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An Ecosystem Service Approach to Assessing Agro-Ecosystems in Urban Landscapes

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Abstract: Creating sustainable urban landscapes in light of growing population pressures requires interdisciplinary multi-functional solutions. Alternative agro-ecosystems described as food forests, permaculture gardens, and/or edible landscapes among others could offer potential ways to address the social, economic, and ecological goals of various stakeholders simultaneously. Current research is lacking a comprehensive tool that can assess the performance of alternative agro-ecosystems that have both functional and aesthetic values. The present research uses a novel rubric, the Permaculture and Agro-ecosystems Sustainability Scorecard (PASS) that combines agricultural sustainability and ecosystem services (ES) indicators in order to assess alternative agro-ecosystems. The rubric evaluates provisioning, regulating, supporting, economic and cultural ES and includes benefits such as pollinator presence, increased biodiversity, alternative pesticides and fertilizer use, carbon sequestration, food security, and human interactions. Based on the concepts and principles drawn from four popular frameworks and sub-disciplines, namely, SAFE, SITES, permaculture, and agroecology, we identify sixteen broad ES indicators and 59 sub-indices and measure them using data collected through site observation, survey, interviews, and documentary research. For easy comparison across different urban agriculture sites, the above sub-indices are further aggregated into five ES criteria using stakeholder-informed weights. The weights are developed through pair-wise comparison of criteria by sample survey respondents. The PASS framework is used to score twelve sites in South Florida that meet specific criteria in the small farm, residential, and public space categories. Sample respondents place the highest weight on cultural services. Contrary to the popular notion of promoting urban agriculture for food security, the results show that the majority of the sites score highest in the supporting services provided, followed by regulating and cultural services, and lowest in the economic services category. The supporting service for most of the sample sites score consistently very high, close to the highest possible level of 5.0. There is a wide variation in provisioning and economic values across the study sites. The paper offers several ideas for mainstreaming the ES indicators into urban planning and decision-making and some of the practical difficulties one might face along the way. We conclude that in order to realize the broader ES benefits of urban agriculture in particular and agro-ecosystems in general, a multi-pronged policy and planning approach is necessary.

Keywords: urban agro-ecosystems; permaculture; agroecology; ecosystem services; sustainability indicators

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1. Introduction

The Millennium Ecosystem Assessment (MA), the largest assessment of the health of the Earth's ecosystems to date, found that the last 50 years have brought an unprecedented change in the structure and function of ecosystems, primarily to meet demands for food, fresh water, and other products [1]. Agriculture is intrinsically related to the ecosystem services that support it; therefore, future productivity and sustainability depend on the ecosystem services such as air quality, climate regulation, erosion, pest control, and pollination [2]. Yet, ecological degradation associated with agriculture is severe. For example, second only to the burning of fossil fuels, agriculture and deforestation account for nearly half of all greenhouse gas emissions worldwide. The degradation will only worsen without significant changes being made in policies, institutions, and practices around the world [1].

Nowhere are the impacts of these changes in ecosystem structure felt more than in urban areas, with over 60% of the world's population predicted to reside in cities by 2030 [3]. These hot spots for global environmental change are central to the discussion of sustainable development and growth [4]. To make cities more sustainable, urban planners grapple with the question of how we achieve the multiple goals, including that of at least partially meeting the urban food demand while retaining the urban ecosystem services. Many alternative farming systems that regenerate ecosystem services have been demonstrated for varying environmental conditions [5,6]. Over the last few decades, many cities have adopted green infrastructure programs that focus on urban forestry, developing trails that connect neighborhoods, restoring habitat, and urban agriculture as comprehensive solutions to urban challenges [7,8]. The goals of these programs are varied, including: (a) improving micro climate of the urban environment (e.g., lower temperature and better air quality); (b) improving overall aesthetics; (c) providing health and recreational benefits; (d) increasing biological conservation in urban areas; and (e) increasing urban food security.

Urban landscape designers are increasingly promoting multi-functionality to address multiple needs and functions simultaneously as natural and financial resources become more limited with increasing population pressures. In landscape planning, multi-functionality refers to multiple ecological, social, and economic functions being considered and combined in the process of design and decision making in order to use space more efficiently [9]. The multi-functionality design of agricultural systems is a potential way to bridge the gap between aesthetic and practical functions of the urban landscape, with far-reaching implications for both food security and public health among other benefits.

Sarah [10] reports that local food policy councils and advocacy groups played a key role in promoting urban agriculture (UA) in developed countries. From a survey of 55 cities in the Southern United States, Fricano and Davis [11] find that some form of UA exists in about 87% of the study cases. In fact, there has been a steady increase in households in the US that are involved in some type of food gardening [12]. The challenge among urban planners is to view UA within the conceptual framework of the design and construction of cities and as a component to address economic and environmental issues rather than as a competing land use [13].

There are several forms of UA currently being practiced in vacant lands, rooftops, school grounds, housing facilities, community-supported private farms, and other locations [11,14]. Relatively new practices in the urban environment such as urban food forests seek to integrate UA, urban forestry, and agroforestry practices in productive landscapes that maximize utility and services. Seattle, Washington, is a case in point, where part of their green infrastructure vision is to utilize urban forests not only for the hydrological services but also as a source of goods such as fruit, nuts, building materials, and fuel in order to achieve the highest potential of urban sustainability [7]. Permaculture gardens [15] are another alternative found primarily in private land but with a tremendous potential across different scales and functions.

Alternative agro-ecosystems characterized by diverse perennial polycultures have both aesthetic and functional value and great potential for meeting human needs while providing essential ecosystem services in urban landscapes. However, as a result of the complexity and heterogeneity of these productive landscapes, there is a lack of information and understanding of their overall benefits. Ecosystem services, such as pollination, water and air purification, and aesthetic value can be useful as indicators of the performance of these designed systems, which link science, design, and management [16]. There is a need for researchers to design tools that quantify and monitor these benefits so that decision-makers can make informed land-use policy decisions [13,16–18]. Furthermore, having tools to measure the outcomes of the ecosystem services provided by urban agro-ecosystems will ensure that future initiatives will have more realistic goals and help cities become more sustainable [16].

The overall goal of this research is to assess the performance of alternative agro-ecosystems that have both functional and aesthetic values for productive landscapes in urban environments. In order to accomplish this goal, we aim to develop a new rubric called Permaculture and Agro-ecosystems Sustainability Scorecard (PASS) and illustrate the same in the context of South Florida's (USA) urban and peri-urban landscape. This rubric draws important ecological and socio-economic concepts from the literature. The key concept we will include is ecosystem services (ES) which are defined as all the benefits that people obtain from ecosystems including provisioning, regulating, supporting, and cultural services [1].

Past literature is replete with studies that have developed assessment indicators and tools based on a myriad of concepts and disciplines such as ecosystem services, agricultural sustainability, landscape sustainability, permaculture, and agroecology. "Ecosystem Services" (ES) indicators capture the benefits that people obtain from ecosystems including provisioning, regulating, supporting, and cultural services [1]. The ES framework uses a cascade model that begins with the biophysical structures, which form the basis for various ecosystem processes, functions, benefits, and finally, the values obtained from the ecosystem benefits [19]. Indicators based on the notion of "agriculture sustainability" first recognize that the intensification of food production has led to well documented ecological consequences, such as pollution, loss of genetic diversity, dependence on non-renewable resources, as well as the loss of local control over agricultural production, which can lead to large scale inequalities in the distribution of food [20]. In order for agriculture to be sustainable, the production practices must support the integrity of the underlying ecosystems and maintain diversity, productivity, regeneration capacity today and in future generations [21]. de Olde et al. [22] identified 48 agriculture assessment tools that were founded on the basic sustainability principles. One of the tools they review is the Sustainability Assessment of Farming and the Environment (SAFE), which is a hierarchical framework for assessing the sustainability of agricultural systems. This tool follows a holistic approach, covering all the components (i.e., physical, biological, and economic) of agricultural production [23]. A noteworthy feature of this framework is that it works on multiple spatial levels from farm or site level to the regional or state level.

Created as a collaborative effort between the United States Botanic Garden, the University of Texas at Austin, and the American Society of Landscape Architects, The Sustainable SITES Initiative (hereafter called SITES) offers a "systematic comprehensive set of guidelines and a rating system that defines sustainable sites, measures their performance and ultimately elevates the value of landscapes" [24] (Sustainable SITES Initiative, 2014). SITES recognizes that using appropriate design as part of the given agroecological system not only maintains ecosystem services but also enhances them. While the framework is relevant to improve outdoor "landscape sustainability," it still lacks in being tailored particularly for multi-functional urban agriculture projects as they are intended for projects suitable for parks to office buildings.

The next set of indicators draws from principles that guide "permaculture" design, namely, ethical tenets of care for the earth, care for people, and a return of surplus [25]. Central to permaculture is the idea of maximizing the synergy between elements so that the whole becomes greater than the sum of its parts. The concept is grounded in the work of Joseph Russel Smith's "Tree Crops: A Permanent Agriculture" and the science of systems ecology which largely focused on interactions and transactions between biological and ecological systems and their relationship to human interactions. There are twelve main principles and practices focusing on soil, water, energy, biodiversity, plant yield, etc., each of which is expected to enhance one or more ecosystem service benefits [15,25,26]. For instance, its "Observe and Interact" principle requires that the site and all of its existing ecological and human components be carefully analyzed and considered before taking any action. It treats the landscape as an experiment needing constant reevaluation of the results and an adaptive strategy for change when necessary. It calls for inter and multi-cropping methods for the purposes of pest control and soil regeneration. The permaculture practice demands that human knowledge, to natural plants or "weeds" growing in a site, and system diversity be preserved and encouraged.

The final system of indicators and assessment that guide this study is based on the growing discipline of "agroecology," which posits an agroecological food system as "one that maintains the resource base upon which it depends, relies on a minimum of artificial inputs from outside the farm system, manages pests and diseases through internal regulating mechanisms, and is able to recover from disturbances caused by cultivation and harvest" [20]. The natural ecosystem is used as a point of reference and the principle holds that if an agroecosystem is similar in structure and function to the natural systems of that bioregion, the system will be sustainable. For example, in a natural system resilience and diversity are relatively high while reliance on external human inputs is low [27]. The agroecology-based production system entails utilizing traditional knowledge, mimicking nature, utilizing multi-species, integrating soil fertility management techniques, and utilizing diversification of crops to reduce pest populations [6,28,29]. The framework for measuring and quantifying sustainability within agroecology comes from the science of ecology which already has a well-developed set of methodologies for quantifying ecosystem services such as nutrient cycling, population dynamics, and species interaction. It also borrows from behavioral science disciplines to evaluate socioeconomic characteristics such as autonomy or dependence on external forces or stability of the organization and activity [20].

While SAFE and SITES possess the aforementioned merit, a comprehensive rubric based on scientific and ethical principles for evaluating site- or farm-specific agricultural and ecological attributes was missing. PASS, the framework developed in this study, uses some of the useful elements from SAFE [23] and SITES [24], but it is more grounded in scientific and ethical principles of permaculture and agroecology. For instance, SAFE is more holistic in nature and SITES is very prescriptive about the quantitative approach to rating the performance of different services. This study adds to the agriculture sustainability assessment literature in three distinct ways: (a) a novel rubric created by synthesizing the ecological, economic, and ethical principles of two well-established agriculture subdisciplines, namely, permaculture and agroecology; (b) traditional urban agriculture literature has mostly focused on practices, resources, and policies that are necessary to maximize food production in urban areas [11,30,31]. By following the Millennium ES approach, our rubric aims to capture not only the traditional urban food security benefit but also a host of functional, aesthetic, ecological, and cultural co-benefits. That is, our approach explicitly integrates the two popular evaluation systems, namely ecosystem services benefits and the traditional urban agricultural benefits, into a common framework. This integration of a broader range of benefits opens up new opportunities, resources, policies, and public support for sustaining urban agro-ecological systems in the long run; and (c) using a variety of urban agro-ecological systems, this study identifies challenges and opportunities that exist in making urban agriculture ecologically, economically and culturally more robust. This information is highly valuable to urban planners as well as practitioners of urban agro-ecological farming.

2. Methods

2.1. Study Area

South Florida is unique for many reasons, including being the only subtropical region within the continental US, part of the Greater Everglades Ecosystem, and one of the most vulnerable regions to climate-driven sea-level rise in the world [32–34]. The subtropical climate gives producers a year-round growing season and an abundant diversity of potential woody perennial crop species to choose from. Yet, because of its location on a low-lying Peninsula and unique geological history, Southeast Florida is particularly vulnerable to harsh conditions including occasional freezes, rainfall extremes, saltwater intrusion, coastal erosion and flooding, inland flooding, and extreme storms [35]. Miami-Dade County has the largest population with diverse cultural background in the area, with approximately 2.5 million people from 121 countries, growing at a rate of 2.1% per year. However, South Florida is not as densely populated as other urban areas across the United States. For instance, in Miami-Dade County alone nearly 514,450 ha of vacant land are present, 62.5% of which belong to Parks/Conservation and Recreational Spaces, and 10.6% are undeveloped vacant land. Miami-Dade county ranks 11th in the nation in food insecurity, with 11.8% of its population being food insecure in 2018 [36]. Even though Miami-Dade is the second-largest agricultural producer in the nation over 95% of its fresh produce is sold outside of the county [37]. This not only affects the quality of the food available to people but also increases the carbon footprint.

We selected sites that are representatives of various agro-ecological types in the study area based on the following broad ecological and geographic criteria: (a) site that represented one of the following urban built or natural environments: residential homes, public parks/community gardens, or small farms; (b) those with five or more plant species that are grown for food production; (c) at least 20% of site is comprised of perennial polycultures with 3 or more species; and (d) site is used for 2 or more functions such as production, education, and tourism. The above criteria were adapted to ensure that the sample study sites included urban food production types that were functionally, ecologically, and culturally diverse, and that allowed us to compare and contrast systems based on a wide range of ecosystem services and benefits. The sample sites were selected through research of the area and from recommendations from colleagues and practitioners in the field.

A total of 17 sites were considered before the final 12 that adhered to the above sampling criteria were chosen. Eight of the sites were in Miami-Dade County, two in West Palm Beach, and two in Fort Myers on the West Coast of Florida. Four of the sites—two schools, one residence, and one farm—were in urban areas while the remaining sites were in peri-urban areas.

The twelve sample sites (Table 1 and Figure 1) fall under one of three main categories: farm, residential/private and public, with some overlap, for example, several employees live on-premises at Treehuggers Farm while Earth n Us although considered an urban farm is primarily a residential community. The categories were assigned based on the primary activity conducted on each site. Although the majority of the sites have multiple purposes, six of them had education as their primary purpose, with two others being residences with very close ties to education, two to food production, one to nursery production and one to residence. One of the major difficulties of this study, and of comparing these systems in a rigorous manner is the wide range of sizes and years established. The size ranged from 743 m^2 to 4 ha and the years established from 1 to over 40 years. It is important to note that during our field observations and interviews, we focused on approximately a 743 m^2 area for the sake of comparison, for example, as far as the cost of maintenance. While with other factors such as the presence of a water management scheme the site was looked at as a whole.

2.2. Identification of PASS Framework Indicators

There is no agreement among researchers as to what ecosystem service indicators are appropriate for assessing alternative agro-ecosystems. Nor is there an agreement on how one should define and measure each service. For instance, for the SAFE framework, Van Cauwenbergh [23] characterizes food production service as the production capacity being compatible with society's demand for food and being able to produce quality food. Permaculture definition of food production focuses more on the practice aspect of food production: with a small intensive production system with diversified species and maximum space utilization [15]. Similarly, the SITES definition of fresh water service is to reduce water use for landscape irrigation [24] whereas the agroecology interpretation of the same is more practice-oriented, such as adaptation to distribution and variability of water [6,20].

For the PASS framework developed in this study, we use a synthesized version of all the four main frameworks for each ecosystem service. Table 2 features different ES indicators and sub-indicators used in the study and the disciplinary/framework bases (i.e., SAFE, SITES, Permaculture and/or Agroecology) that each sub-indicator is rooted in.

Table 1. Descriptive characteristics of the sample study sites.

Sites	Category	Area	Main Crops	Ownership	Year Established	Location	Primary Goal
Muni Farms	Farm	4.05 ha	Nursery Plants	private	2012	Redlands	Nursery Production
Guara Ki Eco	Farm	1.21 ha	Lychees/ Mamey/ Greens	private	1996	Homestead	Education
Echo Global Farm	Farm	4.05 ha	Moringa/ Rice/ Sorghum/ Vegetable	ngo	1981	Ft. Myers	Education
Little Haiti Garden	Farm	0.20 ha	Arugula/ Kale/	private	2008	Little Haiti	Food Production
Treehuggers Farm	Farm	1.86 ha	Annual Vegetable	private	2012	Davie	Food Production
Florida Gulf Coast Food Forest	Public	0.40 ha	Fruits	public	2011	Fort Myers	Education
Booker T. Washington Food Forest	Public	743 m^2	Fruits	public	2015	Overtown	Education
Mounts Botanical	Public	743 m^2	Annual Vegetable	public	2004	West Palm	Education
Twin Lakes Food Forest	Public	1208 m^2	Perennial greens	public	2011	Hialeah	Education
Earth n Us Farms	Residential	1.21 ha	Annual Vegetable	private	1977	Little Haiti	Residence/ Education
Gaia Ma	Residential	743 m^2	Fruit/Greens	private	2014	North Miami	Residence
Unbelievable Acres	Residential	0.81 ha	Fruits	private	1970	West Palm	Residence/ Education

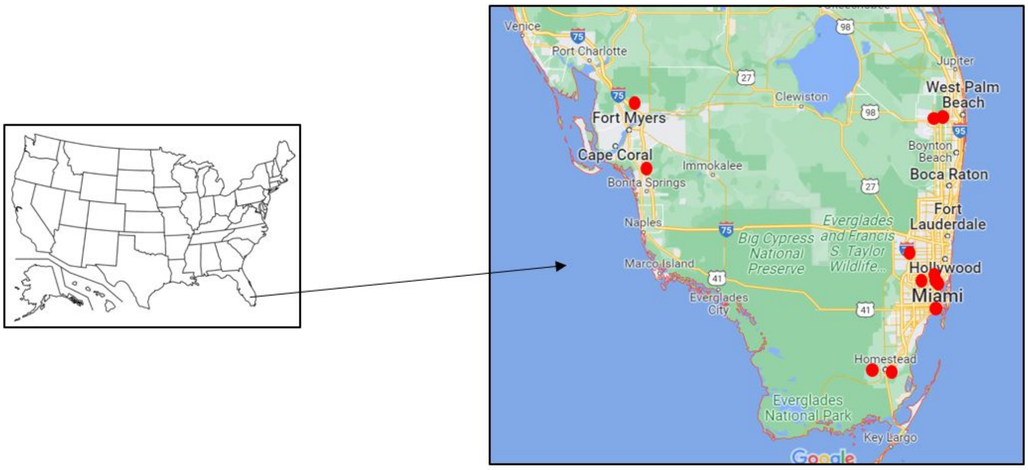

Figure 1. Map of sample farm sites in South Florida (created by authors using the study area map from Google [38]).

Table 2. Ecosystem service-based sustainability criteria and indicators and the rubric used in the P+ ASS.

Ecosystem Services Indicators	Sub-Indicators	Unit for Rating	Ideological Bases of Sub-Indicators: [1] SAFE SITES Permaculture (PERM) and/or Agroecology (AGRO)
	Provisioning Services		
Food Provision: Cultivation of edible plants harvested and used for human nutrition	diversity of food: maximize use of space and diversity of productive species	5 species (1 low)—40+ species (5 high)	AGRO
	quantity of food: (1) internal, (2)market, and (3) restaurant	marginal (1)—maximized (5)	SAFE, SITES
	food produced year-round	no (0)—maximized all year (5)	SAFE
	local food security needs	all exported (0)—all locally distributed (5)	AGRO
	use of available space	10%–25% (1)—90%–100% (5)	PERM, SITES
	Production layers	1–2 layers (1)—6–7 layers (5)	PERM
Fresh Water Provision: Freshwater available for drinking, irrigation, and other uses	rainwater harvested on site	no methods used (0)—significant portion of water used (5)	AGRO
	water is recycled on-site	no system in place (0)—all (5)	PERM
	aquatic systems are enhanced or restored	none used (0)—methods used to enhance and restore (5)	PERM
	micro-irrigation is used to reduce water needs	none (0)—all (5)	SITES
Raw Materials: Other products such as wood for fuel or construction, medicinal plants, forage plants such as mushrooms, oils, and ornamentals	biomass is optimized	minimal (1)—maximized (5)	SITES
	canopy structure is managed for optimal rates of light transmission	minimal (1)—maximized (5)	AGRO
	building energy use is minimized	minimal (1)—maximized (5)	SAFE; SITES
	Supporting Services		
Soil Formation: The facilitation of soil formation processes which include chemical weathering of rocks and the transportation and accumulation of inorganic and organic material	soil loss is prevented	no methods used (0)—3–4 methods used (5)	SAFE; PERM; AGRO
	soil chemical and physical quality is enhanced	no methods used (0)—3–4 methods used (5)	SAFE; AGRO
	all organic matter is recycled on-site	none (0)—all (5)	SITES; AGRO
	disturbed soils are restored and enhanced	none (0)—all (5)	SITES
Biodiversity: The presence of selected species, groups of species, habitat components, and species composition	Increased biodiversity at the site	low (1)—very high (5)	SAFE; PERM; AGRO
	diverse habitat in wild places or non-production areas	low (1)—very high (5)	PERM
	spatial and temporal diversity	low (1)—very high (5)	AGRO
	functional diversity	low (1)—very high (5)	AGRO
	genetic diversity	low (1)—very high (5)	SITES; PERM

Table 2. *Cont.*

Ecosystem Services Indicators	Sub-Indicators	Unit for Rating	Ideological Bases of Sub-Indicators: [1] SAFE SITES Permaculture (PERM) and/or Agroecology (AGRO)
Nutrient Cycling: The capacity of an ecosystem to prevent the irreversible outputs of elements from the system, and the ability for nutrient and matter cycling	organic matter is utilized on-site	none (0)—all (5)	SITES; AGRO
	nitrogen fixers	none (0)—maximized (5)	PERM; AGRO
	composting	none (0)—maximized (5)	PERM; AGRO
Regulating Services			
Climate Regulation: Long-term carbon storage in aboveground biomass and soil organic matter. Moderation of local climate components such as wind, temperature, and radiation	use of long-lived perennials	10%–25% (1)—90%–100% (5)	PERM
	windbreaks are used	none (0)—maximized (5)	SAFE; PERM
	microclimates are created	none (0)—maximized (5)	SITES
Air/soil Quality: Capturing and filtering of dust, chemicals, and gases	use of synthetic fertilizers	all nutrient needs (0)—none (5)	PERM; AGRO
	use of pesticides	all pest control (0)—none (5)	PERM; AGRO
	surplus waste is managed on-site	none (0)—all (5)	AGRO
Biological Control/Pollination: Animals and insects that contribute to pollination of plants. The capacity of the ecosystem to control pests and diseases due to genetic variations and the action of predators and parasites	use of crop diversity	5–10 species (1)—over 50 species (5)	AGRO
	pest problems are managed	many pest related problems found (1)—little to no pest problems found (5)	SITES
	plants present that attract pollinators	2–3 species (1)—over 10 species (5)	PERM
Water Use/filtration: Maintaining of water cycle features and the capacity of an ecosystem to purify water from sediments, pesticides, microbes, and pathogens	water is preserved through a water management scheme	none (0)—all (5)	AGRO
	precipitation is managed on site	none (0)—most (5)	SAFE; SITES
	water is recycled on site	none (0)—all (5)	PERM
	drip irrigation is used	none (0)—all (5)	AGRO
Erosion/Flood Control: Soil retention and the capacity to prevent and mitigate soil erosion and to maintain water cycles features such as natural drainage	soil mass flux is controlled and buffered	some (1)—very prevalent (5)	SAFE
	vegetation is always present to hold soil in place	in some areas (1)—always (5)	SITES; AGRO

Table 2. *Cont.*

Ecosystem Services Indicators	Sub-Indicators	Unit for Rating	Ideological Bases of Sub-Indicators: [1] SAFE SITES Permaculture (PERM) and/or Agroecology (AGRO)
Economic Services			
Economic: Project is economically sustainable overtime and only minimally dependent on subsidies, supporting and contributing to the local economy	dependency on external finances and subsidies	all (1)—none (5)	SAFE; PERM; AGRO
	project supports local economy	1–2 ways (1)—5–6 ways (5)	PERM; AGRO
	cost of establishment	very high (1)—low (5)	SAFE
	cost of maintenance	very high (1)—low (5)	SAFE
Cultural Services			
Recreation and tourism: All forms of leisure and tourism related to the system including tours, volunteer activities, and leisure	number of visitors per year	0–25 (1)—over 200 (5)	PERM; AGRO
	number of special events and activities	1–2 events (1)—6 or more (5)	SITES; PERM
	community service/volunteer programs	none (0)—year-round (5)	PERM
Educational activities: The education derived from the system in terms of traditional knowledge and specialist expertise	learning activities and events	0–5 (1)—over 25 (5)	SITES; PERM
	site is used as a case study	none (0)—most of the time (5)	SITES
	site is monitored for performance	none (0)—most of the time (5)	SITES
Natural and cultural heritage: The maintenance of historically important landscapes and types of land use	cultural and historic value features are enhanced or maintained	none (0)—maximized (5)	PERM
	natural value features are enhanced or maintained	none (0)—in-depth (5)	PERM
	local crop varieties are incorporated	none (0)—all (5)	AGRO
	local knowledge and culture is incorporated	none (0)—in-depth (5)	SAFE; STIES; PERM; AGRO
Design aesthetics: The visual and functional quality of the system arrived at by the strategic process of design which influences human well being	pre-design site analysis was conducted	none (0)—in-depth (5)	SITES
	stakeholders are engaged in design process	primary only (1)—all (5)	SITES
	aesthetic considerations	none (0)—in-depth (5)	SITES; PERM
	functional considerations	none (0)—in-depth (5)	AGRO
	design elements are placed relative to one another with multiple uses in mind	none (0)—all (5)	PERM

[1] SAFE = Sustainability Assessment of Farming and Environment [23]; SITES = Sustainable SITES Initiative [24]; PERM = Permaculture [15,25]; AGRO = Agroecology [6,20].

The present study intended to compare a variety of sites that were highly heterogeneous both in scale and in nature, to maximize the application of PASS. Additionally, due to their size, economics, and missions, most system operators did not keep detailed records as in other types of agricultural operations. Previous studies have considered qualitative indicators based on the presence or absence of certain practices, and on potential for certain ecological and socio-cultural benefits [6,15,20]. The conceptual framework for the study therefore utilizes practices and/or overall qualitative benefits of the service as proxies for indicator measures when exact data were not available at each of the sites.

A total of 16 ES indicators were selected within five categories: 3 provisioning services, 3 supporting services, 5 regulating services, 1 economic service, and 4 cultural services. Each of the 16 main indicators consisted of multiple sub-indicators, which in total amounted to 59 sub-indicators. Our study farms or gardens were so diverse that no single indicator for any ecosystem service would have captured all the study sites. Therefore, we considered multiple indicators for each main ecosystem service criterion. Each main ecosystem service (provisioning, regulating, etc.), therefore, was a composite of multiple ecosystem service indicators, and in turn, sub-indicators. See Table 2 for the final criteria, indicators, and sub-indicators included in the PASS framework.

Each of the 16 ES indicators, their underlying definitions, and the measurement approaches were designed by keeping in mind the diverse goals that modern urban agro-ecological systems had tried to achieve [5–8]. For instance, food provisioning ES in Table 2 considered six different attributes of local food system, namely, the food diversity, quantity, year-round production, local food security needs, use of space (spatial extent), and use of space vertically (maximum 7 layers). While the primary goal of the modern scientific advances and technological innovations related to agriculture has been to increase food production [39], alternative agro-ecosystems focus on multispecies cropping systems, which have many potential advantages, such as increased biodiversity, nutrient cycling, and carbon sequestration [40].

Similarly, cultural ES are any non-material benefits that people obtain from interacting with the site including cultural enrichment, recreational experiences, and educational opportunities. These services are considered one of the most difficult to measure and access and the one with the least potential for mediation once it has been degraded [1]. Community service activities were shown to help participants establish a great sense of communal bonding, empowerment, and interaction among community members. Edible gardens were proven to be a versatile and effective tool to teach all age groups about environmental sustainability, healthy eating, cooking. Past studies have used techniques to measure the socio-cultural impact of sites through surveys, focus groups, questionnaires, and in-depth interviews [41]. We used a combination of non-structured interviews and participant observations to derive values of various cultural ES values. Particularly, we estimated the values of different sub-indicators, namely, number of special events and activities held, community/volunteer service events, and number of visitors per year, as measures of social, leisure, and tourism ES.

Design aesthetics deals with how people experience their environment through the senses, combining art and science, intuition and logic. Although very hard to measure, visual aesthetic values are an important service of the built environment and a primary consideration for designers, including proportion, scale, proximity, and other design principles. The tradition of ecological design goes beyond aesthetic principles and also prioritizes ecological functions as a basis for urban and site design where change is embraced and the design self-organizes and persists such as nature [42]. Permaculture design in particular is holistic in nature and firmly grounded in ecology taking into account the inter-relationship and interdependence of living things and their environment. Using the tools of observation, analysis, and synthesis the results are applied to the design, which is a combination of site-specific requirements and the goals of the owners [25].

2.3. Measurement of Indicator Values

Indicator values were obtained through observation, participant surveys, and consulting literature. We held a detailed discussion with each sample respondent to understand the agro-ecological practices, and their performances or outcomes (e.g., physical, biological, and social). At the end of this discussion, with the combination of the input provided by stakeholders and our best-educated judgment, we arrived at appropriate performance values for each of the indicators. While assigning performance values, the rubric scale ranging from 0 to 5 was used in such a way that the small number was low (inferior) and large number was high (superior). See Table 2 for the rubric values for each indicator and sub-indicator.

2.4. Weights of Indicators

In assigning a value to each of the indicators and sub-indicators, it is important to recognize that not all of them have equal significance in the eyes of the operators/farmers and society in general. Therefore, weight has to be assigned in order to aggregate sub-indicators, indicators, and ES criteria, in order to facilitate comparison across agro-ecological sites. This was carried out in three steps. First, for simplicity, we assumed that each main indicator (e.g., food provision, freshwater provision, etc.) is a composite of multiple sub-indicators representing different aspects of the same indicator attribute. All sub-indicators within an indicator group received equal weights; for instance, food provisioning indicator had six sub-indicators, and therefore, each sub-indicator was assigned a weight of one-sixth.

Second, the weights were assigned to all the indicators within each of the five ES categories based on the literature. A comprehensive inventory conducted by the European Commission's Joint Research Center in 2012, which reviewed 70 peer-reviewed articles on the use of indicators for quantifying ES, found that within provisioning service indicators 28 dealt with food provision, 20 with water provision, and the remaining 10 with other raw materials provision [43]. Food provision received the most attention (i.e., about 40% of the studies), followed by water provision indicators. Regulating services had the largest number of articles (nearly 75% overall) of any ES and among them, climate regulation had the overwhelming majority. This was followed by water flow regulation with one-third of the studies in this category. Using the emphases given by the literature on different ES indicator attributes, we assigned appropriate weights, which are reported later in Table 3 (last column).

Table 3. Indicator Weights.

Category	Category Weights	ES Indicators	Indicator Weights
Provisioning	0.25	Food Provision	0.50
		Fresh Water Provision	0.30
		Raw Materials	0.20
Supporting	0.20	Soil Formation	0.25
		Biodiversity	0.50
		Nutrient Cycling	0.25
Regulating	0.12	Climate Regulation	0.40
		Air/Soil Quality	0.10
		Biological Control	0.10
		Water Regulation	0.30
		Erosion/Flood Control	0.10
Economic	0.13	Economic	1.00
Cultural	0.30	Physical/Social Activity	0.20
		Educational Activities	0.40
		Cultural/Historic Value	0.20
		Design	0.20

Third, we assumed that the sample study site owners had attached a varying degree of importance to the five broad ES criteria. We implemented the Analytic Hierarchy Process (AHP) [44] (Saaty, 1980) to develop weights representing the importance they placed on the ES criteria. AHP is a common approach used in past multi-criteria decision analysis to prioritize different criteria of a given system or program [45–47]. Following these studies, we asked a sub-sample of eight participating farmers to compare two criteria at a time to each other (i.e., a pair-wise comparison) in terms of the intensity of preference on a scale from 0 to 9 (0 means no difference in importance between the two criteria and 9 means one criterion is nine times more important than the other). Each farm operator did the pair-wise comparison independently. This intensity scoring method resulted in total intensity score for each criterion relative to all other criteria. Then, weight of each criterion was obtained by taking the ratio of its total intensity score to the sum total of intensity scores of all criteria. We then computed the sample average weight for each criterion.

2.5. Data Collection

Data for the study were gathered through a tour of each site, casual observation, and an in-person interview of each owner/operator or relevant staff of the case study site using a survey instrument during 2015. We asked specific questions that informed each of the five ES sections in the rubric, specifically 16 main indicators, and 59 sub-indicators. For instance, with regard to the food provisioning service, we asked what the main crops were grown on-site, if they kept records of the yield for these crops, how much of the food they consumed and/or disposed to the market, what percent to local market and what percent exported out of the region, and if their site followed the seven layers of permaculture design. With regard to freshwater provisioning, we asked various questions on how water (surface, ground, and soil) was managed on-site, if they recycle water, and what water use efficiency measures they used (including micro-irrigation). Similarly, the survey continued with specific questions and observations with regard to supporting services involving soil, nutrient recycling, and biodiversity. Visual observation of the soil on site was made to give a value to the soil quality indicator, followed by specific questions on year-round practices on soil building, cover cropping, mulching, use of diverse plants on cropland and surrounding area, and finally soil nutrient management.

The survey continued with questions with regard to practices covering four regulating services, namely, carbon sequestration, biological pest control, water usage, and erosion/flood control. Specifically, the survey asked what percent of the site was planted with perennial plants as a proxy for potential for carbon sequestration. We also asked what kind of pest-control measures the respondent used on-site, i.e., whether synthetic, organic, or combination of the two. The survey tried to find out if one or more of the following water use mechanisms were used: grey water, small ponds, rain barrels, micro-sprinkler system, drip-liners, and water filtration system. The purpose of these questions was to assess the extent to which the study site maintained water cycle features that would enhance agro-ecosystem's capacity to purify water from sediments, pesticides, microbes, and pathogens. Finally, we also inquired whether the study site adapted any practices to hold soil in place from erosion and flooding.

In the next section, we asked a few questions about various input needs of the site including free (volunteer) and purchased labor, and the overall costs of production of standard unit size. We were also interested in the length of time involved in establishing the study site. Finally, we asked a number of questions on the cultural aspects of the study site: how many visitors they received annually, how many volunteers and school groups visited the site, what kind of educational and social activities they conducted at site, if they provided opportunities for agro-tourism or recreation if their site was used as a case study for observations, and if the site made any "design" attempt to enhance the visual and functional quality of the system.

The pair-wise comparison questionnaire was taken at eight sites. Questions related to each ES indicator in the rubric were asked of the site owners or operators who were familiar with the design, installation, and ongoing maintenance of the system.

3. Results

3.1. Ecosystem Indicator Weights

Table 3 presents the weight attached to each ES category based on the inputs provided by site owner/operators using pair-wise comparison. In our study, eight of the site owners responded to complete the pair-wise matrix survey: four in the farm category, three public, and one residence. The survey results showed that six out of eight farmers/operators favored cultural practices overall. One respondent each favored economic service and provisioning services, respectively. Thus, the average weight of the cultural score was 0.30, followed by provisioning services (0.25), supporting services (0.20), economic services (0.13), and regulating services (0.12). Table 3 also shows the weights attached to ES individual indicators within each criterion. Weights of all indicators within each criterion add up to 1.0. Some of the significant intra-criterion indicator weights to note were food provision (provisioning service) with 0.5, climate regulation with 0.4 (regulating service), and educational activities with 0.4 (cultural service).

3.2. Ranking According to PASS

Figure 2 and Table 4 present aggregate PASS values of the five main ES criteria for the sample farms/gardens. The radar diagram in Figure 2 suggests that the supporting, regulating, and cultural services receive consistently high scores overall, i.e., the more sample farms register scores closer to the highest possible level of 5.0. There appeared to be a wide variation across the sample farms in terms of scores registered for provisioning and economic values, thus making their average values lower than the averages of supporting, regulating, and cultural services.

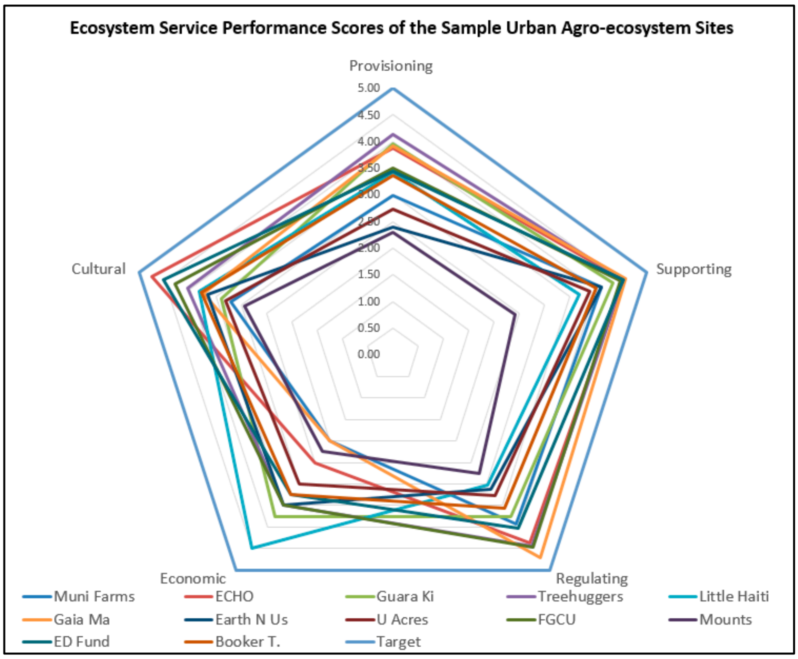

Figure 2. PASS ecosystem service scores of sample urban agro-ecosystem study sites.

Table 4. Ecosystem services ranking of representative agro-ecological systems based on PASS.

ES Category	Urban Farms					Residential Food Gardens			Public Space Farms/Gardens			
	Muni Farms	ECHO	Guara Ki	Tree-Huggers	Little Haiti	Gaia Ma	Earth n Us	U Acres	FGCU	Mounts	Twin Lakes	Booker T.
Provisioning	2.98	3.88	3.96	4.14	3.43	3.91	2.40	2.73	3.50	2.29	3.45	3.36
Supporting	4.11	4.55	4.34	4.56	3.67	4.60	4.12	3.88	4.49	2.41	4.55	4.01
Regulating	3.94	4.36	3.77	4.45	3.04	4.72	3.13	3.27	4.46	2.76	4.02	3.56
Economic	2.00	2.50	3.75	3.50	4.50	2.00	3.50	3.00	3.50	2.25	3.25	3.25
Cultural	3.19	4.76	3.38	4.06	3.82	3.74	3.66	3.30	4.30	2.93	4.52	3.78
Composite score	3.30	4.23	3.84	4.20	3.72	3.78	3.09	3.02	4.11	2.32	3.70	3.67

ECHO Global Farms had the highest score overall (4.23) and the highest cultural score (4.76). Treehuggers Farm (4.20) and the FGCU Food Forest (4.11) were in second and third place, respectively. Treehuggers had the highest score for provisioning services (4.14). Little Haiti Community Garden had the highest economic service score (4.50). Gaia Ma, a residence, had both the highest supporting (4.60) and regulating score (4.72). Overall the composite scores in the Farm Category were higher than the residential and public category. The lowest score was for Mounts Botanical Edible Gardens (2.32) and Unbelievable Acres (3.02).

3.2.1. Urban Farms

There are five sample farms in this category: (a) three in peri-urban areas of Florida City/Homestead and Davie, which included Muni Farms, Guara Ki Eco Farm, and Treehuggers; (b) one in an urban part of Miami, Little Haiti Community Garden; and (c) one in a peri-urban area of Fort Myers, ECHO Global Farms. The sites in the farm category had the highest scores overall and two of the highest scores were for cultural and provisioning services. On average supporting services scored highest in the farm category followed by regulating and cultural services. The Little Haiti Community Farm had the most well-balanced approach to each of the categories, followed by Guara Ki and Treehuggers, with Muni Farms leaning more heavily towards the supporting and regulating services and ECHO towards cultural services.

Muni Farms is a four-hectare family farm in the Redlands established in 2012. Their vision was to create a sustainable farm model that works with nature by using bio-mimicry in a self-maintained ecosystem. This project was in its beginning stages with a comprehensive permaculture design for all its area therefore individual parcels were not developed to their full potential yet and the cost was high running at USD 100,000 a year for labor and materials. These two reasons could explain why it scored the lowest in the farm category (3.30); once in full production, their score will probably change considerably. Special focus and attention were given to creating a native wind break and wildlife habitat surrounding the garden with over 25 species including Stoppers, Cocoplum, etc. The farm paid special attention to preserving and enhancing the natural heritage of the property, as well as providing a space for educational activities such as permaculture workshops; this probably helped explain the cultural service score for this farm of 3.19. Planting beds are covered with organic mulch to keep soil from eroding and perennial peanut is used as a groundcover. These practices earned the fourth-highest score (4.11) for supporting services.

Guara Ki Eco is a two-hectare learning farm in Homestead, which is part of the local non-profit Earth Learning. It hosted a variety of workshops, classes, and tours year-round, as well as selling products directly to restaurants and consumers. The farm had multiple tropical fruit trees and vegetables. Layers were integrated among the fruit trees of edible perennial and annual species following the permaculture and food forest model. The farm did not use fertilizers or pesticides but relied on organic mulch, horse manure, compost, chicken manure, and worm castings produced on-site. Guara Ki followed the trend of the farm category with the highest scores in the supporting (4.34), provisioning (3.96), and regulating services (0.87), respectively, followed by economic (3.75) and cultural (3.38).

Treehuggers is a working farm and community on 1.86 ha of land, the main focus of which is feeding the soil rather than the plants, and enhancing diversity. They sold their produce at an internal market on the weekends and once a week at two different external markets. They were a key example of ways that a localized food production system could offer better prices for farmers. They received the highest provisioning score (4.14) of any site and the second-highest score overall (4.20). In the farm category, this site gave the most importance to provisioning services (4.14) and in the pair-wise matrix as well, since one of its primary goals was to become a profitable enterprise and an established farm. The farm devoted much of its land to perennial production at about an 80/20 ratio but since some of these species took 3 to 5 years to start producing, much of their current sales and production came from annuals (between November and April). Additionally, contributing to the high provisioning score, the site established a large pond recently, which provided the majority of the water for irrigation on the property. In addition, the farm also had a huge influx of topsoil and mulch brought in to raise the land by up to 6 ft. Perennial polycultures around the farm included Lemon Bay Rum, Katuk, Mango, Bananas, Loquat, Jaboticaba, Figs, Dragon Fruit, and Globe Artichoke. The farm had a high cultural value (4.06) with around 300 visitors per year including high school groups, as well as customers.

The ECHO Global Farm is a part of the larger organization, called Educational Concern for Hunger Organization (ECHO), which acts as an information hub for development practitioners around the world. This is a work and training farm with many demonstration areas, including an area for appropriate technologies. This farm held one of the largest collections of edible tropical plants in the United States. The farm's primary function was to serve as a place for case studies and trials of seed varieties and appropriate technologies before they were sent overseas. Because of this, many areas of the farm were not optimized for production as certain experiments were being conducted or environmental conditions were being mimicked. However, the farm had the highest cultural rating of all the sites (4.76), with nearly 9000 visitors each year, including visitors from schools, churches, garden clubs, foodies, and sustainable technology enthusiasts groups, who came for tours, workshops, and volunteer opportunities. The farm also served as an in situ gene bank with over 33 varieties of Moringa, scoring high on the biodiversity indicator. This farm scored high in regulating and supporting services as well (4.36 and 4.55). Animals were integrated throughout the garden including chickens, goats, and ducks. This is unique to the sites visited but significant for nutrient cycling and productivity. The regulating score (4.55) was the highest in the category since particular attention was given to improving soil and air quality and preventing erosion and flooding, an issue in many of the countries that benefit from the research on the site.

The Little Haiti Community Garden was founded by a private owner in a derelict 1250 m^2 urban lot that had once been used as a dump site. What began as a community garden had turned into a micro business and urban farm over time. Although privately owned, the farm itself was a non-profit organization and community garden that used permaculture techniques to grow fruits, vegetables, and medicinal plants to be purchased by the community. Through donations from local foundations, the garden was able to hire a full-time gardener, a Haitian native who fled after the hurricane, who was the primary caretaker of the operation. They sold produce directly to restaurants and customers in the neighborhood in a once-a-week on-site market. About 95% of the lot was planted out with a combination of perennial and annual species including Malanga, Bananas, Avocados, Yucca, Coconut Palm, Passion Fruit, and Curry. This farm received the highest economic rating overall (4.50) because it had achieved financial independence from external sources of funding, did not take a large financial investment to establish, hired a local employee, and sold to the local market directly impacting the food security needs of the neighborhood. The second highest score within the site was for cultural services (3.82), with nearly 200 volunteers and visitors that came through the site each year from schools, universities, and homeless shelters.

3.2.2. Residential Category

The residential category included private homes that were landscaped primarily for private use, although the educational component and community engagement were present in some cases. Two of the residences, Gaia Ma and Earth n Us, are located in urban Miami, and one, Unbelievable Acres, in peri-urban West Palm Beach. Although they were permanent residences they were each unique in that Earth n Us was comprised of several rental units and acted as a community of residents with shared common spaces. Gaia Ma was built as a prototype and model for sustainable urban housing and Unbelievable Acres had evolved into a private botanical garden and collection that was open for public tours at specific times. This category had the highest scores in the supporting, regulating, and provisioning with cultural services close behind.

Gaia Ma is a permaculture garden in a Biscayne Park residence that was created as a prototype for Urbaneco Development, a green building and design company. Drawing on an abundance of private financial investment this project was planned right from the start. The plot of nearly 743 m^2 was prepared for a year before any planting was performed through the addition of high-quality compost and mulch. Components such as a 15,142 L water catchment system were installed to meet the water needs of the garden, a detailed permaculture design that utilized every part of the space with several elements layered in a relative placement to each other made the project extremely effective in providing ES but also very expensive. This explained the low economic score (2.00) and the high supporting (4.60) and regulating services (4.72) assigned to this site. Although this was a private residence, several workshops and tours were held at the house on a monthly basis, which was a factor in earning a cultural service score of 3.74.

Earth n US Urban Eco-village is located in the Little Haiti neighborhood of Miami. Established in 1977 by the owner, over many years, 11 parcels of land and houses were purchased until he had a 0.8 ha lot in the heart of the city. From the beginning, the owner established a garden, planted fruit trees, and created an animal sanctuary with goats, chickens, bees, emus, and a pig. Over the years the role of this urban "farm" in the community had evolved into organizing field trips for schools, community dinners, and training courses. The primary income of the farm was the rent generated from the many single and multi-family residences on the property. A green preschool, a bike cooperative, and short-term rental accommodations had all been sources of income and community engagement on the site. Most recently the owner purchased an adjacent property where a food forest was planted. Members in and around the community were encouraged to compost on-site, and this along with the manure produced from the animals, and the vermin-culture system creates a rich soil amendment that is used wherever crops are grown. This accounted for the high supporting score of 4.12 and cultural service score of 3.66.

Unbelievable Acres was established in 1970 in West Palm Beach in what used to be an empty cow field. A combination of tropical vines, orchids, bromeliads, and tropical fruits was planted to mimic a tropical rainforest. The garden was established with one man's continued efforts and hundreds of volunteer hours throughout the years. Due to the minimal maintenance, the canopy was not managed for optimal light, therefore production is minimal, but the biodiversity, formation of soil, and climate regulation are significant. This was reflected in the performance scores, which were high for supporting (3.88) and medium for regulating services (3.27), but low overall (3.02). With the canopy having almost 100% cover, there was little productivity in food crops of the lower layers of the forest. However, its age and character made it a significant cultural contribution to the neighborhood, housing dozens of rare species and specimens, such as the oldest Jaboticaba in the US. The site attracted hundreds of visitors each year during their once-a-month tours, contributing to the cultural service score of 3.30.

The results show that all of the alternative agro-ecosystems in the study contributed in four or more areas to ES analyzed. Each site had unique attributes that either facilitated or hindered its ability to provide various ES. The weight data affected the study results somewhat because overall most sites valued the cultural services more than the others, so more weight was given to this criterion. All of the sites had strong cultural components, with education, recreation, and volunteering elements being central goals, and provisioning and economic considerations only used to support the culture. Comparison between the categories indicated that sites designated as farms, whether the purpose was education or production, had higher ES overall than residential and public land categories.

3.2.3. Public Land Area Category

The public land category systems in this study were on land areas that were held by central or local governments. A public university, high school, elementary school, as well as a county-owned botanical garden were included in this category. The university food forest at FGCU was located in Fort Myers, the two public schools in urban Miami-Dade

County, and the Botanical Gardens in the city of West Palm Beach. The public category included the site with the lowest overall score and lowest scores at 0 in economics due primarily to how the projects were structured, with the primary goal being education and recreation within cultural services. We found that overall the provisioning and economic services were less important than the cultural, supporting, and regulating roles in these systems.

The FGCU Food Forest was a student-run botanical garden with a large number of tropical and sub-tropical edible species arranged in a forest-like environment. It was established by a group of students, funded by the student government, who designed, installed, and maintained it. The site received the third-highest score overall (4.11) and the highest in the public category. A well thought out permaculture plan was designed by students, and many techniques and processes were implemented to build the soil, recycle nutrients on-site and provide regulating services, such as biological pest control and water flow regulation, which accounts for the high scores in both supporting (4.49) and regulating services (4.46). Cultural services received the second-highest score in this category (4.30), with initial and continuing participation by students and the community. The garden relied on donations of both money and plants given by donors including local organizations such as the Naples Botanical Garden and Home Depot. The site was an active part of the University and many students and professors utilize it as part of their classes and research. The Food Forest included over 40 species of edible and native plants that produce fruit year-round. As with the other public sites, the economic role of the system was not as important as other ES but this site had the highest economic score in this category (3.50) since it was inexpensive to establish and was designed to be free from intensive management or outside resources to sustain itself and also contributes indirectly to the local economy by providing free food to the student body and community who can harvest at no cost.

The Booker T. Washington High School edible forest garden was established as a demonstration and working garden in Miami. Although the garden was very new some of the trees were already on-site and, due to the microclimate created by the walls surrounding the courtyard, there has seen substantial growth in the first year. The primary function of the garden was to be used as an outdoor classroom for both the culinary and environmental science programs at the school, which contributes to its high ratings in cultural services (3.78) primarily in education, aesthetics, and the design process. This design process also accounts for the low standard deviation between the ES scores and a balance between the criteria since this was built in by design.

Mounts Botanical was linked to agriculture from its inception serving the Palm Beach County Extension Service since 1964. In the 1990s, a master plant was initiated by the University of Florida and completed in 2004. This public garden is a destination for thousands of visitors from the South Florida area. The Garden housed meetings for over ten associations including the Herb Society of Palm Beach County and the Palm Beach Rare Fruit Council. Once-a-month classes on book discussions and art in the garden series were held, for which we assigned this site the highest cultural score of all sites in this sample category. The property included a variety of features such as tropical forest, rain garden, and butterfly garden. For the sake of the study, we concentrated on the edible landscape garden, which encompassed about 743 m^2 of space. This site received the lowest score (2.32) of all the sites primarily because it did not utilize the space efficiently or integrated the perennial and annual plantings, relied on external inputs such as inorganic fertilizers, and due to regulations, did not distribute or sell the crops that were produced on-site.

The Twin Lakes Elementary Food Forest is part of a growing movement of school gardens sponsored by corporate or foundation donors whose purpose is to educate and engage youth around science, nutrition, and food production. This garden had evolved over the past five years from mostly annual raised garden beds to a designed and implemented food forest with many layers of complexity, moving from a 10/90 ratio of annual to perennial to the opposite ratio of 90/10 of the plants all over the site. This transition increased biodiversity and introduced nectary and other beneficial species, decreased the need for external inputs, increased leaf litter and organic matter recycled on-site, increased soil water retention, and decreased pests. This accounted for the highest score in the supporting ES in this category (4.55). As in other public sites, the score of the cultural service was high (4.52) with nearly 150 students utilizing the garden on a weekly basis for education, recreation, and as a gathering focal point for the school community.

4. Discussion

Based on the study results presented above we find that the main factor that motivated the establishment and operation of most of the case study urban agro-ecological sites was the desire to establish a place of natural and cultural value and to educate the public. In a few exceptions, some of the farms wanted to create a livelihood from the selling of food crops produced in the system. The food provisioning ES has a recognizable market value that can translate into income or a product that can meet the basic livelihood needs. On the other hand, the socio-cultural ES are often times unrecognizable and non-marketable in nature, meaning they may not yield direct cash flow to owners [48]. This begs the question, is such ES even sustainable in the long run? The results of our study reveal the following key factors that are found to be critical for the adoption, scalability, and sustainability of the agro-ecological practices in large urban areas:

4.1. Funding

The adoption of agro-ecological practices in urban areas depends on the availability of external resources, economic feasibility, such as the presence of a market for diversified products [11,31].

In most sample study cases, the sites depended on external grants, local market food sales, and tourism dollars, which were not adequate to fully sustain their operations. Past studies do suggest mechanisms to translate the market value of certain ES into actual cashflows, which directly incentivize service providers [49]. While most of our study sites received high-performance values in the area of cultural, supporting, and regulating services, there were no public or private market mechanisms that enabled site owners to appropriate those ES benefits in a significant manner with the exception of sites that conducted paid educational tours. Expanding urban agro-ecological projects therefore can be challenging and requires constant communication with urban residents, public agencies, and donors for continued financial support. One such effort could involve making a connection with organizations interested in promoting food security, economic empowerment, and public health. Vacant lands, which have a positive correlation with increased crime, reduced property values, and invasive species, can be utilized in a way that creates resilience and support for the community and produces job and neighborhood revitalization [10].

There is a need for markets for diversified products, which provide new distribution networks for urban farms. Farmers/operators of the study sites have a difficult time distributing their produce because they produce in such varieties and in small quantities. One exception in our studied cases is the Treehugger farm, which has access to local farmers' markets. The current system requires large quantities of uniform fruits and vegetables to be sold at markets. Having farmer co-operatives, farmers markets, community-supported agriculture, consumer clubs, and other distribution networks that are direct from site to the consumer would insure they have a market [11,50].

Finally, funding from the United States Department of Agriculture (USDA) and support from state and local governments are the largest source of financial support for programs related to agriculture and forestry is the USDA, whose strategic goals are consistent with the goals in many of the sites in this study [50]. In fact, since the majority of USDA spending is to insure that people have nutritious food to eat, a logical next step is to fund projects that feed people directly while creating jobs and many other benefits. Discretionary funding (about USD 23 billion in 2015) from the Farm Bill could be redirected to fund permanent comprehensive community-based alternative agro-ecosystems initiatives to simultaneously address food security, climate change, economic and ecosystem service challenges facing urban environments. The 2018 Farm Bill created the new Office of Urban Agriculture and Innovative Production and provides for limited funding to urban organizations that help promote urban agriculture. Furthermore, more than 19 states in the U.S. have passed legislation that facilitates the creation and expansion of urban agriculture farms through a variety of measures, including direct funding, favorable terms of legal contracts between urban property owners and farming tenants, property tax breaks for landowners, etc. [51].

4.2. Complexity and Lack of Measurable Data

It is important to establish ways to measure and develop a set of reference values for each indicator formulated either by established scientific values or by comparison of the systems. In addition, specifically targeted values or threshold values must be established. By knowing what needs to be measured and how to measure it, operators could keep more systematic records. Stakeholders and planners need to have the knowledge of or seek the support of those who are familiar with appropriate methods for gathering the data. Scholte et al. [41] identify several approaches available for gathering socio-cultural data, for instance, expert-based methods, observation, focus groups, surveys, document research, etc. Similarly, de Olde et al. [22] document a multitude of approaches for developing data for physical indicators of agricultural systems.

Mainstreaming the use of ES indicators will have the effect of making the business case for ES more self-evident. Our study provided a potential way to accomplish this. Once entry points are identified, such as extension offices, non-profit organizations, and urban forestry organizations, tools such as PASS can be distributed to be implemented.

4.3. Policy

In many regions, regulatory codes and zoning laws currently prohibit growing food crops and/or gathering on public lands. This institutional framework assumes that citizens should be separate from nature ignoring the potential for food, medicine, aesthetic, cultural, and educational values to be supplied by these spaces. Urban gatherers exist and their practices can be implemented and utilized in this context as a part of the management plan.

Carbon sequestration is the most popular ES studied in the literature [52,53]. The sample respondents in this study also gave regulating services higher importance than economic and provisioning services in general. Therefore, there is a need for proper economic incentives such as carbon credits or property tax breaks in order to motivate the adoption of carbon farming methods. National strategies, such as low-interest loans to help farmers transition to sustainable agriculture, or requiring a certain percentage of trees to be planted by law in farming systems, have proven to be effective ways to incentivize carbon sequestration. Many countries have started using Payment for Environmental Service (PES), which is basically a way to pay farmers for the other ES they provide through the use of sustainable and carbon sequestering practices [54]. In Australia, the Carbon Farming Initiative (CFI), which is funded through a cap-and-trade system provides financial rewards to farmers who implement specific practices [55]. However, the existing carbon offset market in the U.S. is nascent and still maturing. Carbon market enthusiasts and environmentalists are divided on the feasibility and reliability of the agricultural carbon offset market [56]. In the urban context, other ES co-benefits may be stacked with carbon sequestration benefits in order to enhance the marketability and scalability of the carbon credit market. However, we recognize that not all urban sites might be suitable for implementing carbon credits, particularly when sites are small and widely distributed across large urban areas. Furthermore, the relationships between the providers and beneficiaries of ES are often unclear. Establishing, monitoring, and enforcing market-based schemes to promote such services will require complex institutional mechanisms [49].

4.4. Best Practices

Some of the studied cases fell short of their potential in ES due to a lack of best practices in management. For example, Unbelievable Acre could score higher in provisioning service if its canopy was managed properly. A presentation of indicators without a clear strategy of how to integrate it can result in a fragmented and erroneous understanding of the system under analysis [57]. With a clear indication of criteria to select soil building techniques, plants, and water management the adoption of these systems will become more approachable. Even after implementation, having clear maintenance schedules is important including plans of potential volunteer and urban foraging groups that can help in managing the project.

4.5. Scaling Up

Scaling up can mean enlarging the existing operation or replication of operations in other places. As with most projects scale can have a great impact on the costs involved with installation and maintenance. Implementing a master planning process at a city-wide to regional scale, elements such as nurseries to produce plant stock, composting facilities, equipment for harvesting and maintaining gardens, and distribution centers for local food could be shared by smaller gardens optimizing efficiency and reducing costs of implementation and maintenance.

To replicate successful operations, the dissemination of information is essential. On a local and broad scale, the implementation of productive landscapes in the form of alternative agro-ecosystems needs to be compiled as case studies to be shared among practitioners through the establishment of conferences on the subject, online resources for practitioners, and tools such as PASS being available for use during the planning process. Educating the public through extension services for residential implementation can also be an effective way to encourage the implementation of these systems.

5. Conclusions

Alternative agro-ecosystems have evolved as a reaction to ecological and social issues related to industrial agriculture. Studies have shown a variety of practices and systems based on traditional knowledge and innovative technologies that are being put into practice at various degrees and scales. There is a growing interest in the assessment of urban agro-ecosystem services and how they affect human well-being. However, there was no framework available to measure the sustainability of these systems and to help understand the challenges and opportunities they embody. Most available tools of agricultural sustainability assessment focused on crop yields, economic profits, and environmental impacts [22], but lacked the consideration of a broader set of ES, including the socio-cultural and regenerative aspects of small urban agro-ecological systems. This study developed the PASS framework as a comprehensive approach to assessing the sustainability of alternative agro-ecosystems in urban areas. The framework was built upon prior sustainability indicators integrating concepts of ES [1], SAFE [23], SITES [24], Permaculture principles [15], and Agroecology principles [6,20,27] into a cohesive and case-specific rubric that was tested in 12 urban agro-ecological sites.

While it is hard to quantify various contributions of urban agro-ecological systems, particularly less tangible, socio-cultural and architectural design benefits, we emphasize the significance of the comprehensive nature of the framework developed in the paper. Communities and local planners may not have the expertise and wherewithal to conduct a more complex and objective assessment of certain ES, including regulatory and supporting services. However, we argue that including even qualitative, yet a broader range of benefits, can effectively advise local planning and decision-making. Furthermore, such an approach is more suited to paying attention to socio-economic contexts and engaging local communities in the decision-making process. Any tool or process that facilitates engaging local communities in the decision-making will ultimately increase the community support, and the likelihood of making real policy changes, toward the intended goal.

Despite numerous potential benefits of the ES from urban areas, the major challenge lies in making these values reflect through urban planning, decision making, and market and other private choices. While urban agriculture (UA) is gaining momentum around the country and the world, its true value is not understood beyond its ability to solve urban food insecurity. In order to realize the broader ES benefits of UA in particular and agro-ecosystems in general, a multi-pronged policy and planning approach is necessary. Such approaches may be pluralistic [41] and multi-layered [49]. These programs may include urban planning, eco-friendly fiscal policies, resident education, and financial support for private and community operators of urban agro-ecosystems. Market-based policies promoting payment for carbon and other ES benefits may facilitate this movement.

We suggest two specific areas of improvement to the methodology developed in this study. First, as noted earlier, the indicators of the PASS framework are primarily qualitative in nature. We measured them through observations, surveys, and personal interviews. Furthermore, the values of some indicators were based on no written records, but purely on the recollection and opinion of site operators. Measuring some of the traditional agricultural and ecological indicators may require scientific expertise and complex modeling tools. Future studies may use more objective approaches to valuing appropriate indicators. The second area where the PASS framework can be improved is by giving explicit consideration to system transition, both from ecological and socio-cultural viewpoints. Amjath-Babu and Kaechele [58] have developed specific indicators to assess the system transition from more bio-diverse production systems to monoculture systems. For instance, they estimated indices of land-use suitability, input use intensity, and farm system diversity for different cropping systems. Similar thinking may be applied to socio-cultural aspects in order to measure, for instance, changes in the social connectedness of the system with the surrounding community over time. Developing and tracking indicator values that capture the system transition of urban agro-ecological sites in relation to their baseline and target levels will help us manage the system more effectively.

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