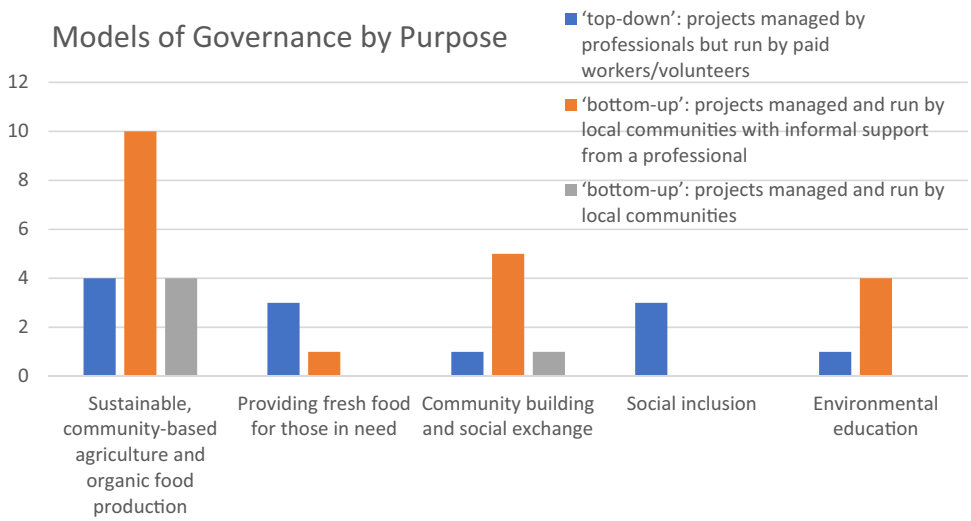

Fig. 7 Models of governance of community gardens in Austin by purpose

primary purpose is to grow food also indicated at least one secondary purpose. Only gardens with a governance structure 'top-down': projects managed by professionals but run by paid workers/volunteers indicated social inclusion as their primary goals. These gardens are managed by senior centers and aim to improve the lives of older adults by involving them in the community.

According to this analysis, gardens that grow food primarily to help those in need (low-income citizens, homeless, women's shelter) receive support from the non-profit organizations and businesses. The same model of governance (*'bottom-up': projects managed and run by local communities with informal support from a professional*) is associated with environmental education. Gardens with the governance structure *'bottom-up': projects managed and run by local communities* operate primarily for sustainable and organic food production. This purpose is also associated with the highest perceptions of the success (Fig. 6).

The key informants also identified some issues, problems, or concerns that they are experiencing in their community garden. Five main categories of issues/problems were established (Fig. 8):

1. Funding. Some gardens experience a funding shortage and require additional funds to cover different expenses, such as obtaining tools, materials, and seeds. Example:

> 'We need new tools for the garden (we started with used, donated tools), but we have been unsuccessful in obtaining grant funding for these tools. We sit on the edge of two widely diverse socio-economic groups, so we have been turned down for City grants because of our location. Funding for items such as tools has been an ongoing struggle since we became established.'—Cherry Creek Community Garden.

2. Pests, bug infestation, weeds, water shortage.

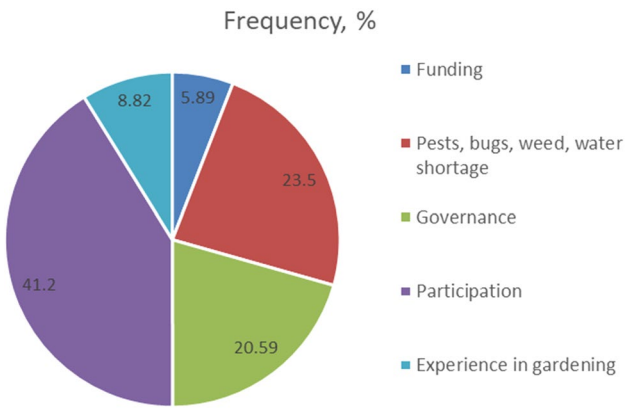

Fig. 8 Categories of issues/problems identified by community gardens

3. Governance. This category includes problems with organization, leadership, communication, and networking. Examples:

> Gardeners want to be involved and participate but don't want a leadership role. Understanding the best management and policies to govern the garden [needed]—St. David's Foundation Community Garden.
> Lack of consistent communication which we are trying to improve.—Emerald Wood Community Garden.

4. Participation. This category includes both low participation and high demand on plots (long waiting lists). Some gardens experience low involvement in common duties, such as maintenance of common areas.

> …a relatively few number of members contributing to the overall maintenance of the garden.—Patterson Park Community Garden.
> Low participation makes it hard to keep up the garden common areas.—Unity Park Community Garden.

5. Experience in gardening. Example:

> …many gardeners are new to gardening and productivity is low.—Anonymous Informant.

Participation was the most common problem among the interviewed gardens. It is almost equally experienced by all three governance approaches. In community gardens, participation is a fundamental aspect as it creates both physical objects (individual plots, functioning zones, and biomass) and social capital (networks, socio-ecological memory, social exchange). Participation levels reflect a garden's value to the community. Low participation leads to low amounts of biomass in the garden and weak social capital. On the other hand, weak social capital (low levels of trust and cooperation, unwelcoming atmosphere) can negatively affect participation. In fact, participation issues in some interviewed community gardens resulted from poor management and/or communication:

> It seems that people enjoy working on their plots and running into other gardeners occasionally but are less likely to participate in group activities. This is partly due to a lack of consistent communication which we are trying to improve.—Emerald Wood Community Garden.
> Participation in our mandated community work hours has always been problematic, with a relatively few number of members contributing to the overall maintenance of the garden.—Patterson Community Garden.

Participation is a fundamental aspect of community gardening because it creates both physical objects (individual plots, functioning zones, and biomass) and social capital (networks, socio-ecological memory, social exchange). The

level of participation reflects garden's value to the community. Studies argue that participation levels are higher when people share common interests and enjoy collective efforts (Colding and Barthel 2013, p.160). Community gardens' managers need to consider the cultural and social characteristics of the community to promote participation (Holland 2004). Several key informants included weak governance in the list of problems. These issues are related to weak management/organization:

> A challenge that we have been trying to better address is organization and communication. We have been trying to engage the gardeners in group workdays and other fun events at the garden but find that it's difficult to organize and participation is low when something is organized.—Emerald Wood Community Garden.

Most of the gardens that experience issues with governance rated their perceptions of success as 'successful, but with a few issues/problems' and use the *'bottom-up': projects managed and run by local communities with informal support from a professional approach*. According to the interviews, gardens that are managed by professionals do not have governance problems. This supports the views of scholars who argue that 'top-down' governance structures provide more expertise in organization and management (Austin et al. 2006; Follmann and Viehoff 2015; Ghose et al. 2014; Palamar 2010).

On the other hand, studies argue that successful gardens apply 'bottom-down' models of governance where certain groups of citizens take leadership (Ghose et al. 2014, pp.100–102). Participation in the management of urban gardens provides community members with a feeling of control over 'their' urban space, increasing the feeling of power among marginalized or disadvantaged groups (Eizenberg 2012a, b, p.113). Co-management also benefits community members by involving them in decision-making, and this develops positive social capital (Andersson et al. 2007; Rydin and Pennington 2000). When stakeholders share common interests and values, communicate with each other, and operate on the large scale, they can produce more adequate governance rules and norms with less need to develop monitoring and sanctioning mechanisms (Ostrom 2005).

Community gardens in Austin appear to be less aware or less concern with the ecological services related to gardening (such as biodiversity, microclimate regulation, filtration of atmospheric particulates, rainwater retention, noise attenuation, and carbon sequestration). Only three community gardens mentioned biodiversity as one of their goals. One of the purposes of this research was to draw community members' attention to the environmental aspect of gardening and potential ecological benefits resulted from the produced biomass by estimating carbon sequestration as an example of vegetation's productivity. Ecological services can represent an additional motivation to participate in community gardening. Including ecological services, such as carbon sequestration, in their mission statements can also open possibilities for community gardens to collaborate with local non-profit environmental organizations, extend their networking systems, and obtain funding.

5.5 Limitations

There are several limitations to this study that must be made clear. First, most of the interviews were conducted during the COVID-19 pandemic which likely affected the data collection. Social distancing—a crucial measure for slowing the spread of COVID-19—might have negatively affected the participation in community gardening and slowed the interview process. Many representatives of community gardens in Austin who initially agreed to participate in the interview became unavailable during the COVID-19 pandemic. Second, this research analyzed participants' perceptions of the success of community gardens. Some of key informants might have not expressed their true opinions regarding the gardens' success due to their specific roles of managers or PRs. This paper does not define 'success'; instead, the success of community gardens depends on goals, priorities, and values of their members. The purpose of this study was to let community members express their perceptions of the success based on what they want to achieve collectively in a community garden. For example, some gardeners evaluate their success based on the amount of produce they grow, while others prioritize social factors, such as interpersonal relationships or charity work. Future research should analyze the factors influencing community members' perceptions of their success. Finally, there are also limitations to the calculations of NPP. The boundaries of the community gardens were manually delineated in ArcGIS software using the best estimation approach. Although previous research suggests that high-resolution remote sensing imagery allows for accurate delineation of a site's boundaries (Forkuor et al. 2014), there is still a certain degree of error, for example, due to clouds or shadows. The NPP values were calculated for the entirety of each garden. But other land covers like concrete sidewalks, footpaths, worktables, or seating areas that are not garden plots, trees, or shrubs are also within the delineated patch. These areas were not excluded from the analysis, which likely affected the accuracy of the calculations. Developing a database with the percentages of the areas in Austin's community gardens that are used for production

would provide significant benefits for this study and future research. Future research can also compare NPP of gardens with NPP of empty lots to analyze the differences in carbon sequestration by urban agriculture and natural vegetation possibly occupying empty lots (such as, grass). There is also a slight date mismatch for some satellite images resulted from the availability of data.

6 Conclusion

This paper investigated the relationships between the community gardens' governance, social outcomes of gardening (gardeners' perceptions of their success) and gardens' biophysical productivity (carbon sequestration), using Ostrom's SES framework to understand how the rules and regulation in use, the specific biophysical characteristics of the gardens, and the attributes of the community affect the participation, productivity, and perceptions of success. The productivity of gardening depends on the cumulative input of ecological factors (sunlight, rain, and soil), the application of seeds, tools, and fertilizer, and the human factor (volunteer efforts of community gardeners). Production of biomass in community gardens requires human effort, time management, gardening skills, environmental knowledge, and commitment to the collective action. These factors depend on how the garden's activities are organized and governed. Governance approach determines how the garden is managed and operated with the assumption that successful governance improves gardens' socio-ecological performance.

The analysis revealed that most of the gardens (13 out of 26) follow the governance approach: *'bottom-up': projects managed and run by local communities with informal support from a professional*. Eight community gardens employ a '*top-down': projects managed by professionals but run by paid workers/volunteers* approach. These gardens are governed by senior centers, churches, community associations, and educational centers. Five community gardens function without external support and utilize the governance structure *'bottom-up': projects managed and run by local communities*. There are no community gardens in Austin that hire workers to run the garden or hire professionals to help with the organization and management. Community gardens receive professional assistance from schools, non-profit organizations, churches, and businesses also on a voluntary basis. This reflects a sense of community and social capital in Austin.

This analysis revealed that the highest measurements of the social and ecological performance were associated with 'bottom-up' governance structures where community members are in charge of decision-making and management. A predominant model of governance that is associated with high socio-ecological performance is *'bottom-up': projects managed and run by local communities with informal support from a professional*. This model is utilized by community gardens with the highest seasonal increases in NPP and highest perceptions of their success. This approach recognizes community members' involvement in the management of their garden, but also incorporates assistance from professional organizations. This finding supports the previous research, which argues that collaboration with the government and NGOs can positively affect collective action and ecological conditions by providing stability and longevity to the garden (Austin et al. 2006; Palamar 2010). Participation was indicated as the most common problem among the interviewed community gardens, including participation in common duties, such as maintenance of common areas and composting. Effective management strategies and better organization represent a solution to this problem.

This study contributes to the existing scholarship by analyzing the success of community gardens and their ecological performance as a function of their governance and the spatial interaction of actors with socioeconomic and environmental conditions. The conceptual model used in this study can be applied by international scholars and practitioners. It also proposes new variables to the SES framework that are specific to community gardening analysis (Appendix A). Gardeners' perceptions of their success and their levels of satisfaction depend on whether they were able to achieve their goals. The most common goals associated with 'very successful' gardens include sustainable, community-based agriculture and organic food production and community building and social exchange. The analysis of key informant interviews did not reveal any associations between the perceptions of success and socio-demographic characteristics of the gardeners, such as ethnic composition and age. Future research should be conducted to investigate the relationships between different socio-demographic characteristics of the gardeners and other socio-ecological measurements of gardens' productivity.

Appendix A

See Table 5.

Table 5 Second- and third-tier variables of the SES framework from Ostrom (2009:421) applicable for studying community gardens. Asterisks indicate factors proposed by this research. Double asterisk indicates a variable proposed by Vogt et al. (2015)

SES variable (code)	SES variable (name)	Explanation/reason for inclusion
Related Ecosystems (ECO)		
ECO1	Climate patterns	This variable includes climate characteristics that are common for all the community gardens in Austin, TX. It affects ecological performance measures (O2)
Resource Systems (RS)		
RS2	Clarity of system boundaries	
RS2-1*	Researcher-defined boundaries of a resource system through on-screen digitizing	This variable affects ecological performance measures (O2)
RS3	Size of resource system	
RS3-1*	Researcher-defined size of resource system	This variable includes gardens' areas and affects ecological performance measures (O2)
RS5	Productivity of system	This variable includes Normalized Difference Vegetation Index (NDVI). It affects ecological performance measures (O2)
RS7	Predictability of system dynamic	
RS7-1*	Consistency of activity related to resource system	This variable describes a consistency of gardening activities. It affects both social and ecological performance measures (O1, O2)
RS8	Storage characteristics	This variable estimates the amount of water stored (Evaporation Stress Index). It affects ecological performance measures (O2)
RS10**	Ecosystem history	
RS10-1*	The longevity of resource system	This variable describes how long a garden exists. It affects both social and ecological performance measures (O1, O2)
Research units (RU)		
RU5	Number of units	This variable includes the number of garden plots. It affects manual delineation of gardens' boundaries through on-screen digitizing
Actors (A)		
A1	Number of relevant actors	This variable includes the number of gardeners and describes the level of participation. It affects both social and ecological performance measures (O1, O2)
A2	Socioeconomic attributes	This variable includes socioeconomic and demographic characteristics of the gardeners. It affects social performance measures (O1)
A5	Leadership/entrepreneurship	This variable describes a model of governance and affects social performance measures (O1)
A6	Norms (trust-reciprocity)/social capital	This variable affects both social and ecological performance measures (O1, O2)
Governance systems (GS)		
GS3	Network structure	This variable includes the number and types of stakeholders involved in a community garden
GS4	Property-rights systems	This variable indicates who owns the land on which a community garden operates
GS5-1*	Rules and protocols	This variable describes who establishes and implements rules and protocols
GS8	Monitoring and sanctioning rules	This variable describes who is in charge of monitoring and sanctioning
Interactions (I)		
I1	Harvesting	This variable includes gardening activities related to crops/vegetables/fruits production as well as planting of flowers
I7	Self-organizing activities	This variable includes activities related to self-governance, garden's maintenance, formal and informal environmental education, and leisure activities
I8	Networking activities	This variable includes activities related to funding, external stakeholders, tenure secure, promotion, distributing surplus
I9	Monitoring activities	This variable includes the process of monitoring
Outcomes (O)		
O1	Social performance measures	Gardeners' perceptions of their success
O2	Ecological performance measures	The seasonal differences in carbon sequestration

Appendix B

See Table 6.

Table 6 The SES variables used as codes to analyze members' perceptions

Open code	Properties	Examples of participants' words
RS7-1 Consistency of activity related to resource system	Describes a consistency of gardening activities: Regularity of workdays, level of participation	Participation is stable/growing/decreasing
		Garden membership is constantly revolving and evolving
		Gardeners coming each day
		Monthly workdays/assigned days to tend the garden
RS10-1 The longevity of resource system	Describes how long a	2009
	garden exists. Includes a year when a garden was established	1978
		November 2011
A1 Number of relevant actors	Includes the number of gardeners and describes the level of participation	15 gardeners
		25 members
		Members from six
		Households
		56
A2 Socioeconomic attributes	Includes socioeconomic and demographic characteristics of the gardeners	Age is for 60 + Seniors, Mostly Asians
		Families or couples in their late 20 s/30 s
		Post-grad students at the University of Texas
A5 Leadership/entrepreneurship	Describes a model of governance	Governed by a Board of Directors
		A core group of 4–5 leaders
		An informal committee
		A selected President
A6 Norms (trust- reciprocity)/social capital	Includes the aspects of community gardening that facilitate actions of cooperation for mutual benefit	Social exchange
		Social events
		Community work days to encourage group cohesion
		Outreach to the neighborhood
		Sharing of knowledge
O1 Social performance measures	Gardeners' perceptions of the success of their community garden	on the LIKERT scale from 'unsuccessful' to 'very successful'
I1 Harvesting	This variable includes gardening activities related to crops/vegetables/fruits production as well as planting of flowers	Sustaining biodiversity
		Wide variety of regionally suited vegetables and herbs
		Plant fruit/nut trees
I7 Self-organizing activities	This variable includes activities related to self-governance, garden's maintenance, formal and informal environmental education and leisure activities	Park cleanup and maintenance events
		'Hands-on' learning about sustainable food
		Regularly held social events
		Labor Day party
		Environmental classes
		Weekly meetings
I8 Networking activities	This variable includes activities related to funding, external stakeholders, tenure secure, promotion, distributing surplus	Collaboration with a local assisted living home
		Building partnerships with local businesses
		Learning laboratory for Cunningham Elementary students
		Donate food to a nearby food bank
		Donate to the women's shelter

Appendix C

See Table 7.

Table 7 Variables used to calculate carbon sequestration (CASA model)

Variable	Description	Units
NPP	Net primary production	g (grams)
PAR	Photosynthetically active radiation	MJ/m2 (megajoules per square meter)
APAR	Absorbed photosynthetically active radiation	MJ/m2 (megajoules per square meter)
LUE	Light use efficiency factor	g/MJ (grams of carbon dioxide per megajoule of energy produced)
NDVI	Normalized difference vegetation index	Unitless
ε°	The maximum possible efficiency/globally uniform maximum	g/MJ (grams per megajoule)
W	The evaporative fraction	Unitless
ESI	Evaporative stress index	Unitless
T_{opt}	Mean temperature during the month of maximum NDVI	°C (degrees Celsius)
T_{mon}	Mean monthly air temperature	°C (degrees Celsius)
T1 and T2	The temperature factors related to plant growth regulation (Acclimation)	Unitless

NPP = APAR*LUE

NDVI = APAR/PAR

NDVI = NIR-RED/NIR + RED

LUE = ε°*T1*T2*W, where W = 0.5 + ESI

Appendix D

The questionnaire.

1. What is the purpose of your community garden? What are your primary and secondary goals? (For example, your goals might be access to fresh food, saving money, providing fresh produce for those in need, promoting environmental education, creating a meeting place for the social exchange, etc.)

2. When did your community garden open?

3. Who owns the land on which your community garden operates? (Is it publicly or privately owned?).

4. How is your community garden governed? In other words, who is responsible for the decision-making in your garden and who is involved in its management? (For example, you may have a group of selected or elected people who make all the decisions, or each gardener is involved in management. You might instead have an external manager—for example, a non-government organization—who conducts the management.)

5. Please describe some management techniques or strategies that you use to achieve the goals of your community garden. (For example, if the purpose of your community garden is to produce food for disadvantaged and vulnerable population groups, then your strategies may include collaboration with food banks, participation in a charity, etc.)

6. How many plots are in your garden? What is the approximate total area of your garden?

7. Do you receive funding from external sources? Would you please name the sources of your funding? (For example, support from a particular non-governmental organization, a sponsor, government, or gardeners themselves.)

8. Is your garden open to the general public? Is membership eligibility defined by a specific community or neighborhood? Who can join? Do you have a waiting list for access to a garden plot?

9. How many members or gardeners do you currently have? How many people (in addition to the gardeners) participate in any other aspect of your community garden? Is participation growing or decreasing?

10. Do you have a sense of the demographics of your participants? What is the age distribution of members of your community garden? Can you describe, in general terms, the ethnic composition of your community garden? Are any ethnic groups prevalent in the membership or are participants diverse (ethnically speaking)?

11. Do you advertise your community garden? If yes, where and how do you advertise?

12. What type of vegetables/plants are grown in your community garden? Are any specific products dominant in the garden's production or do people choose to grow a wide array of plants with significant variation?

13. Please identify any issues, problems, or concerns that you are experiencing in your community garden. (For example, insufficient funding, insufficient space, insufficient participation, or too much unmet demand for space).

14. Please indicate your perception of the success (your personal measure of success) of your community garden by checking the appropriate box on the scale below. (For example, you may consider your garden successful if it serves its purpose(s), achieves its goals, has stable or growing participation, has sufficient funding, etc.)

Unsuccessful	Unsuccessful, but has a potential for improvement	Successful, but with many issues/problems	Successful, but with a few issues/problems	Very successful

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