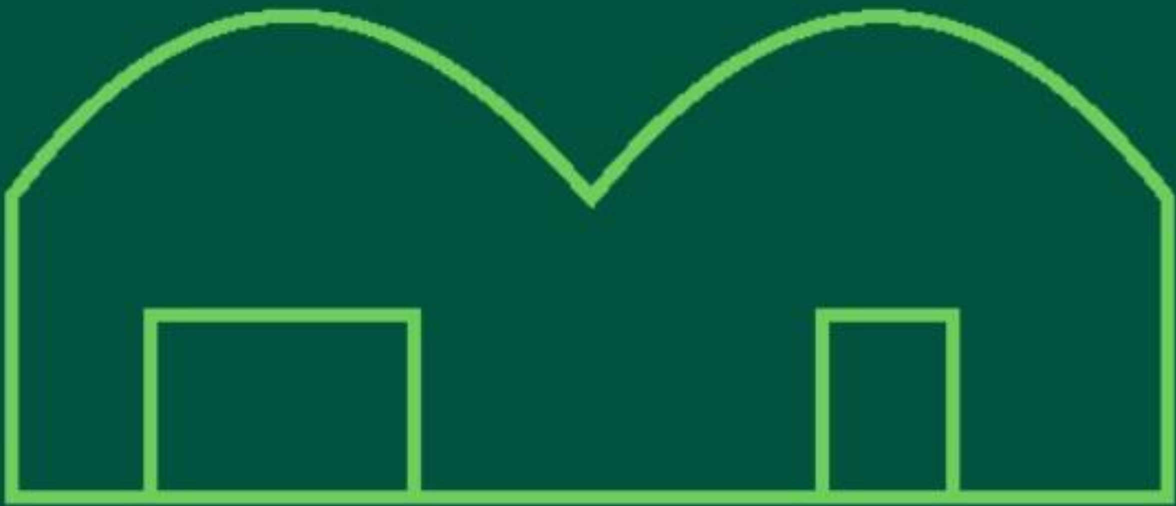
living the sustainable development



a university permaculture project as an ecosystem service provider

2009 / 2023

HortaFCUL case study

Universidade de Lisboa
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HortaFCUL

Living the sustainable development: a university permaculture project as an ecosystem service provider

The HortaFCUL case study (2009-2023)

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Though the problems of the world are increasingly complex, the solutions remain embarrassingly simple.

- Bill Mollison

When we work with nature instead of trying to impose our will, the solution is often found within the problem.

- David Holmgren

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0. ABSTRACT

In the decade of action for sustainable development, growing urbanization phenomena pose both environmental and social challenges to human populations' wellbeing. Community-based projects are bottom-up initiatives that address those challenges by aiming to improve livelihoods within urban areas. Amongst these projects, community gardens have become a popular approach to tackle a wide range of issues, from public health, food security and sovereignty, climate action and people's empowerment. Although there are extensive literature references on the positive outcomes of community gardens, most of the studies mainly consider qualitative indicators and results are often context-dependent in terms of analysis. In this report, we propose a case study-based research of a community garden established in 2009 at the University of Lisbon, Portugal (HortaFCUL), due to its consistent and long-term historical record as a reference for other community-based projects. The study aims to describe the extent of the positive impacts (the added value) of this project's ecosystem for the surrounding community by means of comparing significant sustainability-based indicators in the case study areas and equivalent campus facilities. Indicator selection was derived from TEEB's Ecosystem Services Framework, which considers 4 categories of services provided by ecosystems (support, regulation, provisioning and social/cultural). Another universally replicable framework, the UN's Sustainable Development Goals (SDG) Agenda was added to the analysis to strengthen the comparability of a study of this sort. To further situate project's impact evolution, indicators were framed in a space-for-time substitution approach based on subprojects born at different moments in time since 2009. Results show clearly that all ecosystem services were attained by several activity outputs and the added value to the faculty's community was substantial. HortaFCUL's events analysis underpinned the importance of social-cultural services in a community garden project. SDGs 2 (Zero Hunger), 4 (Quality Education), 6 (Clean Water),11 (Sustainable Cities),12 (Responsible Consumption and Production, 13 (Climate Action) and 15 (Life no Land) were the most expressive in relation to the reference indicators used in this report, totalizing 17 targets addressed between them. Overall, the present study seeks to explore the potential of a community garden example to promote bottom-up nature-based solutions near decision makers and institutional stakeholders, as well as to objectively measure the regenerative and transformative potential that these projects have within their local communities.

Keywords: Permaculture; Community gardens; Sustainability; Living Labs; Ecosystem services; Sustainable Development Goals.

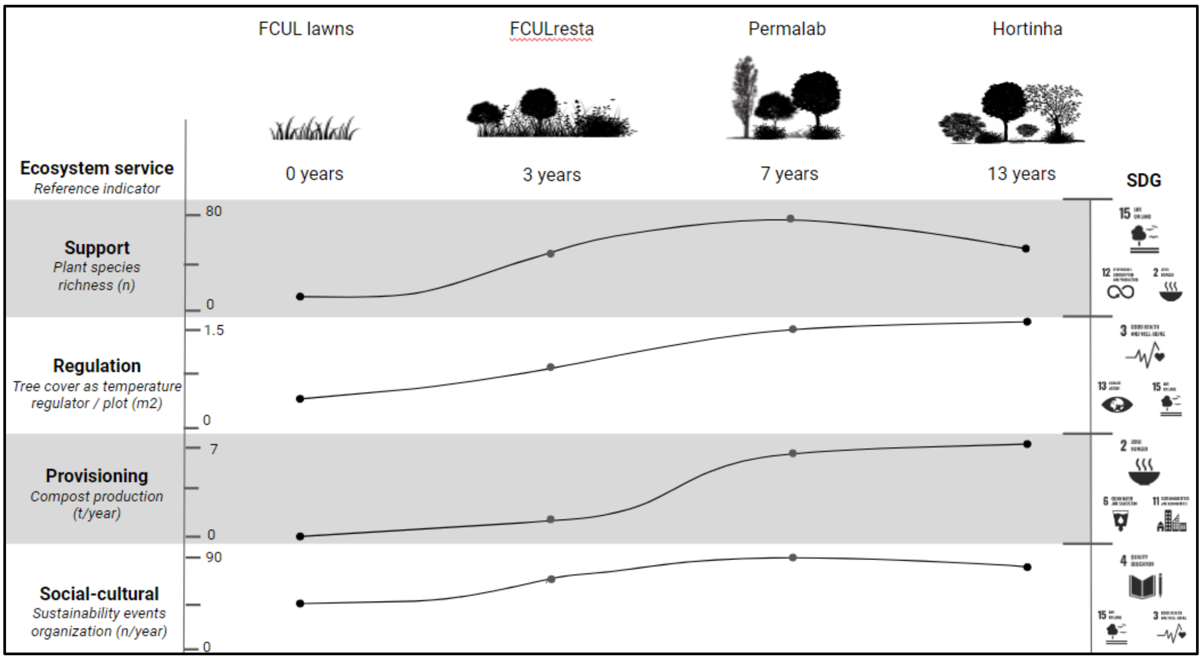


Figure 1 Graphical abstract with the main reference indicators representing a universe of 25 indicators analyzed and organized within the four ecosystem services. The four ecosystems (horizontal axis) represent 4 different stages of a permaculture designed garden with different ages of maturity as in a space-for-time substitution framework.

1. INTRODUCTION

1.1. Urban areas: challenges and opportunities

Over half of the world's population currently resides in urban areas and this number is steadily increasing, with an estimation that by 2050, over 70% of our species will live within an urban environment and most of the future growth of our population will happen in cities **(UN, 2018)**. This increase in urbanization is closely tied to economic growth and increased demand for public services, infrastructure development and therefore further industrialization **(World Bank, 2021)**, which in turn exacerbates global warming mainly through increased CO_2 emissions **(Shabani et al., 2022)**. City dwelling populations are much more susceptible to extreme weather events, such as floods and heatwaves **(Rentschler et al., 2023; Jabbar et al., 2023)**, which heavily impact public health and quality of life, and these phenomena will only become more commonplace with climate change. They also disproportionately affect lower income sections of cities and their communities **(Erman et al., 2019; Hsu et al., 2021)**, creating further divide between economic groups.

Many issues arise with the increase in population inside cities as economic divides become more prominent and even basic services that provide an adequate quality of life become scarce within certain communities **(Haworth et al., 1978)**. In these situations, it's commonplace for people with similar needs to gather and attempt to provide these services for themselves, whether that be shelter, food, recreational activities, healthcare, or green spaces, among others, through community-based projects **(McLeroy et al., 2003)**. It has been shown that these types of projects are drivers of social inclusion for marginalized groups by giving them a sense of ownership, impact and purpose in their surroundings and making them feel welcomed in diverse social settings **(Morgan et al., 2020; Tanrıkul, 2023)**. Additionally, many efforts by these communities can be used as models and lessons for governing bodies to use in relatively neglected scenarios such as adapting to climate change and maintaining biodiversity **(Archer et al., 2014; Singh, 2008)**.

1.2. Community gardens

Green areas within cities are capable of not only mitigating many of these concerns through temperature regulation **(Aram et al., 2019)** and water retention **(Zimmermann et al., 2016)**, but also provide many other quality of life benefits, such as improvements in mental health **(Alcock et al., 2014)**. However, with the rapid loss of biodiversity inherent to city expansion and development **(Simkin et al., 2022; Li et al., 2022)**, these locations will become rare and damages to them irreversible. Community gardens are an example of bottom-up initiatives that address both environmental and social issues. On the one hand, community gardens (CG) aim to improve the access of local populations to quality green areas and, on the other, promote citizen's active engagement and social inclusion, especially through food production **(Turner et al., 2011).** In literature, misconceptions regarding the definition of CG as opposed, for instance, to allotment gardens are very common **(Kwartnik-Pruc & Droj, 2023)**. For clarification purposes, in this report, a community garden is a green area (in this case, located in an urban matrix), whose governance is assigned to a citizen's collective **(Guitart et al., 2012; Egli et al., 2016)**. The latter is responsible for the garden's management - including food production, social organization, community's engagement and landscape design - within a democratic decision-making atmosphere **(Glover et al., 2005)**. CG policies vary from project to project, but they are generally open to the public, namely a local community, for which the garden has a constructive role. These two assumptions - open-access and collective management - are not mandatory in allotment gardens, where a common area is divided into individually managed allotments. Indeed, dynamics and processes concerning each allotment are usually independent from each other, and routinely decision-making is left to tenants **(Bell et al., 2016)**.

In the last decade, it has become more and more evident that CG's have a positive impact on the surrounding environment **(Lovel et al., 2014; Carney et al., 2012)**. Studies have shown that community gardens are key role-players in areas such as mental health promotion, inclusion of segregated communities or the access to information and knowledge on sustainable practices **(Draper & Freedman, 2010)**. Many examples are found in the US, where CG's have been adapted to a diverse set of scenarios. CG's have been central in several minority communities to tackle poverty, discrimination and low access to healthy food **(Mangadu et al., 2017)**. Regarding the latter, there have been reports of successful partnerships between CG and hospitals to promote healthy routines **(George et al., 2015).** CG's are also seen as crucial structures to celebrate multiculturalism by prompting the use of traditional practices brought by migrant communities, for instance **(Cutter-Mackenzie, 2009).** Moreover, these projects were introduced in schools and universities due to their educational potential amongst younger publics **(De Young et al., 2015)**. Some case studies show clear positive results concerning student's well-being, social bonding and even academic performance **(Baur, 2022; Walshe & Law, 2020).** Student rotational governance, lack of financial support and community engagement have been underlined as the main challenges of CG's within campuses **(Urzetta et al., 2023).** At a larger scale, lack of financial aid, poor access to materials and resources and long-term management are pointed out as central struggles for the maintenance of CG **(Drake & Lawson, 2015).**

1.2. Permaculture: definition and principles

There is a vast list of practices developed in CG, from traditional and conventional to regenerative and innovative. Amongst some of the most popular disciplines applied in community gardens nowadays is permaculture **(Calvin, 2011).** Permaculture was proposed as a new discipline by Bill Mollison and David Holmgren during the 70's. Its name results from the portmanteau of the words "permanent" and "culture", presenting an innovative thinking approach concerning landscape design and the interaction of human beings with nature **(Mollison & Holmgren, 1978)**. In summary, these two authors state that permaculture is the conscious planning of landscapes, taking into consideration the relations of interdependence that exist between systems and living groups. Permaculture recognizes the planetary limits of consumption and use and proposes, as a solution, regenerative practices that can be applied in diverse contexts such as urban planning, sustainable agriculture, biodiversity management, sociology, anthropology and engineering. These regenerative practices seek to mimic ecological patterns and processes within human production systems in order to create balanced and interdependent ecosystems.

Mollison and Holmgren have put forward three major ethical principles that should serve as guidelines when implementing permaculture systems: Earth Care, People Care and Fair Share **(Habib & Fadaee, 2022)**. These three principles underpin the importance of conscious and smart resource use (Earth Care), inclusive participation, education and empowerment (People Care) and social and environmental justice (Fair Share). To complement these ethics, a set of 12 design principles were later advanced by Holmgren in order to mentor planning processes: *(1) observe and interact with the landscape, (2) catch and store energy, (3) obtain a yield, (4) apply self-regulation and accept feedback, (5) use and value renewable resources and services, (6) produce no waste, (7) design from patterns to details, (8) integrate rather than segregate, (9) use small and slow solutions, (10) use and value diversity, (11) use edges and value the marginal, and (12) creatively use and respond to change* **(Mannen et al. 2012; Holmgren, 2007).**

1.4. Ecosystem services framework as a study tool

During the last decade, project-based communities have been studied by means of different frameworks, although there is some consensus around using the ecosystem services framework **(Tallis et al., 2008)**. Ecosystem services framework (ESF) is a unique tool to understand the benefits of ecosystems that revert to human communities. Likewise, this framework is divided in four broad categories: (1) support - which are described mainly by biodiversity indicators and habitat provisioning -; (2) regulation - which includes thermic and water regulation and nutrient cycling -; (3) provisioning - with a focus on production, like food and biomass -; and lastly (4) social/cultural services - the aesthetic and human community values that are generated by a certain type of ecosystem **(Balvanera et al., 2017)**.

Some experts suggest that caution is needed when using ESF because it reinforces significantly the idea that nature should be regarded as a commodity for human societies, like the framework used by The Economics of Ecosystems & Biodiversity **(TEEB, Ring et al., 2010).** Nonetheless, it is a broad framework that became very popular amongst researchers since it translates in a simple way the environmental benefits of ecosystems, emphasizing nature's value to human communities **(Turner, 2008)**. Many of these ecosystem services are key to human activities related to agriculture. For instance, pollination and pest control are essential processes for both food production and security **(Power, 2010).** Other services, such as carbon sequestration, provide a regulatory role for climate and biogeochemical cycles, whose changes are threatening human livelihoods and causing general economic losses **(Gasper et al., 2011).** There is a general scientific consensus that biodiversity loss - which is the most basic pillar for supporting services in ecosystems **-** is directly linked to climate change, and that both of these phenomena affect one another synergistically **(Habibullah et al., 2022; Pires et al, 2018)**.

In contexts where the social dimension is disproportionately important, ESF provides a clear tool to analyze ecosystems from this perspective. However, due to its criteria openness, researchers often segregate valuable information (usually associated with cultural and social services) from this framework, which in turn reflects a certain degree of subjectivity when it comes to defining descriptive parameters for these services **(Hirons et al., 2016)**. There have been several attempts to systematize workflows and guidelines regarding ESF. Other than the above-mentioned TEEB framework, the main references in this area are the Common International Classification of Ecosystem Services **(CICES, Haines-Young & Potschin, 2012)**, the Millennium Ecosystem Assessment **(MA, Board, 2005)** and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services **(IPBES, Diaz et al., 2015).** Criteria objectivity is key to create reproducible frameworks which can be applied to a diverse set of contexts.

With this in view, several ES-based scientific works have been produced in recent years with a focus on urban agriculture, community gardens and other alternative novel ecosystems within urban areas. Studies are mostly focused in Western developed countries, where modern urban development started earlier as well as research resources are mostly available **(Evans et al., 2022)**. Some of these works have approached some specific ES in a given context. Although there is a vast body of literature concerning social and cultural services provided by urban green spaces **(Dickinson & Hobbs, 2017; Krellenberg et al., 2021),** some works have delved into the centrality of urban green space as environment regulators **(Matos et al., 2019; Jaung et al., 2020; Yang et al., 2015)** or even as structural supporting agents for biodiversity **(Ungaro et al., 2022).** Another popular approach in this field is the use of meaningful case studies to assess the impact of urban green areas as ecosystem service providers through objective indicators **(Cabral et al., 2017; Misiune et al., 2021; Capotorti et al., 2019).** Case studies are especially relevant since most study objects are constrained to their own contexts and they should encourage informed decisions by local policy makers and urban planning officials **(Niemela et al., 2010).**

1.5. UN's Sustainable Development Goals (SDG) framework

The Sustainable Development Goals (SDGs) are a set of 17 global goals established by the United Nations in 2015 **(Katila et al., 2019)**. These goals are designed to address a wide range of global challenges and promote sustainable development in economic, social, and environmental dimensions (**Alcamo et al., 2020)**. The SDGs were built upon the Millennium Development Goals and aim to be more comprehensive, inclusive, and applicable to all countries, regardless of their level of development. The 17 Sustainable Development Goals are listed in Table I.

Table I . Sustainable Development Goals and their respective description **(Katila et al., 2019)**.

SDG	Description	Icon
SDG1: No Poverty	End poverty in all its forms everywhere	1 NO POVERTY
SDG2: Zero Hunger	End hunger, achieve food security and improved nutrition, and promote sustainable agriculture	2 ZERO HUNGER
SDG3: Good Health and Well-Being	Ensure healthy lives and promote well-being for all at all ages	3 GOOD HEALTH AND WELL-BEING
SDG4: Quality Education	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	4 QUALITY EDUCATION
SDG5: Gender Equality	Achieve gender equality and empower all women and girls	5 GENDER EQUALITY
SDG6: Clean Water and Sanitation	Ensure availability and sustainable management of water and sanitation for all	6 CLEAN WATER AND SANITATION
SDG7: Affordable and Clean Energy	Ensure access to affordable, reliable, sustainable, and modern energy for all	7 AFFORDABLE AND CLEAN ENERGY
SDG8: Decent Work and Economic Growth	Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all	8 DECENT WORK AND ECONOMIC GROWTH
SDG9: Industry, Innovation, and Infrastructure	Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

SDG	Description	Icon
SDG10: Reduced Inequality	Reduce inequality within and among countries	10 REDUCED INEQUALITIES
SDG11: Sustainable Cities and Communities	Make cities and human settlements inclusive, safe, resilient, and sustainable.	11 SUSTAINABLE CITIES AND COMMUNITIES
SDG12: Responsible Consumption and Production	Ensure sustainable consumption and production patterns	12 RESPONSIBLE CONSUMPTION AND PRODUCTION
SDG13: Climate Action	Take urgent action to combat climate change and its impacts	13 CLIMATE ACTION
SDG14: Life Below Water	Conserve and sustainably use the oceans, seas, and marine resources for sustainable development	14 LIFE BELOW WATER
SDG15: Life on Land	Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	15 LIFE ON LAND
SDG16: Peace, Justice, and Strong Institutions	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable, and inclusive institutions at all levels	16 PEACE, JUSTICE AND STRONG INSTITUTIONS
SDG17: Partnerships for the Goals	Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development	17 PARTNERSHIPS FOR THE GOALS

In the last decade, scientific works have examined the interconnectedness between ESF and the SDG. **Wood et al. (2018)** suggest that ecosystem services address multiple SDG's and have direct impacts on 12 of the 17 SDG's. The synergistic relationship between SDG's is highlighted by the multifunctionality of ES concerning the improvement of both environmental indicators and human well-being **(Yang et al., 2020)**, since addressing one goal often involves addressing issues related to others. The SDGs provide a shared blueprint for countries, businesses, and civil society to work together towards a more sustainable and equitable future. Progress toward these goals is monitored through a set of indicators, and countries regularly report on their efforts to achieve them. Studies stress the need to prompt the application of these universal frameworks to withdraw sound conclusions from the progress made in terms of sustainable development targets **(Rozas-Vasquez et al., 2022)**.

1.6. Case study: HortaFCUL

1.6.1. Project’s main features

HortaFCUL is a community-based permaculture project based in Lisbon University’s Faculty of Sciences campus, or FCUL for short **(Chaves & Vieira, 2020)**. The initiative was launched in 2009 by a group of students whose main goal was to create public awareness amongst the university community towards innovative permaculture practices that could answer some of the biggest challenges we face, such as food security and sovereignty, ecosystem degradation and climate change. This bottom-up project developed an important role, within the campus and beyond, as a generator and catalyst of solid practical and technical knowledge based on experimentation and scientific evidence. Through its years of existence, HortaFCUL became a resilient, sustainable and inclusive community, allowing the general public, regardless of its field of expertise or studies degree, to learn more about nature-based solutions - i.e. approaches which seek to solve human challenges by mimicking natural processes and dynamics **(Maes & Jacobs, 2017)**- in an urban context. For more information on HortaFCUL history and mission, **see Appendices 8.2.14 and 8.2.15b**.

1.6.2. Sociocracy as an organizational model in HortaFCUL

The inclusion of new members relies on an organizational model that follows sociocracy principles **(Eckstein, 2016)**. In other words, sociocracy suggests a self-organized governance model characterized by the absence of hierarchies when it comes to decision making. According to **Owen & Buck (2020)**, this alternative approach implies critical thinking and dialogue to overcome conflicts, as well as pragmatism (small and day-to-day decisions should be made regardless of a community member's absence) and trust (the community will trust in each member’s workflow to address his or her tasks). In a volunteering-based project like HortaFCUL, member’s inclusion doesn't rely on a complex decision process between members (hereafter called *guardians*), but rather on one’s active participation and commitment to the project. As a consequence, each guardian shares part of a collective responsibility for keeping the project active and functional. This is possible thanks to a system that entrusts each person the task of protecting and facilitating one specific dimension or process of the project, in order to keep all the guardians aware of the different needs regarding the latter. For example, members can assume roles as guardians of communication, vegetable garden, treasury or even plant nursery, depending on their skills and interests, and they are committed to inform the group of any development, event or challenges concerning that project’s section.

Figure 2 Dragon-dreaming session with HortaFCUL guardians (left picture). Post-its are used to sum-up every participant's ideas for the several project dimensions (columns on the board). A guardian’s meeting session (ca. 2018, right picture)

Several tools are applied in sociocracy systems, of which John Croft’s dragon dreaming approach **(Kruger et al., 2018)** and the 5 A’s meetings **(Silva & Avelar, 2015)** are the most relevant within HortaFCUL’s context. In a few words, the former states the division of the collective creation process into four phases: dreaming (information gathering, motivation, energy), planning (strategy design, solution screening), doing (implementation, monitoring progress) and celebrating (knowledge consolidation, collective reflection, cherishing the accomplishment). Since two of these phases are energy sinks (planning and doing) and the other two are energy sources, Croft suggests that we should equally invest our time through the four phases. For a new cycle to begin, the group should experience the four steps of the process **(Fig.2, left picture)**. See **Appendix 8.1.3.2**. for additional information.

As for the 5 A's, this tool underlines the need to promote effective and productive meetings between members by assigning 5 rotational roles (in Portuguese, all 5 role names start with an A, thus, the origin of the term): the Admiral, or *Almirante* (meeting facilitator, makes sure all the topics are addressed and allocates fair talking times to the meetings' participants), the Minuter, or *Atado* (registers all the important information discussed in the meeting and will be the admiral in the next meeting), the Welcomer, or *Acolhedor* (makes sure that people who arrive late are well-informed while not disturbing the meeting), the Watcher, or *Alcoviteiro* (surveys conflicts, challenges and social interactions during the meeting, gives uncommented feedback to the group and/or individuals at the end of the meeting) and the Time-keeper, or *Acertado* (guarantees that the Admiral and all the group are responsible for the time available). Moreover, 5A's meetings require pragmatism, trust and conscious participation to ensure that the meeting produces clear and objective decisions in a short time **(see Fig. 2, right picture and Appendix 8.2.11c.)**.

1.6.3. HortaFCUL's subprojects in campus

Nowadays, HortaFCUL is spread between 5 sub-projects **(see Fig. 3)**.

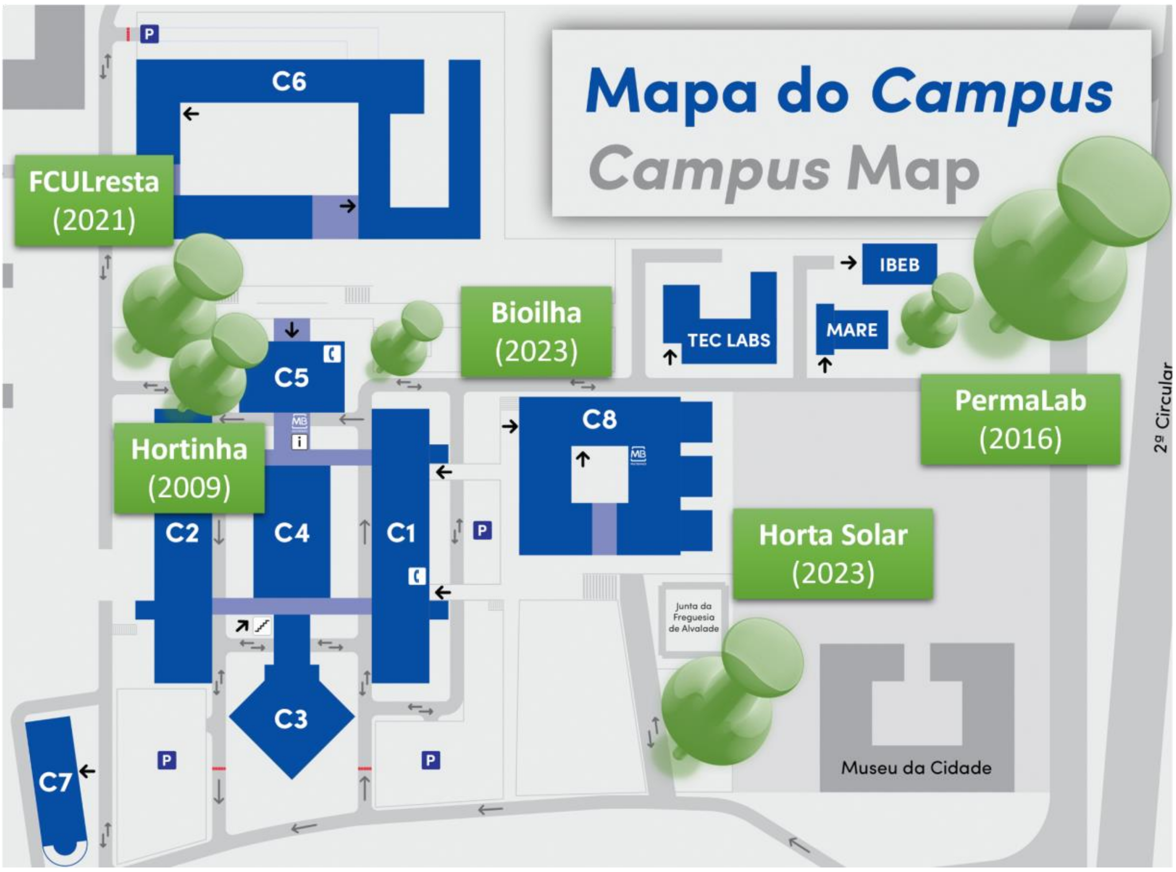


Figure 3 FCUL campus map with the location of HortaFCUL subprojects sites (green pins).

1.6.3.1. Hortinha

Hortinha is the cradle of the project and was HortaFCUL's only area of intervention in campus during the first 7 years (2009-2016). Starting as a permacultural agroforest oriented towards food production in an old campus lawn, Hortinha gradually expanded its area along its 14 years of existence and it is, nowadays, a 170m^2 edible garden that includes a small pond and a recreational area with a shelter, built in partnership with a local architecture atelier **(see Figure 3)**. This edible garden hosts, namely, fruit trees, aromatic bushes and other ornamental perennial plants, providing the campus community an opportunity to have an immersive experience **(Conway & Brannen, 2014)**. See **Appendix 8.3.13c** for more information.

Figure 4 Hortinha's shelter during construction phase (left picture) and fully functional, a short time after its inauguration in 2018 (right picture)

Figure 5 Hortinha, the project's first area of intervention, in the past (ca. 2011, left picture) and as of today (2023, right picture). The area in the picture's foreground is nowadays a pond covered with vegetation.

1.6.3.2. PermaLab

In 2016, a vacant lot area of approximately 1500m^2 close to Lisbon's main highspeed ring road (2ª Circular) was converted into the Permaculture Living Lab (PermaLab). The project's first intention was to convert part of a 500m^2 lawn into a permaculture experimental site, which would serve as scientific groundwork for two doctoral thesis. Since the surrounding infrastructure was in part unused, HortaFCUL expanded the project's initial area. Today, PermaLab is HortaFCUL's headquarters, increasing the project's capacity to welcome students and interns interested in permaculture-oriented scientific research **(Ulm et al., 2019)**. Since its beginning, several scientific works have been developed to test innovative permaculture solutions inserted in an action-research framework.

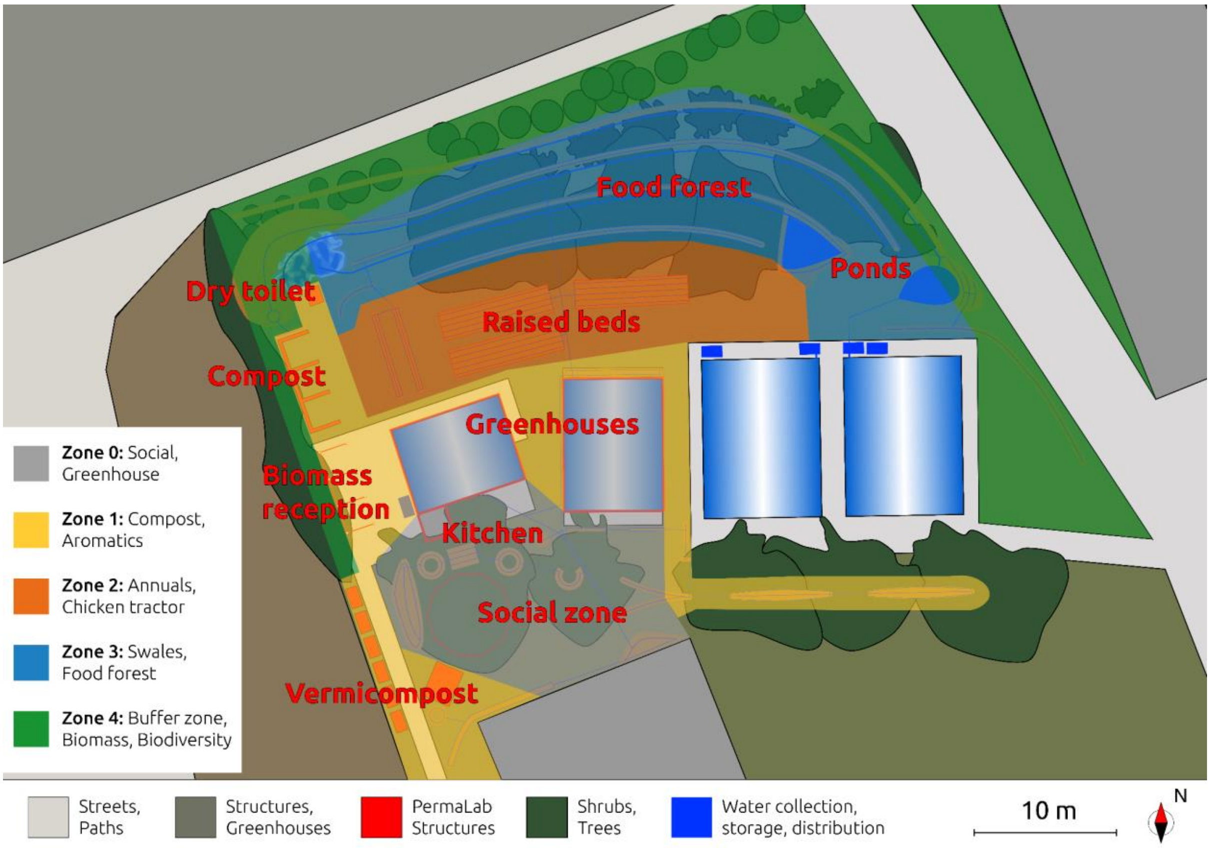


Figure 6 Permalab's graphical map. Zones are encircled as described above. Other landscape features are highlighted as described above. High speed ring road is located in the northwestern part of the map.

Permalab's landscape follows the permaculture's zonation principle **(Salleh et al., 2018)**, where the area is zoned according to the distance to a reference point, usually a house. In the case of Permalab, the house is the main greenhouse **(see Fig 6),** which works as a plant nursery, workshop and kitchen. This principle states that zones are defined based on the use frequency, which in theory decreases as the distance to the reference point increases. Thus, Zone 0 (the surroundings of the house) is the most intensely used zone, which in Permalab corresponds to a social area used for gatherings, meetings and celebrations; Zone 1 comprises (1) a compost station where the campus' gardening residuals are transformed and processed and (2) a vermicompost station, in which the organic leftovers of campus' cafeterias are turned into enriched compost; Zone 2 includes a vegetable garden for annual crop production; Zone 3 is occupied by a 600m^2 agroforest area with a pond and a small water purification pond, plus a 100m^2 recently restored lawn (2023), designed according to syntropic agriculture principles; Zone 4 is defined as the buffer area which divides Permalab from the its outskirts (buildings and high speed roads; **see Fig. 8**). **See Appendices 8.1.3.10., 8.2.15c, 8.2.15f, 8.2.15g and 8.2.15h** for more information.

Figure 7 PermaLab before the intervention (April 2016, left pictures) and PermaLab as of today (January 2024, right pictures). Both sets of pictures were taken on opposite sides of Zone 2 (see Fig. 4).

Figure 8 A perspective on PermaLab seen on its eastern side facing north. The green buffer (Zone 4) is clearly visible on the left side of the picture, while the ring road stands beyond the green gates (*Credits: Inês Leote / Mensagem de Lisboa*).

1.6.3.3. FCULresta

More recently, in 2021, HortaFCUL was pioneer by promoting the implementation of the first Mediterranean fast-growth Miyawaki forest in a 300m^2 lawn **(Schirone et al., 2011, see Fig. 9)**. This methodology proposes that plantations should follow a diversity and density principle to achieve faster results in terms of growth. Diversity, in this case, should be seen as a tool to potentiate co-associations of plant species that naturally occur in the plantation's local context (native species); and density - this method proposes an initial density of 3 to 4 plants/m^2 - simulates the natural competition of plants for a limiting resource, which in this case is light exposure **(Lewis, 2022)**. FCULresta has served as a baseline model for 10 other micro-forests in Lisbon's Metropolitan Area, designed and promoted by NGO's VIDA and URBEM, HortaFCUL's partners.

Figure 9 The evolution of FCULresta. Prior to 2021, the project's location (top-left picture) was a lawn with sparse native trees (*Olea europaea* and *Quercus suber*). During the intervention (top-right picture), swales were added, as well as compost and straw mulch, which is clearly visible after the conclusion of the plantation phase in March 2021 (bottom-left picture). As of 2023, the changes in vegetation density are evident (bottom-right picture).

1.6.3.4. BioIlhas

Following FCULresta's groundbreaking experiment, in 2023, HortaFCUL pioneered the creation of two biodiverse outdoor classrooms, called Bioislands (Bioilhas, as in the original project name, see Fig. 10), using a methodology applied in EU's LIFE Desert Adapt, whose main goal was to develop solid and science-based tools to mitigate desertification processes occurring in the Mediterranean region **(Da Silveira Bueno et al., 2021)**. Two old lawn areas of the campus comprising 600m^2 were converted to a plantation zone with clearings for the campus community's own leisure, work and studies. In summary, Bioislands are multifunctional spaces **(Van Leeuwen et al., 2010)** that (1) provide an opportunity for scientific activities in the context of education for various courses related to environmental and sustainability areas (academic/scientific function); (2) support urban biodiversity on campus (ecological function); (3) promote outdoor leisure spaces that enhance mental health and connect people with nature (social function); and (4) disseminate information/knowledge and raise awareness in the community about the importance of these new green spaces in an urban context (educational/pedagogical function).

Figure 10 The transformation process of Bioilha do C5. The existing lawn before the intervention (top left); the appearance after planting (with mulch visible, top right); the first month of plant succession with the annuals sprouting (bottom).

1.6.3.5. HortaSolar

In the same year, HortaFCUL supported the creation of the agrovoltaic system called HortaSolar, a new approach that intends to create synergies between photovoltaic-based energy production and food production **(Gaikwad et al., 2023)**. This project will serve as a hub to generate scientific knowledge on this newly-born methodology **(see Figs. 11 and 12)**.

Figure 11 Picture of the HortaSolar plantation day that took place on the FCUL campus on March 21, 2023, the International Day of Forests, within the framework of Sustainability Week.

Figure 12 "Preparing a vegetable bed" workshop organized by HortaFCUL in partnership with HortaSolar's taskforce. The workshop was designed for Masters students in the Ecological Sustainability course.

The configuration of the garden was designed to explore the effect of shading from solar panels on the productivity and irrigation needs of crops planted in the underlying zone. The study of these synergies is one of the main focuses of the research, and several advantages have already been registered:

- For plants: Depending on plant type and solar exposition, plants may benefit from the shading of the panels, especially in summer, as this will reduce heat stress and irrigation needs;

- For the panels: in the presence of plants, less dust is deposited on the panels, allowing a better functioning; the panels become more efficient when the temperature is lower, a situation favored by evapotranspiration of plants; Although they constituted a more expensive system, the bifacial panels produce more energy because they are further from the ground and receive more solar radiation.

1.6.4. Case study added value

As of today, it is possible to say that a vast body of literature has been published concerning permaculture-based sustainability initiatives. As an example, at European level, a significant description of the roles and impacts of ecovillages, transition towns as well as other permaculture projects can be seen in a report launched by ECOLISE in 2019 **(Penha-Lopes & Henfrey, 2019)**. In Portugal, examples of documented urban community gardens and permaculture-based projects are still scarce. Furthermore, most studies assume a qualitative baseline to evaluate the results of these initiatives. Although some studies have managed to produce interesting and impactful outcomes **(see Malberg Dyg et al., 2020)**, it is often difficult to use them as a comparative referential, since they are prone to a wide range of interpretations. In reality, civil society agents and policy makers increasingly need objective and clear results based on internationally recognized frameworks to support and promote bottom-up initiatives like community gardens.

HortaFCUL is, due to its longevity, mission, work output and institutional relationships, a meaningful case study when it comes to community gardens impact on their surrounding environment. Moreover, there is no other relevant example of a long-lived urban community garden in Portugal, especially in a university context. The scarcity of projects that combine these conditions as well as the growing interest in creating similar gardens in other communities stress the need to translate the project's activity in a clear indicator list that can be either applied to similar studies and contexts and used as a support for decision-making. In the case of HortaFCUL, although the list of projects and events is quite extensive, there hasn't been any attempt yet to create a systematic database that allows a quantitative analysis of its regenerative potential. This fact stresses the need to collect and organize data under the umbrella of universal frameworks that can be implemented in similar projects, while consolidating the importance of these projects and presenting the findings to decision-makers.

1.7. Objectives and Research Questions

The study aimed to identify and quantify the ES that were provided by HortaFCUL, both in spatial and temporal scales. TEEB's framework rationale was chosen in this context since it provided an objective structure concerning the selection of indicators and their respective groups and classes, although the groups defined in this paper as well as the indicators were adapted to fit HortaFCUL's context. Furthermore, the framework clearly states supporting services as the basis for the other three ES. Therefore, the connection to the ES framework answered the following question: Did HortaFCUL's activity outputs significantly embrace all ecosystem services?

The indicators identified for each of the services were also measured in other areas of the FCUL campus premises so as to allow a sound comparison between the current scenario and a scenario where HortaFCUL wouldn't exist. In other words, the data gathered on FCUL performance in terms of ecosystem services defined the baseline, or the control referential of this study. Since HortaFCUL is a living organism made up of sequential sub-projects in time (Hortinha, 2009; Permalab, 2016; FCULresta, 2021), FCUL's baseline was inserted, as Year 0 situation, in a space-for-time substitution framework **(Pickett, 1989)** which included FCULresta (3 years), PermaLab (7 years), and Hortinha (13 years). Each of these areas represented a different moment in HortaFCUL's timeline. Thus, this process answered the question: How exactly did HortaFCUL enhance ecosystem service indicators within the campus facilities throughout the years, as compared to a situation where no project of this type would exist (Year 0, or FCUL baseline)?

In order to situate HortaFCUL in a general public-oriented and transversal framework, ES indicators were used to bridge HortaFCUL's ecosystem performance and the UN's Sustainable Development Goals (SDG). The SDG framework has been widely applied in this context and allowed creating a common-ground language between parties and entities. This framework connection raised the question: (1) Which SDGs does HortaFCUL address?

All in all, this report aims to meet an urgent need to transcribe scientific outputs into wider frameworks used globally by institutions, so that decision-makers can impartially perceive the impact of nature-based solutions integrated in community projects, as well as the benefits of supporting active and participative citizen groups. Although the rationale behind a bottom-up initiative is to eliminate top-down bureaucracies, institutional support and validation is a valuable asset to prompt initiatives of this sort. Thus, this report seeks to provide scientific evidence of the added value of these types of initiatives as well as to incentivize other projects and researchers to invest their time to objectively document their own positive impacts at community level.

2. METHODS

This report followed both the Ecosystems Services framework and Sustainable Development Goals framework in separate but complementary methodologies. The Methods section is organized by ES type and their respective indicators with an exclusive section for SDG methodology.

2.1. Supporting services

2.1.1. Land cover assessment

In order to characterize land cover types at both HortaFCUL and the FCUL campus, several areas were identified in terms of function through aerial imagery and ground-proof measurements **(Cabral et al., 2017)**. Built infrastructure and paths were considered impervious surfaces, while permeable surfaces included composting facilities, managed green areas (agroforests, edible gardens and lawns), managed perennial beds and annual crop beds. Blue infrastructures, such as ponds, were also considered.

Figure 13 Hortinha's (left picture) and PermaLab's pond (right picture) in 2019.

2.1.2. Above-ground carbon captured in biomass

2.1.2.1. Trees and large shrubs

All existing trees were mapped, their diameters at breast height determined and, using allometric biomass models from various sources, their aboveground biomass was estimated. Only trees with diameters larger than 4 cm were considered and where diameter at breast height was not feasible to measure (too many branches, etc.), diameter at ground height was used. In particular, for *Populus alba*, a model from **Neto and Sarmento, 2019**, was used, while for *Eucalyptus globulus* the https://www.fs.usda.gov/research/treesearch/52933 data base was used, with the corresponding dry weight density factor from the global wood density database (http://db.worldagroforestry.org/wd), for *Prunus spp.* a model from **Yoon et al., 2013**, was used, again with the corresponding weight density factor from the global wood density database, for *Olea europea* a model from **Kebede and Soromessa, 2018**, was used, and lastly, for *Quercus suber,* a model from **Jorge et al., 2023** was used, again with the corresponding weight density factor from the global wood density database.

2.1.2.2. Biomass production through annual crops

For biomass production through annual crops, data from maize production in **Ulm *et al.* (2019)** was used and extrapolated to a whole year. To model a normal planting and fertilization regime, medium fertilization (municipal compost + green waste compost) as well as mixed planting (open pollinated + hybrid variety) was assumed.

Figure 14 Maize crops grown for *Ulm et al. (2019)* scientific article (July 2016).

2.1.2.3. Remote sensing

In order to describe microclimatic conditions based on vegetation status, two indices were selected: (1) Normalized Difference Vegetation Index (NDVI) and (2) Normalized Difference Moisture Index (NDMI). The former is a widely used, simple but effective index for quantifying green vegetation. In other words, NDVI is a measure of the health of vegetation, based on how plants reflect light at certain wavelengths, namely the red and near-infrared spectral bands **(Huang et al., 2021)**. NDVI values vary between -1 to 1. Negative NDVI values (values close to -1) correspond to water. Values close to zero (-0.1 to 0.1) generally correspond to arid areas of rock, sand or snow. Low, positive values represent shrubs and meadows (approximately 0.2 to 0.4), while high values indicate tropical and temperate forests (values close to 1).

As for the second index, NDMI is used to determine the water content of vegetation and monitor droughts **(Ochtyra et al., 2020)**. The range of NDMI values is -1 to 1, of which negative NDMI values (values close to -1) correspond to infertile soil. Values around zero (-0.2 to 0.4) generally correspond to water stress. High, positive values represent the absence of water stress (approximately 0.4 to 1).

Image collections from the Sentinel Hub were used, namely Sentinel-2 L2A, since they provide high-resolution data and images **(Dyke et al., 2021)**. The satellite is equipped with a multispectral optoelectronic sensor with a spatial resolution of 10 to 60 m in the visible, near-infrared (VNIR) and short-wave infrared (SWIR) spectral zones, including 13 spectral channels, which ensures the capture of differences in the state of vegetation, including temporal changes, and minimizes the impact on the quality of atmospheric photography **(El Hachimi et al., 2021)**.

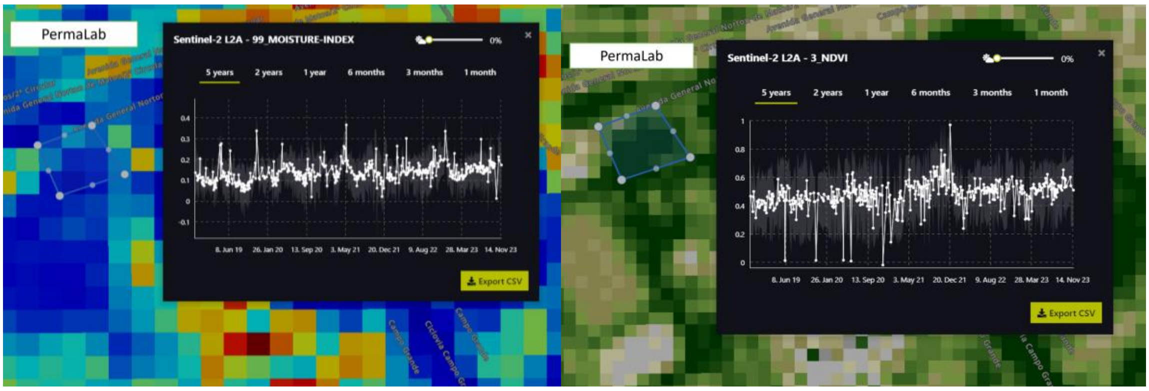


Figure 15 Example of Normalized Difference Vegetation Index (NDVI) and Normalized Difference Moisture Index (NDMI) extracted from Sentinel-2 L2A to the PermaLab plot.

2.1.3. Plant diversity and composition

To characterize the plant community at HortaFCUL, species inventories were made at five different locations: (1) Permalab's social area (zone 0) and perennial beds (zone 1); (2) Permalab's sintropic agroforest; (3) Permalab's swale agroforest (zones 3 and 4); (4) Hortinha; and (5) FCULresta. A criterion based on management was used to select the inventory data to be collected. For the first and second locations, all the perennial individuals - i.e. individuals with life cycle longer than 2 years - were counted and identified at least to the genus level. However, no data on individual morphology was collected since these two areas have considerable management intensity (periodic cuttings). As for the remaining areas, due to their low management frequency, individual's height and cover were measured. In the case of FCULresta data was provided by previous monitoring work (**António Alexandre & Madeleine Toisoul Laurent, unpublished data**). Regarding cover, each individual's crown was assumed to be elliptical and two measurements were taken as the major and minor axis of the crown's ellipse **(Porto et al., 2013)**. Each plant species was then classified as being part of the bush or the tree strata, as well as their origin (exotic or native). From a functional point of view, another classification was made based on utility (food provisioning, biomass, aromatic, ornamental or biodiversity support). This utility judgement was based on the landscape designer's intention when selecting the species to be planted. Classification was adapted from some references in literature **(Berthon et al., 2021; Avolio et al., 2020).** Structurally, individuals were classified as either trees or bushes according to their ability to provide shade (*potential* in the case of young individuals or *existing* as for adult individuals).

To set the plant diversity status prior to HortaFCUL's intervention in the campus, another survey was conducted in FCUL's green areas. This survey only took into consideration green permeable areas that were easily accessible by the community (observer's judgment). Only perennial species present at the faculty's green areas were recorded. Crown cover of structurally significant individuals, such as medium to large trees, was also measured via satellite imagery, as well as the green plot area. A distinction was made between a lower stratum (bushes) and a higher stratum (trees).

Two diversity metrics were considered to describe each plant community: Simpson Index (SI) and Shannon-Wiener Diversity Index (SWI). Both indices take into account species number and their relative abundances within the community. SI formula is described as follows:

$$1 - D = \frac{1}{\sum_{i=1}^{S} p_i^2}$$

where,

- S represents the total number of species.

- pi is the proportion of individuals of the *i*th species relative to the total number of individuals in the community.

SI varies between 0 and 1 and its value states the probability of two individuals pooled randomly from the same community belonging to different species. Values closer to 0 indicate greater dominance of few species and values closer to 1 suggest greater diversity and evenness through species of community.

On the other hand, SWI's formula is expressed as:

$$H = -\sum_{i=1}^{S} p_i \cdot \ln(p_i)$$

where,

- S is the total number of species in the community.
- pi is the proportion of individuals of the *i*th species relative to the total number of individuals in the community.

SWI varies between 0 and + ∞. The higher the value, the more diverse and even the community is. Usually, communities with values over 2 are assumed as fairly diverse. To complement these two metrics, species richness and family richness were also considered.

2.1.4. Macroinvertebrate diversity

Macroinvertebrate sampling in the **Autumn period** covered three distinct areas in different successional stages: a recently interventioned FCUL lawn (Bioilhas), FCULresta and Hortinha (the oldest plot with dense vegetation). The aim was to strategically choose representative locations that would yield comprehensive data regarding the entomological fauna in the area.

Regarding the traps used, plastic cups measuring 15 cm in length with a 10 cm diameter opening were employed. Notably, containment barriers were not included in this setup. These cups were filled to approximately 2/3 of their total volume with an aqueous solution containing detergent additives. This specific solution aimed to reduce the water's surface tension, thus aiding in the capture of invertebrates. To maximize the representativeness of the collected samples, the spatial distribution of traps was carefully planned.

Monitoring and collection procedures were diligently executed post-installation. Regular checks of the traps occurred from November to December at two-week intervals: specifically, from November 12th to 26th and from December 3rd to 17th. Upon retrieval of the traps, the collected material underwent meticulous sorting and identification. The laboratory analysis primarily focused on taxonomic classification and specimen counting. It's noteworthy that parameters such as size and physical condition were not included in the evaluation during this phase.

In order to cover the **Spring period**, a scientific work conducted by FCUL students in April 2022 was retrieved **(Maria Teresa Rebelo & Ana Sofia Reboleiro, unpublished data)**. This study was conducted within the FCUL campus area, encompassing seven different sampling locations, two of them at Permalab's zone 0 and another point at FCULresta. The remaining sampling sites were located in other FCUL green areas. Conditions such as vegetation type (ground vegetation, trees, or agricultural crops), sunlight exposure, surrounding environment, or even pollution levels (potential high pollution near a road) varied across the seven sampling locations.

Various sampling methods, both passive (pitfall and yellow adhesive traps) and active (beating with an entomological net, direct collection of specimens from rocks and water), were employed. The sampling efforts were comparable (10 to 15 minutes per active method by each group member and 24 hours for passive methods) to ensure data comparability. In total 4 main sampling methods were employed in this study.

Pitfalls

Described earlier in the Autumn sampling period.

Yellow adhesive trap

At each location, a yellow adhesive trap was hung. This trap attracted flying insects due to its yellow color resembling flowers, which entrapped the insects in the adhesive. After 24 hours, the traps were collected, and a biological liquid, Bio-Clear, was used to remove the insects, which were then stored in tubes with 70% ethanol for subsequent identification.

Active collection from rocks and branches

At all locations, an active collection was conducted using forceps or by hand of arthropods under some rocks and near branches on the ground, which were then stored in tubes with 70% ethanol for subsequent identification.

Beating on vegetation

Using an entomological net, vegetation in all locations was beaten to capture arthropods. These were aspirated and stored in tubes with 70% ethanol for subsequent identification.

Species observation and identification were conducted in FCUL laboratories using magnifying glasses, dichotomous keys, and databases (Biodiversity4all, Naturdata). Diversity analysis (Shannon, Simpson and Species richness) was conducted in R Studio **(R Core Team, 2022)**.

2.1.5. Carbon captured in compost

In order to estimate carbon captured in compost production, methods and results from **Horta (2021)** were retrieved and used as the baseline information **(see Fig. 16)**. In this work, several compost properties were analyzed. Initially, sub-samples were subjected to pre- and post-oven drying to determine dry weight, enabling the estimation of water content using a defined formula. To achieve textural homogeneity, each sample underwent a grinding procedure in a ball mill. Organic matter in both input material and compost was evaluated using a modified loss on ignition method. This procedure involved burning dried and milled samples at 550°C for 4 hours, exceeding the recommended time to prevent underestimation of organic matter. The resulting loss after ignition was considered as organic matter, calculated using a specific formula.

Regarding the assessment of C/N ratio and isotopic fractionation, compost materials from various cycles were ground, encapsulated, and then analyzed for isotopic ratios at the Stable Isotopes and Instrumental Analysis Facility. Isotopic fractionation was determined using continuous flow isotope mass spectrometry coupled with elemental analyzers. Precision was maintained through laboratory standard material analysis interspersed among samples.

To compute the total mass of each feedstock and compost, an equation factoring in fresh and dry weights was utilized. Biomass, nitrogen, and carbon masses in the piles were then determined based on their concentrations and dry weight. Additionally, the assessment of losses involved calculating the percentage change between initial and final masses for biomass, nitrogen, and carbon. These detailed procedures were crucial for evaluating compost characteristics, with particular emphasis on determining the total carbon weight within the compost pile.

During this study four compost piles were produced with different carbon weight values (g per kg). An average value was computed and extrapolated to the total compost production from 2016 and 2023 (see *2.3.1.1. Production volume of compost and vermicompost*, in *Provisioning Services* chapter). For more on the composting process developed at HortaFCUL, see **Appendices 8.1.3.14., 8.2.7., 8.2.21 and 8.2.22**.

Figure 16 Measuring compost temperature (left picture) and weighing biomass (right picture). These procedures were followed during **Horta (2021)** fieldwork.

2.2. Regulation services

2.2.1. Amount of captured rainwater

To compute the amount of stormwater harvested by HortaFCUL's areas and the reservoirs connected to the greenhouse roofs, data on cumulative precipitation volume was retrieved from the closest weather monitoring station (Lat: 38.77329996244017; Long: -9.18388438153939) for the year 2022. The study assumed that the totality of rainwater that fell in HortaFCUL's areas was collected without losses. This assumption was based on the thoughtful design of the landscape to maximize water percolation and avoid any run-off to the surrounding areas, such as swales, ponds, water reservoirs and constant addition of organic matter to the soil **(Shapiro, 2011).** The same methodology was applied to estimate the amount of water retained in the greenhouse roofs at Permalab. Containers were coupled to the drainage infrastructure to store and spread rainwater **(see Fig 17).** To see the process of rainwater storage, check **Appendix 8.2.10.**.

Figure 17 Plant assisted gray water treatment pond (FitoETAR in Portuguese) in PermaLab (left picture) and municipality's obsolete containers used to store stormwater (right picture).

2.2.2. Tree cover as temperature regulator

Urban areas, due to their high density of artificial infrastructure, are especially vulnerable to extreme heat wave events **(Ramamurthy et al., 2017)**. Urban planning researchers suggest that an increase in accessible and dispersed green shaded areas would offer urban populations climatic refuges and mitigate the deleterious effect of extreme heat waves in public health **(Macintyre et al., 2018)**. The increase and optimization of urban vegetation has been considered an effective mitigation measure of the urban heat island (UHI) effect, with positive effects on human thermal comfort (**Reis and Lopes, 2019**).

In order to assess the impact of HortaFCUL regarding temperature regulation within the campus area, tree cover was used as a surrogate of the cooling effect provisioned by large trees in the surrounding environment. Due to time and resource constraints, it was not possible to measure empirically temperatures in different campus areas nor apply a meaningful model to such a reduced urban scale, however, tree cover has been described in literature as one of the main factors contributing to the cooling island effect **(Wang et al., 2018)**, as opposed to the heat island effect promoted by impervious artificial infrastructure such as buildings, pavements and roads **(Yang et al., 2016)**. Tree covers were measured via satellite imagery Normalized Difference Vegetation Index (NDVI) and subjected to ground-proof sampling to discard any outdated situation in terms of vegetation density. NDVI is usually used to quantitatively assess urban vegetation and tree canopy cover **(Parmerh et al., 2016)** and corresponds to a normalized index that allows for the detection and quantification of vegetation through a difference ratio between the near infrared band and the red band of the electromagnetic spectrum (see section *2.1.2.3. Above-ground carbon captured in biomass*).

Besides the assessment of the tree layer, the underlayer cover was also measured with *in situ* sampling (see *2.1.3. Plant Diversity and Composition* methodology), since more complex vegetation structure can be more effective in terms of temperature regulation **(Ferrini et al., 2020).**

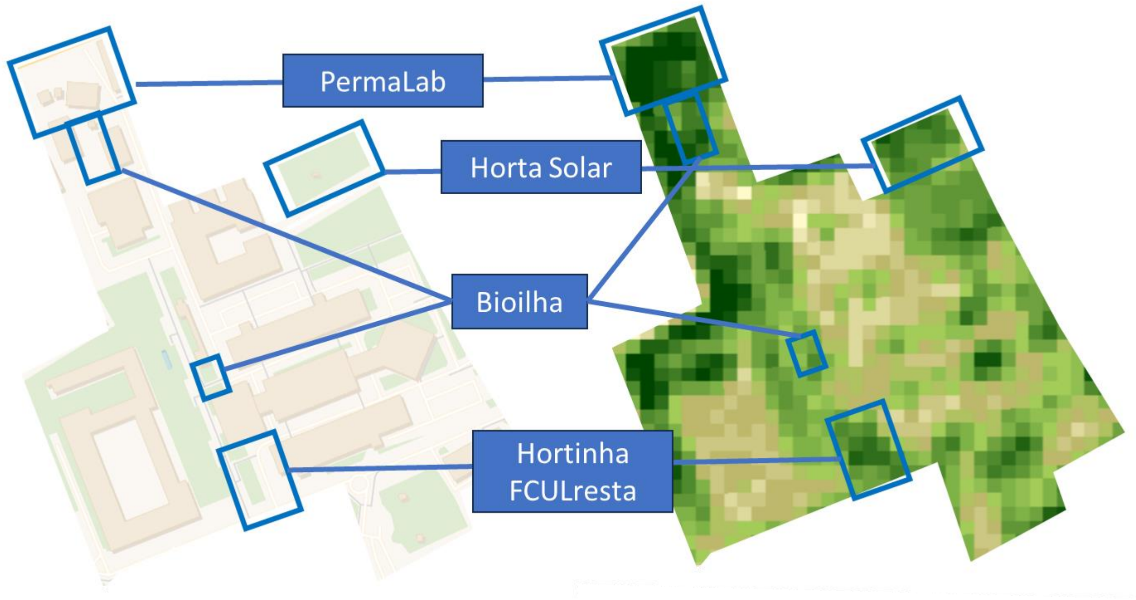


Figure 18 Example of Vegetation Index (NDVI) for the university campus (Sentinel-2, 1st july 2023). The greener pixels correspond to high values of NDVI, which in turn correspond to areas where plant cover is denser. Blue squares highlight HortaFCUL sites.

2.3. Provisioning services

2.3.1. Production volume of compost and vermicompost

2.3.1.1. Compost

In 2016, a composting station was installed in Permalab to process the organic residuals produced by the campus' green areas gardening activities (falling leaves, grass cuttings and branches). The station consists of three compartments, each one with an approximate volume of 4m^3. Each compost pile is formed with alternate layers of "greens" (sources of nitrogen) and "browns" (sources of carbon) and it is transferred from one compartment to the next twice during the whole process to prevent excessive compaction, lack of oxygenation and increase feedstock homogenization **(Figs. 19 and 20).** The period between the first piling and the compost sieving is on average 4 to 6 months.

Figure 19 The process of compost pilling. Compost piles are formed and transferred between stations by volunteers and guardians exclusively by hand, as described in the picture series.

Data on compost production was collected during the station's first active year (2016-2017, **Florian Ulm, unpublished data**), and during 2019, as part of a Master scientific work (**Horta, 2021).** These two data sources were used to extrapolate production volume from 2016 to 2023. According to guardians' feedback on the process, in this period compost production remained constant (with a slight decrease during the pandemic). Average compost pile production was set to five piles a year based on this same feedback.

Figure 20 A scheme of HortaFCUL's composting station. Each compartment has an average volume of 4m^3. Arrows represent the transfer flux from one compartment to the next to increase the input of oxygen into the pile. Infrastructure is not drawn at scale.

2.3.1.2 Vermicompost

Vermicomposting was started during Permalab's first years, however, only in 2019, a proposal to increase the capacity of Permalab's vermicomposting station became effective. Since then, HortaFCUL has been using 8 containers with 1.5m^3 volume, where it processes the raw vegetable organic leftovers from campus cafeterias and bars. Vermicomposting relies mostly on worm activity to catalyze organic matter transformation (although insect larvae and isopods also play important roles in the process). Worms aerate the substrate while enhancing the availability of certain minerals. In HortaFCUL's vermicomposting station, these macroinvertebrates should be added on average, 21 days after organic matter's last input, which is the time it takes for the temperature to decrease to tolerable values for worms - around 25 ºC **(Verhoeven, 2019)**. To ensure worm survival, containers are kept close in a shaded area and they are constantly watered to keep a reasonable humidity level.

On average, it takes about 1 month to fill a container with organic residuals (with alternate layers of "browns", such as dead leaves). Vermicompost maturation peak is reached after 4 to 5 months **(David Avelar, unpublished data)**. For this analysis, the period before and during the pandemic was ignored, since there was no solid basis to evaluate organic residuals input before September 2021. Thus, estimates based on the above-mentioned averages were only computed to include the period between September 2021 and December 2023. Vermicompost density estimates were based on a previous work, which set a value of 0.65kg/dm^3 **(Gil Penha-Lopes & David Avelar, unpublished data).** For more information on the vermicomposting process at HortaFCUL, **see Appendices 8.1.3.9. and 8.1.3.16.**

2.3.1.3. Volume of organic residuals recycled.

Organic residuals collection is made three times a week by FCUL's staff. The circuit includes four cafeterias at campus level. During last year, an estimate of organic residuals' boxes taken to Permalab was made with FCUL's staff feedback on the process. In the course of school months, (mid-September to mid-December and mid-February to mid-June), between 3.5 to 4.5 boxes of residuals were collected, while during the summer and Christmas breaks (mid-July to mid-September and mid-December to mid-January), only 0.5 to 1.5 boxes were collected. During study breaks (January and June), approximately 2 to 3 boxes were filled by the cafeterias staff. Boxes filled with organic residuals were weighted and the volume of each box was measured to guarantee a solid estimate (25-30kg; 30L volume).

2.3.2. Number of plants provided to the community

Since 2014, HortaFCUL has kept a small stand at the center of the campus, called "Gift Stand", where it develops and tests the Gift Economy model **(see Fig. 21).** This alternative approach to the market economy model states that the consumer comes up with the value of a product (generally, money-wise) according to what he/she considers fair both regarding his/her own social-economic condition and the work invested in the production of a certain good **(Cheal, 2015).** This model is viable only when there is a trust "contract" between the two parts (consumer and producer), which is why it is considered by many as challenging to implement **(Thygesen, 2019)**. At the gift stand, HortaFCUL provides goods that are seen as a surplus of its activity in exchange for a donation to the project. The two main products that are made accessible to the faculty community are compost and plants. See **Appendix 8.1.3.5.** for more information.

Figure 21 Gift Stand inaugural day (February 2014). Sign on the stand (left picture) says "Take Horta to your home. Leave what you think is fair. Every donation will fund HortaFCUL's initiatives".

As for the latter, HortaFCUL has kept an incomplete record of the number of plants and the frequency of replacements of the plant stock from 2015 to 2019 and in 2023. In order to obtain a reasonable estimate of the number of plants provided to the community each year, monthly averages were computed for each year and those averages were extrapolated to fill the homologous months with no data recorded. Only 9 months in total were included in the annual contributions to the gift table, given the absence of data for the months of July and August, the 1st half of September and the second half of December, which correspond to the project's periods of low activity. The pandemic period (March 2020 - December 2021) was left out of the estimate.

2.3.3. Number of propagated plants

HortaFCUL's plant nursery has, since 2018, three 10m^2 ebb-and-flow tables which are used mainly for plant propagation **(see Fig. 22)**. The community didn't keep track of the number of plants successfully propagated each year. However, based on observations from previous guardians and photographs from the HortaFCUL's archive, this study assumed that the three ebb and flow tables were full approximately twice a year, and the survival rate of cuttings was fixed at 50%. An estimate of the capacity of each table was made with a simulation of occupation of different recipients often used for plant propagation purposes. The output of this analysis should be regarded as the project's potential capacity to propagate plants in recent years.

Figure 22 Pictures depicting plant propagation procedures (November 2023) and the plant nursery (2023).

2.3.4. Meals cooked

In 2016, HortaFCUL started its "Sopas da Horta", a meal prepared at the end of the working day as a way to celebrate the project's achievements, particularly the activities developed in the same day and also its urban food production. This meal has become a routine when guardians meet at HortaFCUL and it prompts the use of vegetables grown and harvested *in situ.* There is no consistent record of the amount of food locally grown used in these meals. However, in 2023, working days and meal content were qualitatively registered in WhatsApp messages and pictures. A coarse estimate of the volume of soup was calculated based on this record and the dimensions of the pot used for cooking, as well as the harvested vegetable species richness. **See Appendix 8.2.7**. for more information.

2.4. Social/cultural services

2.4.1. HortaFCUL's events and contributions

Regarding social/cultural services, parameters such as education and inclusiveness were described by a set of indicators derived from the project's event record since 2010. This record was compiled by reviewing the best available data sources at the moment: (1) social media accounts (namely Facebook, Whatsapp and Instagram), (2) email address and (3) direct surveys to the guardians. Each event was described as an activity type, which, in order to simplify, were categorized as follows: (1) "Workshop", which includes courses, trainings and workshops; (2) "Article", which includes scientific articles and grey literature as well as scientific media content, whether filmed or written; (3) "Tours" was assigned exclusively to guided tours; (4) "Party" was applied to celebration occasions and other social gatherings; (5) "Fairs" to identify HortaFCUL's participation in this type of events; (6) "Practics" as any intervention at project level that had, as a consequence, the inclusion of new infrastructure or an element; (7) "Partnerships" to describe logistic or social support to another project in the form of sponsorships or resources; and finally (8) "Talks" to represent presentations, talks and debates **(see Fig. 23).** For each event's entry, the following indicators were identified: (1) number and name of the guardians implied directly in the organization of the event; (2) number and the name of partners involved; (3) amount of time invested in the event (in hours and days); (4) year and month of the occurrence; (5) number of participants, if applied; and (6) the location of the event and the spatial scope of the partners, if applied. For the latter, 5 spatial categories were considered: campus (Lisbon University Area); local (comprising the city of Lisbon); regional (Lisbon's Metropolitan Area); national (Portugal's territorial limits); and international scales.

Figure 23 Pictures representing HortaFCUL's main community outreach activity types (clockwise, starting upper left corner): Workshops, Talks, Guided Tours and Fairs.

To further characterize each event in terms of scope, the closing cycles permaculture framework was considered **(see Fig. 24)**. This framework was used for the first time in scientific work in this report and it identifies a set of wide range cycles that address social and ecological dimensions. Every event was associated with one or more cycles, depending on their scope. The following cycles were used in this analysis:

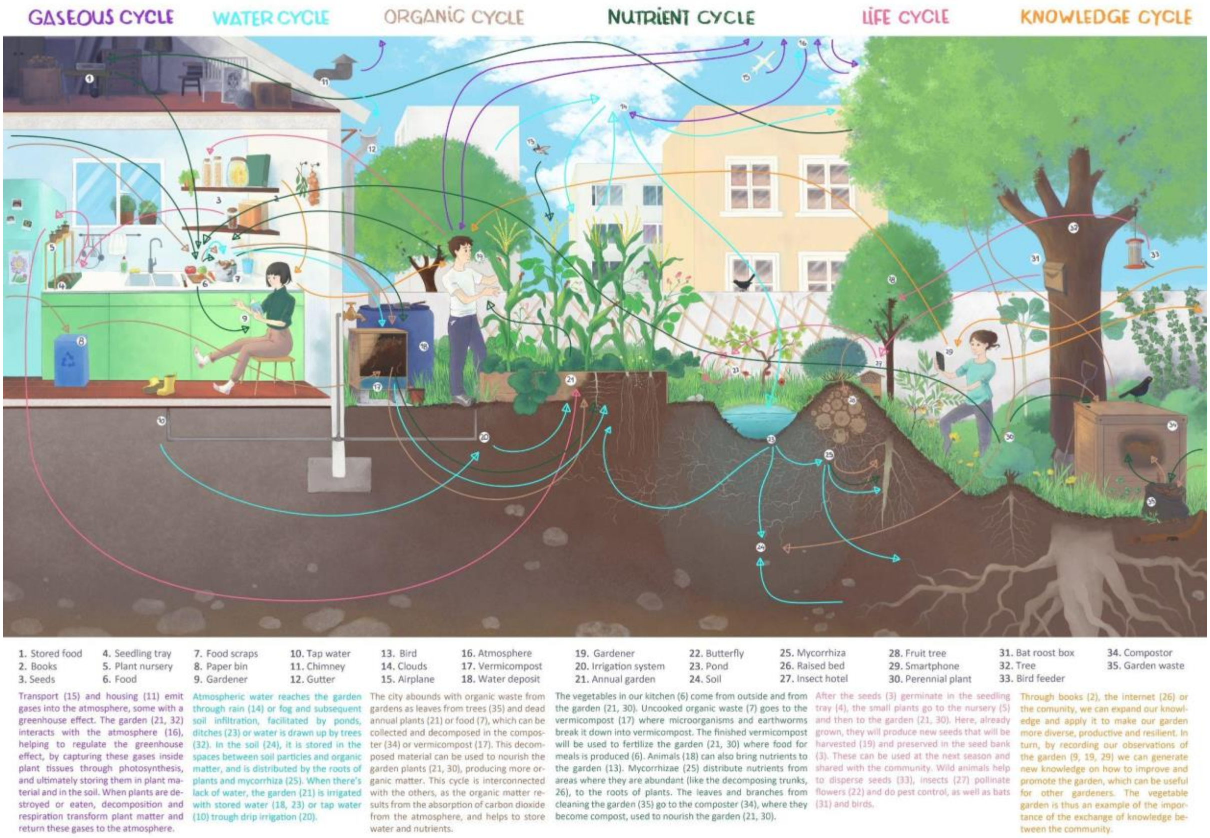


Figure 24 Schematic illustration of PermaLab cycles framework created for "Hortas de Lisboa. Da Idade Média ao Século XXI" exhibition. Cycles in this depiction do not entirely match cycles selected for the ES connection to Permaculture. For instance, Nutrient cycle, Life Cycle and Gaseous cycle - presented in this picture - are embedded in the Ecological and Organic cycles stated above.

Knowledge cycle: activities identified with this cycle are somehow related with knowledge production, ecological awareness practices and education. This cycle includes outputs like articles, workshops and talks with the specific purpose of empowering the community in terms of scientific information and awareness and practical know-how.

Social cycle: activities specifically associated with celebration, conviviality and community engagement. In this cycle the greatest contributors are parties or community gatherings.

Production cycle: This cycle is linked to food production, biomass production and plant propagation mainly

Organic cycle: Any activity related to biomass use and management is integrated in this cycle. An example would be compost production.

Materials cycle: This cycle includes the upcycling processes of residuals and materials that would be otherwise discarded, as well as the activities that reused materials to achieve a certain goal (in construction mainly).

Hydrological cycle: Any activity related to water management (storage, spreading, sustainable use of water resources) is considered in this cycle.

Ecological cycle: All the outputs which aim to enhance ecological indicators and ecosystem function through habitat provisioning are included in this cycle. Agroforestry activities are integrated in this cycle, as well as the creation of new perennial vegetation beds, i.e. novel micro-scale ecosystems and habitats.

Concerning the surveys to the guardians, information on the number of guardians, gender balance and main challenges for the project was retrieved to complement data extracted in the email account and Facebook. In order to capture the balance in terms of guardians participation in events, Shannon-Wiener and Simpson indices (see Supporting services, Plant diversity) were applied. Additionally, a beta diversity analysis was performed to depict guardian turnover from one year to the next. Jaccard dissimilarity method was used to assess beta diversity in this study. The Jaccard method (J) -measures dissimilarities between ecological communities based on species presence-absence data, providing insights into the compositional differences among samples. Jaccard index is calculated as follows:

$$J(A,B) = \frac{|A \cap B|}{|A \cup B|}$$

Where:

- $|A \cap B|$ denotes the cardinality (number of elements) of the intersection of sets A and B (the count of elements common to both sets).
- $|A \cup B|$ represents the cardinality of the union of sets A and B (the count of all distinct elements in both sets combined)

The modified version 1-J was used so that values closer to 0 mean less community turnover (less dissimilarity between sets) and values closer to 1 express higher turnover. In the case of HortaFCUL, each guardian was assumed to be a species and each year's community was assumed to be the unit of comparison (set).

2.4.2. FCUL's events and contributions

In order to provide a baseline in terms of the institution's contributions to sustainability in general, an event search was undertaken for the year 2019 (which is the equivalent to the most recent year prior to the pandemic). This analysis included inputs located in the faculty's website and Facebook page. Keywords such as "sustainability", "climate change" and "conservation" were used to detect events that shared some common ground with HortaFCUL's mission and goals. Each event was registered following the same classification described above in the activity type categories. The data collected for the year 2019 was compared with the events promoted by HortaFCUL in the same period. For this analysis, scientific articles were not taken into consideration.

The statistical analysis was performed in R Studio **(R Core Team, 2022)**. ES indicator list is summarized in Table II.

Table II List of ecosystem services, groups and indicators compiled in the analysis and their information sources.

Ecosystem service	Groups	Indicators	Source
Support	Carbon sequestration	Carbon captured in biomass $yr^{-1}m^2$	Estimates based on vegetation sampling
		Carbon captured in compost	Estimates according to volume of compost
	Biodiversity	Biodiversity indices for plants and macroinvertebrates (shannon, spp. richness)	Sampling in loco. Insect trapping and cover estimations for plants
		Plants relative abundances	Sampling in loco
		Ratio exotic/native plants	Sampling in loco
	Land cover	Relative occupation area for each land cover feature	Aerial imagery analysis and ground-proof check
Regulation	Hydrological cycle	Amount of captured rainwater/m^2	Estimates based on digital sourced data
	Thermic regulation	Average relative temperature	
Provisioning	Food production	Species richness(vegetables)	Photo archive analysis
		Number of soups cooked	Photo archive analysis and extrapolation
	Biomass	Volume of compost produced/year	Data extrapolation based on Ulm, unpublished data and Madalena Horta, Masters thesis
		Volume of vermicompost/year	Data extrapolation based on Gil Penha-Lopes & David Avelar, unpublished data
		Volume of organic residuals captured/month	Estimates based on staff feedback
	Plants	Number of propagated plants	Estimates based on photo archive and guardian feedback
		Number of plants donated to the community	Data extrapolation based on multiple records (2015-2023)
Cultural/Social	Education	Number of workshops, talks/presentations and tours	E-mail, Facebook and Whatsapp data analysis
		Average and total participants in workshops, talks and tours	E-mail, Facebook and Whatsapp data analysis
		Event's relative contribution to permaculture cycles	E-mail, Facebook and Whatsapp data analysis

Ecosystem service	Groups	Indicators	Source
		Event's relative contribution to ecosystem service framework	Expert judgement based on event information
		Partnership number, scope and outreach	E-mail, Facebook and Whatsapp data analysis
		Number of articles/year	E-mail, Facebook and Whatsapp data analysis
	Inclusiveness	Project's activity/ number of active guardians	E-mail, Facebook and Whatsapp data analysis
		Number of celebrations and gatherings	E-mail, Facebook and Whatsapp data analysis
		Total activity/year	E-mail, Facebook and Whatsapp data analysis
		Number of guardians / year	Community enquiry

2.5. Ecosystem Services and Sustainable Development Goals linkages

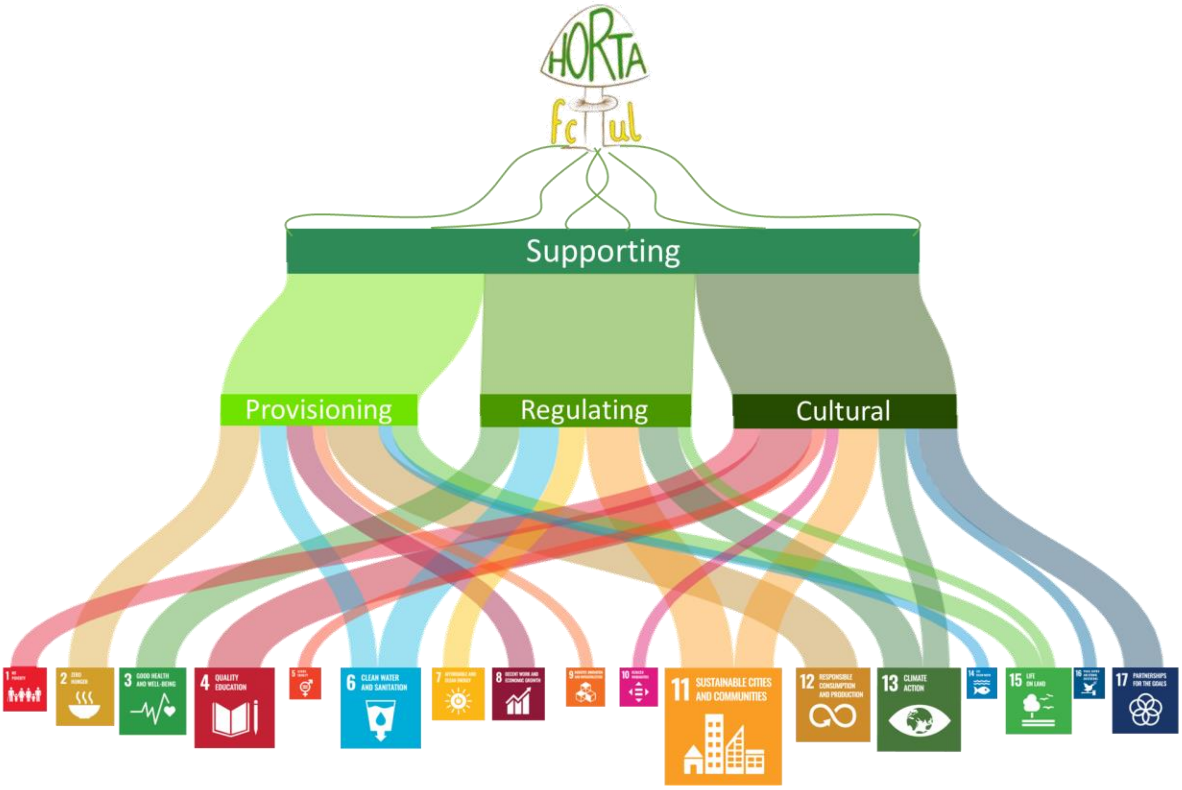


Figure 25 Reports general approach representation, integrating both Ecosystems Services and Sustainable Development Goals methodological frameworks.

To effectively link ES to SDG's, a set of the most relevant indicators was selected to bridge services with specific targets. The attribution of targets to indicators relied on expert judgment, since there is no specific framework to make the connection between ES and SDG's.

Below are the linkages between different dimensions of ecosystem services and the most relevant SDGs:

2.5.1. Supporting Services

Supporting Services form the structural backbone of ecosystem services and encompass essential functions such as nutrient cycling, soil formation, habitat provisioning, and biodiversity maintenance. These services are fundamental, laying the groundwork for various other ecosystem services. Linked to SDGs, they contribute significantly to SDG 15 by preserving biodiversity and ecosystems. Additionally, they address SDG 2 by ensuring food security and promoting sustainable agricultural practices under SDG 12.

2.5.2. Provisioning Services

Provisioning Services include the tangible products directly obtained from ecosystems. These services comprise a wide range of goods, including food, water, raw materials and genetic resources in the form of organisms, such as plants. Their pivotal role is evident in addressing specific Sustainable Development Goals (SDGs), namely SDG 2 and SDG 12, where they contribute to ensuring food security and promoting sustainable agriculture. Furthermore, they play a crucial role in supporting water provisioning services linked to SDG 6 (Clean Water and Sanitation).

2.5.3. Regulating Services

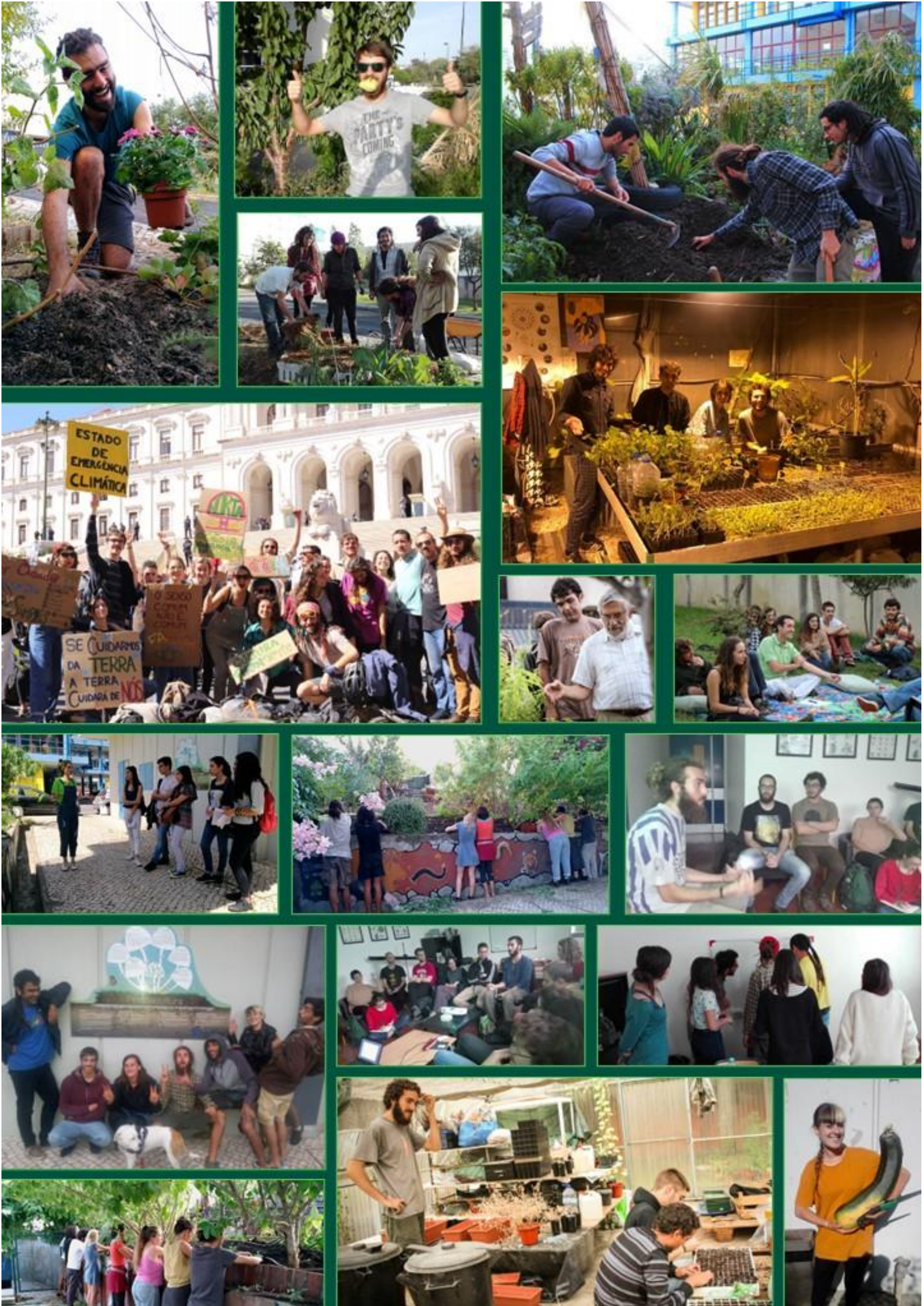
Regulating Services play an important role when it comes to operating environmental processes vital for maintaining ecological balance. These services include climate regulation, disease control, water purification, and pollination. In the context of Sustainable Development Goals (SDGs), they are essential contributors to several goals. They significantly impact SDG 3 (Good Health and Well-being) through disease control measures and contribute to climate regulation under SDG 13 (Climate Action). Furthermore, they are instrumental in addressing the degradation and loss of ecosystems, as outlined in SDG 15 (Life on Land).

2.5.4. Cultural Services

Cultural Services encompass the intangible benefits derived from ecosystems, providing recreational, aesthetic, spiritual, and educational value. These services contribute to various Sustainable Development Goals (SDGs), playing a crucial role in providing educational and recreational opportunities, as highlighted in SDG 4 (Quality Education). Additionally, they contribute to the conservation of cultural landscapes and biodiversity, aligning with SDG 15 (Life on Land), as well as SDG 3 (Health and well-being) by fostering community bonds and purpose among citizens.

2.5.5. Linkages Across Dimensions

The intersectionality of ecosystem services extends across various Sustainable Development Goals (SDGs). SDG 17 (Partnerships for the Goals) emphasizes the interconnected nature of ecosystem services, necessitating collaborative efforts to address complex challenges and foster sustainable development across multiple dimensions.



ESTADO DE EMERGÊNCIA CLIMÁTICA
SE CUIDARMOS DA TERRA A TERRA CUIDARÁ DE NÓS
THE PARTY'S COMING

3. RESULTS

3.1. Supporting services

3.1.1. Land cover assessment

The project's total area amounts to 3782m^2 **(see Fig. 26),** which represents about 4.9% of the whole faculty campus (76172m^2). If we exclude recently converted areas - Bioilhas (as of 2023) -, the area decreases to 2202m2 (3%). Total permeable surface at the campus is 22617m^2 (30%), of which 17% is occupied by HortaFCUL. Lawns comprise more than half of the total permeable surface area (53%).

In terms of the diversity of structures present within HortaFCUL's plots, about 49% is dedicated to semi-natural managed vegetated areas (including, agroforests, edible gardens and micro-forests), while 6,5% is occupied by artificial manmade structures (facilities like greenhouses and paths). The former doesn't include small growing beds with perennial vegetation, which account for 11.3% of the area. Other specific infrastructure such as the two composting stations (4.7%), annual crop plots (3.8%) and ponds (<1%) have lower relative areas. The total permeable surface of the project amounts to 94.5%. If we consider paths as semi-permeable, the percentage rises to 96.4%.

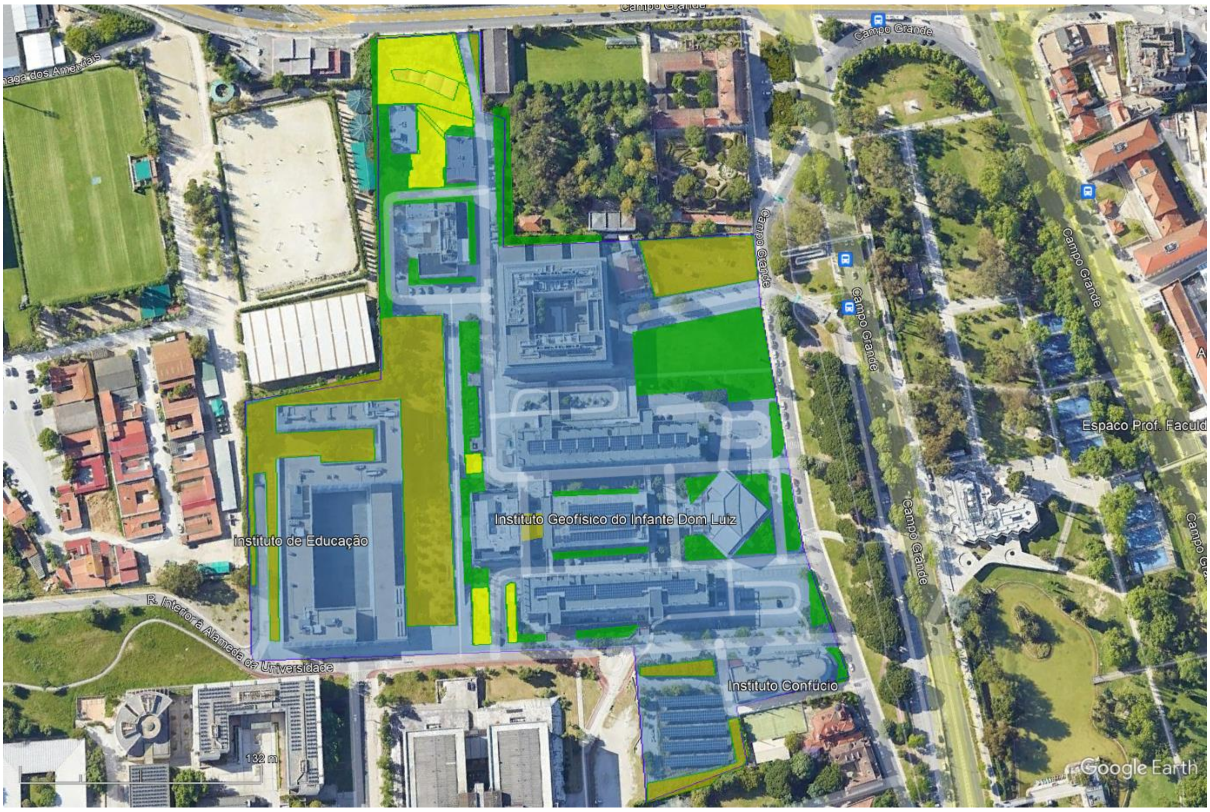


Figure 26 FCUL campus area in Campo Grande, Lisboa. Permeable surfaces (lawns and gardens) are represented in green, while impervious surfaces are highlighted in blue. Brown surfaces (covered with compact sediment) are also featured. HortaFCUL's areas appear in yellow.

3.1.2. Above-ground carbon captured in biomass

3.1.2.1.Trees and large shrubs

The estimated total tree biomass in FCULresta is 609 kg, that is 2.26 kg per m^2. In the PermaLab we find the highest total tree biomass of 11 671 kg, as well as the highest biomass per m^2 with 6.17 kg/m^2. Hortinha has the lowest total tree biomass of 271 kg, and with 1.41kg/m^2 also the lowest biomass per m^2 **(see Table III)**.

Table III Tree biomass estimations in HortaFCUL's subprojects

	FCULresta	PermaLab	Hortinha
Nr of Trees (DBH > 4cm)	21	45	16
Nr of Species	7	11	10
Total Biomass (kg)	609	11 671	271
Biomass (kg) per m^2	2.26	6.17	1.41

Out of the three on-campus subprojects, PermaLab has the highest tree biomass per m^2. This is due to the presence of 12 very large and old *Populus alba* trees, which make up 89% of the total biomass found in PermaLab. Neither in Hortinha nor FCULresta, trees of this size are present. In FCULresta 90% of the Biomass is made up of *Quercus suber*, whereas in Hortinha there is no dominant tree species. This difference may be due to the fact that, despite Hortinha being the oldest subproject, there were no existing trees on the site at the time of the first intervention and all biomass stems from plantings that were done since the beginning of the project in 2009. On the site of FCULresta, some medium sized *Quercus suber* and *Olea europea* were already present when the intervention first started. As stated above, PermaLab already had multiple very large and established trees on the site that stem from long before the establishment of the PermaLab.

3.1.2.2. Biomass production through annual crops

In terms of annual crop production, using the estimates for maize production (mean of local and hybrid varieties) under a medium fertilization regime (Ulm *et al.*, 2019), a total of 54 t dry biomass ha^{-1} $year^{-1}$ can be produced. This total quantity can further be distinguished in 29.6 t dry biomass ha^{-1} $year^{-1}$ in vegetative biomass and 24.4 t dry biomass ha^{-1} $year^{-1}$ in reproductive biomass (seeds).

3.1.2.3. Remote sensing

For both mean NDVI and NDMI data, homoscedasticity and normality assumptions were violated. Therefore, a Welch's t-test was used to determine if there were significant differences between sites, the results can be seen in the boxplot below (**see Fig. 27**).

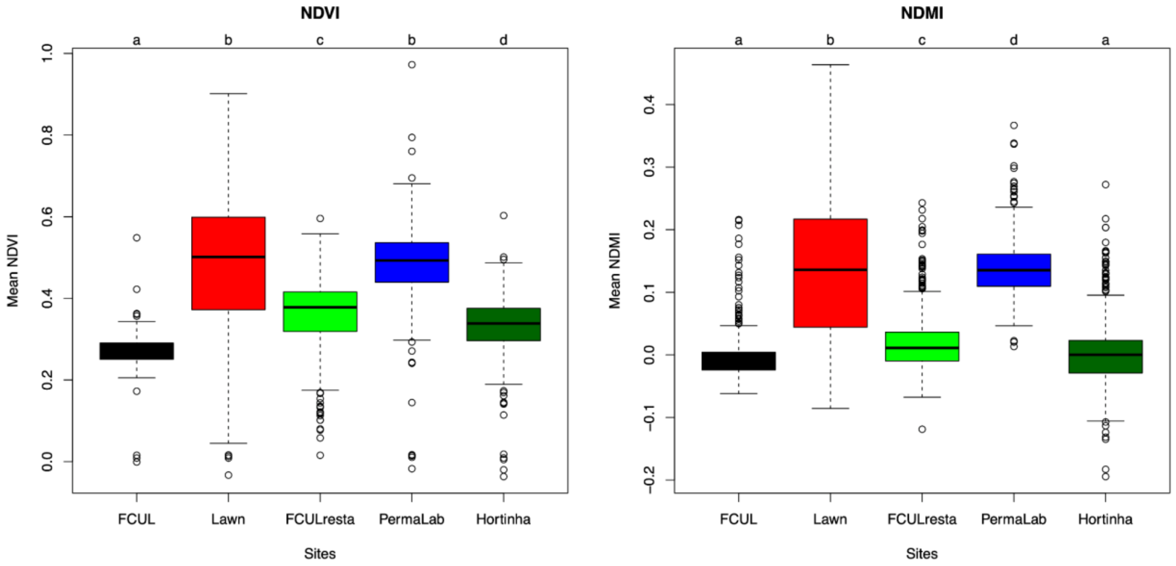


Figure 27 Mean Vegetation Index (NDV - leftl) and Moisture Index (NDMI - right) per site, spanning the time period from December 2018 to June 2023. Letters denominate significant differences as calculated per a pairwise Welch's t-test ($p < 0.05$, $n > 378$).

For NDMI, FCUL and Hortinha had the lowest values, followed by FCULresta, PermaLab and lastly the Lawn. In the case of NDVI, FCUL had the lowest values, followed by Hortinha and FCULresta, with the highest values being found in both PermaLab and Lawn. The whiskers in the plots also clearly indicate the largest variance in the Lawn, which is probably due to the annual variance in this site. To further explore this variance, data was split for each year and the standard deviation calculated per site (**see Fig. 28**). Based on this analysis, standard deviation of both NDMI and NDVI were significantly higher in the Lawn site.

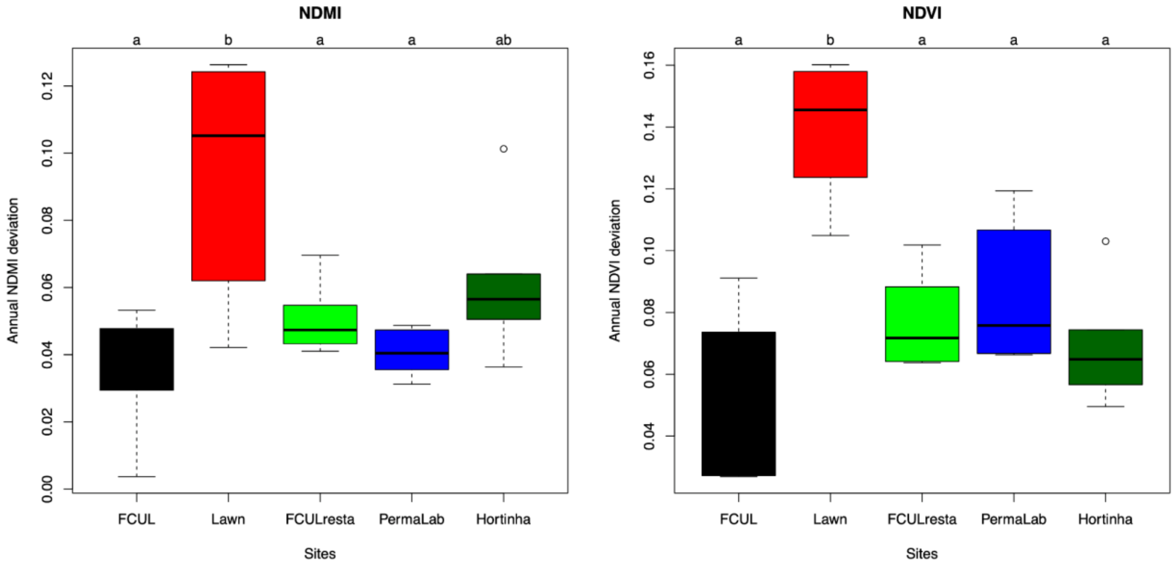


Figure 28 Mean Vegetation Index (NDVI - leftl) and Moisture Index (NDMI - right), spanning the time period from December 2018 to June 2023. Letters denominate significant differences as calculated per a pairwise Welch's t-test ($p < 0.05$, $n > 378$).

From a perspective of trends, both FCUL as a whole and Lawn did not show significant changes for NDMI and for NDMI, only Lawn did not show significant changes (**see Fig. 29**).

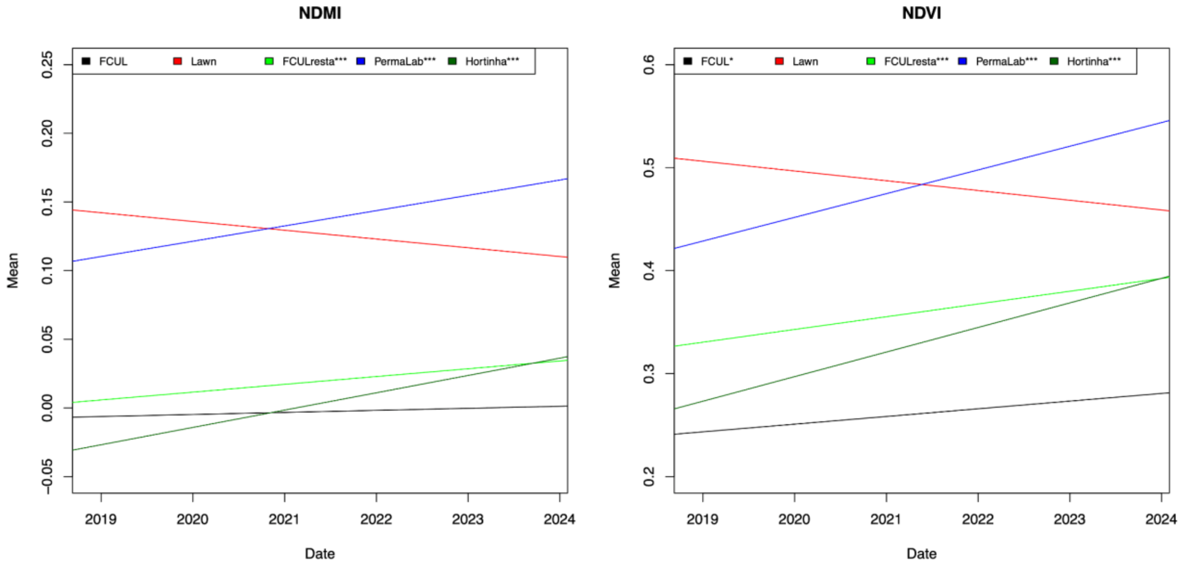


Figure 28 Temporal trends by means of a linear regression of Mean Moisture Index (NDMI - left) and Vegetation Index (NDVI - right) per site. Asterisks denote significant differences: *** = $p < 0.001$, ** = $p < 0.05$, * = $p < 0.01$.

3.1.3. Plant diversity analysis

3.1.3.1. Hortinha

A total of 61 perennial species were identified in Hortinha's 170m^2 area **(see Table IV).** Of this total, 32 species were considered as being part of the bush layer (19 exotic and 13 native) and 29 belonging to the tree layer (12 exotic and 16 native). The tree layer occupied an area of around 237m^2 while the bush layer covered around 77.7m^2. Overall, both Shannon Diversity Index (H) and Simpson Index (D) scored higher values for the bush layer ($D_{tree} = 0.84$; $H_{tree} = 2.54$; $D_{bush} = 0.94$; $H_{bush} = 3.02$)

In terms of function, 53 individuals were marked as pollination promoters (aromatic bushes; 36%), 47 individuals had as main function food provisioning (mostly fruit trees; 32%), 35 individuals were considered biodiversity supporters (native forest species, such as *Olea europaea, Fraxinus angustifolia* and *oak trees*; 24%); 31 individuals were identified as biomass providers (*Plectrathus barbatus* and *Ligustrum sp*. mainly; 21%) and 28 individuals were regarded as ornamental (*Yuca sp., Pelargonium sp*.; 19%).

Table IV List of species identified at Hortinha. Species were divided according to their main function.

Food provisioning	Biomass provisioning	Ornamental	Aromatic/Pollination	Biodiversity support
Acca sellowiana	*Ligustrum japonica*	*Aloe spp.*	*Aloysia citrodora*	*Arbutus unedo*
Capsicum frutescens	*Phyllostachys sp.*	*Bougainvillea sp.*	*Artemisia absinthium*	*Ceratonia siliqua*
Citrus sinensis	*Plectranthus barbatus*	*Canna indica*	*Coronilla sp.*	*Cercis siliquastrum*
Cydonia oblonga		*Chamaerops humilis*	*Cymbopogon citratua*	*Crataegus monogyna*
Diospyros kaki		*Crassula ovata*	*Lavandula dentata*	*Fraxinus angustifolia*
Eriobotrya japonica		*Cyperus alternifolius*	*Lavandula sp.*	*Laurus nobilis*

Food provisioning	Biomass provisioning	Ornamental	Aromatic/Pollination	Biodiversity support
Lycium barbarum		*Cyperus papirus*	*Myrtus communis*	*Medicago arborea*
Malus domestica		*Jasminus sp.*	*Ruta graveolens*	*Morus alba*
Persea americana		*Pelargonium spp.*	*Salvia elegans*	*Olea europaea*
Physalis peruviana		*Podranea ricasoliana*	*Salvia officinalis*	*Phillyrea angustifolia*
Prunus avium		*Yucca sp.*	*Salvia rosmarinus*	*Pistacia lentiscus*
Prunus dulcis		*Zantedeschia aethiopica*		*Quercus robur*
Prunus persica				*Sambucus nigra*
Punica granatum				
Pyrus communis				
Saccharum sp.				
Smallanthus sonchifolius				
Solanum betaceum				
Tropaeolum majus				

3.1.3.2. Permalab: Zone 0 and Agroforest

A total of 53 species **(see Table V)** were identified at Zone 0 perennial beds (28 exotic, 25 native), while at the Agroforest area a total of 37 species were counted (21 exotic, 16 native). In both areas the species with most individuals were, in decreasing order, *Plectranthus barbatus* (30% agroforest, 16% zone 0) *Salvia elegans* (9% agroforest, 10% zone 0) and *Populus alba* (8% agroforest. 7% zone 0). Both Shannon and Simpson indices scored higher values for Permalab zone 0. (D_{zone0} = 0.94 ; H_{zone0} = 3.40; D_{agro} = 0.88 ; H_{agro} = 2.77).

Regarding function, in zone 0 prevailed aromatic species (38%), followed by biomass providers (mostly Plectranthus barbatus, 32%) and food provisioning species (16%). As for the agroforest, 39% of the individuals were biomass providers (*Populus alba, Plectranthus barbatus*), 25% were aromatic species and 16% were food provisioning species.

Table V List of species identified at Zone 0 and Agroforest at Permalab. Species were divided according to their main function.

Food provisioning	Biomass provisioning	Ornamental	Aromatic/Pollination	Biodiversity support
Zone 0				
Physalis peruviana	*Plectranthus barbatus*	*Pelargonium spp.*	*Artemisia absinthium*	*Laurus nobilis*
Prunus cerasus	*Ligustrum japonica*	*Brugmansia sp.*	*Salvia elegans*	*Quercus robur*
Punica granatum	*Pittosporum tobira*	*Lycianthes rantonneti*	*Salvia officinalis*	*Fraxinus angustifolia*

Food provisioning	Biomass provisioning	Ornamental	Aromatic/Pollination	Biodiversity support
Zone 0				
Prunus armeniaca	*Eucaliptus globulus*	*Parthenocissus quinquefolia.*	*Cytisus proliferus*	*Arbutus unedo*
Cydonia oblonga		*Agave sp.*	*Lavandula sp.*	*Olea europaea*
Ficus carica		*Aloe spp.*	*Lavandula dentata*	*Quercus ilex*
Lycium barbarum		*Chlorophytum comosum*	*Cymbopogon citratus*	*Sambucus nigra*
Malus domestica		*Jasminus sp.*	*Aloysia citrodora*	*Cercis siliquastrum*
Musa sp.		*Rosa sp.*	*Ruta graveolens*	*Celtis australis*
Persea americana		*Viola sp.*	*Myrtus communis*	*Populus alba*
Prunus armeniaca			*Mentha spp.*	*Viburnum tinus*
			Persicaria odorata	*Phillyrea angustifolia*
			Lippia alba	
			Plectranthus forsteri	
Agroforest				
Punica granatum	*Plectranthus barbatus*	*Pelargonium spp.*	*Salvia elegans*	*Quercus robur*
Prunus armeniaca		*Jacaranda sp.*	*Cymbopogon citratus*	*Fraxinus angustifolia*
Ficus carica		*Viola sp.*	*Salvia officinalis*	*Arbutus unedo*
Eriobotrya japonica		*Canna indica*	*Salvia rosmarinus*	*Olea europaea*
Persea americana			*Lippia alba*	*Quercus suber*
Citrus sinensis				*Sambucus nigra*
Solanum muricatum				*Nerium oleander*
Acca sellowiana				*Erica sp.*
Citrus limonum				*Laurus nobilis*
Vitis sp.				*Phillyrea latifolia*
Smallanthus sonchifolius				
Malus domestica				
Tropaeolum majus				

3.1.3.3. Permalab

A total of 65 perennial species **(see Table VI)** were identified in Permalab's Zones 3 and 4 (700m^2). Of this total, 26 species were considered as being part of the bush layer (20 exotic and 6 native) and 35 belonging to the tree layer (15 exotic and 20 native). The tree layer occupied an area of around 858m^2 while the bush layer covered around 171m^2. The most abundant species in terms of occupied area were *P. barbatus* (338m^2)*, P. alba* (250m^2) and *Prunus cerasifera* (75m^2). As for the most abundant species in terms of number of detected individuals, *P. barbatus* (61 occurrences), *Salvia elegans* (26 occurrences) and *Physalis peruviana* (11 occurrences) stood out. Overall, both Shannon Diversity Index (H) and Simpson Index (D) scored higher values for the bush layer when considering the number of individuals (D_{tree} = 0.77 ; H_{tree} = 2.44 ; D_{bush} = 0.91 ; H_{bush} = 2.94). However, when employing individual cover area, both indices scored lower values for both layers compared to the former (D_{tree} = 0.73; H_{tree} = 1.81; D_{bush} = 0.70; H_{bush} = 1.95).

In terms of function, 73 individuals were identified as biomass providers (*Plectrathus barbatus* and *Populus alba* mainly; 31%); 64 individuals were marked as pollination promoters (aromatic bushes; 27%), 63 individuals had as main function food provisioning (mostly fruit trees; 26%), 19 individuals were considered biodiversity supporters (native forest species, such as *Olea europaea, Fraxinus angustifolia* and *Morus sp.*; 9%) and 8 individuals were regarded as ornamental (*Yuca sp., Cyperus alternifolius;* 4%).

Table VI List of species identified at Zones 3 and 4 at Permalab. Species were divided according to their main function.

Food provisioning	**Biomass provisioning**	**Ornamental**	**Aromatic/Pollination**	**Biodiversity support**
Capsicum frutescens	*Cortaderia selloana*	*Acanthus mollis*	*Aloysia citrodora*	*Arbutus unedo*
Citrus limonum	*Pittosporum tobira*	*Agave sp.*	*Cymbopogon citratus*	*Ceratonia siliqua*
Citrus sinensis	*Plectranthus barbatus*	*Aloe sp.*	*Lonicera japonica*	*Corylus avellana*
Cydonia oblonga	*Populus alba*	*Brugmansia sp.*	*Pelargonium citriodorum*	*Crataegus monogyna*
Diospyros kaki		*Camellia japonica*	*Salvia elegans*	*Cyperus papyrus*
Eriobotrya japonica		*Cyperus alternifolius*	*Salvia leucocephala*	*Cytisus proliferus*
Ficus carica		*Monstera sp.*	*Salvia officinalis*	*Eugenia uniflora*
Palmeira sp.		*Yucca sp.*	*Salvia rosmarinus*	*Laurus nobilis*
Persea americana				*Jacaranda mimosifolia*
Physalis sp.				*Morus nigra*
Prunus armeniaca				*Nerium oleander*
Prunus avium				*Punica granatum*
Prunus cerasifera				*Quercus robur*
Prunus persica				*Rubus ulmifolius*
Prunus spinosa				*Sambucus nigra*
Pyrus communis				

Food provisioning	Biomass provisioning	Ornamental	Aromatic/Pollination	Biodiversity support
Sechium edule				
Smallanthus sonchifolius				
Solanum muricatum				

3.1.3.4. FCULresta

A total of 46 perennial species were identified in FCULresta in the year 2023. 16 species were considered as part of the tree layer and 29 belonging to the tree layer. 3 species were identified as vine plants. All the species in this HortaFCUL's subproject are native. Overall, both Shannon Diversity Index (H) and Simpson Index (D) scored higher values for the bush layer (D_{tree} =0.83; H_{tree} = 2.08; D_{bush} =0.93; H_{bush} =2.84) Most of the species in FCULresta's plot are biodiversity supporters.

Table VII List of species identified at FCULresta. Species were divided according to vertical strata, since function is similar across the majority of the species.

Bush underlayer	Bush layer	Emergent / Tree layer	Vine plants
Asparagus acutifolius	*Adenocarpus sp.*	*Acer monspessulanum*	*Lonicera sp.*
Jasminum fruticans	*Chamaerops humilis*	*Arbutus unedo*	*Rosa canina*
Lavandula stoechas	*Cistus populifolius*	*Ceratonia siliqua*	*Smilax aspera*
Cistus albidus	*Coronilla glauca*	*Fraxinus angustifolia*	
Cistus crispus	*Crataegus monogyna*	*Morus alba*	
Ruscus aculeatus	*Erica arborea*	*Olea europaea*	
Ruta graveolens	*Erica lusitanica*	*Prunus avium*	
Thymus vulgaris	*Laurus nobilis*	*Prunus spinosa*	
Stachis officinalis	*Myrtus communis*	*Pyrus borgeana*	
Vinca difformis	*Nerium oleander*	*Quercus faginea*	
	Phillyrea latifolia	*Quercus lusitanica*	
	Pistacia lentiscus	*Quercus robur*	
	Prunus lusitanica	*Quercus sp.*	
	Quercus coccifera rivasmartinesii	*Quercus suber*	
	Rhamnus alaternus	*Salix spp.*	
	Rosmarinus officinalis		

Bush underlayer	Bush layer	Emergent / Tree layer	Vine plants
	Sambucus nigra		
	Viburnum tinus		

3.1.3.5. FCUL's green permeable areas compared to HortaFCUL

A total of 260 perennial individuals were recorded in 22 green permeable areas (6974,8m^2 in total, A_{min}= 43m^2; A_{max} = 2146m^2), spanning 80 different species (54 exotic species and 27 native species). Average species richness (SR) was 5.5 (SR_{min}= 1; SR_{max} = 17).

Table VIII Plant community related indicators throughout the 4 most important areas evaluated in this study

Site	Species richness	Shannon Index	Simpson Index
FCUL lawns	5.5 (average); $SR\ max$= 17	1.45 (average) $H\ max$ = 2.54	0.68 (average) $D\ max$= 0.91
FCULresta	29	2.08 (trees) 2.84 (bushes)	0.83 (trees) 0.93 (bushes)
Permalab's zones 3 and 4	65	1.88 / 2.44 (trees) 1.95 / 2.94 (bushes)	0.73 / 0.77 (trees) 0.7 / 0.91 (bushes).
Hortinha	61	2.54 (trees) 3.02 (bushes	0.84 (trees) 0.94 (bushes)

3.1.4. Macroinvertebrates biodiversity richness

Between November and December 2023, pitfall-based macroinvertebrate sampling found 8 species in Bioilhas, 10 species in FCULresta and 10 species in Hortinha **(see Table IX)**. Most individuals weren't identified to the species level. The same 5 classes of macroinvertebrates were detected in the three locations: Malacostraca, Gastropoda, Insecta, Diplopoda and Collembola. Bioilhas scored both the lowest Shannon and Simpson indices values, whereas Hortinha obtained the highest values ($D_{bioilha}$=0,81 ; $H_{bioilha}$ = 1.85 ; $D_{FCULresta}$ = 0.87 ; $H_{FCULresta}$ = 2.26; $D_{Hortinha}$ = 0.88 ; $H_{Hortinha}$ = 2.58). Bray-Curtis dissimilarity index indicated that sites communities weren't meaningfully different in terms of species composition and abundance (average Bray-Curtis = 0.28).

Table IX List of macroinvertebrate species found in Bioilhas, FCULresta and Hortinha. Most individuals' classification is incomplete, due to time constraints.

Bioilha	FCULresta	Hortinha
Armadillidium sp.	*Ambigolimax valentianus*	*Ambigolimax valentianus*
Cochlicella barbara	*Aphaenogaster sp.*	*Aphaenogaster sp*

Bioilha	FCULresta	Hortinha
Collembola	*Cochlicella barbara*	*Armadillidium sp.*
Ommatoiulus sp.	*Collembola*	*Cochlicella barbara*
Oxychilidae	*Formicidae*	*Collembola*
Paradoxosomatidae	*Ocypus sp.*	*Formicidae*
Porcellionides sp.	*Ommatoiulus moreleti*	*Ocypus sp.*
	Oxychilidae	*Ommatoiulus moreleti*
	Paradoxosomatidae	*Oxychilidae*
	Porcellionides sp.	*Paradoxosomatidae*
		Porcellionides sp.

Regarding the sampling campaign conducted in Spring 2022, diversity analysis results were summarized in **Table X**. FCULresta scored the highest species richness value (20 species), whereas a FCUL lawn area scored the lowest (1 species). A densely vegetated lawn obtained the highest Shannon Index value (2.62), while the tree alley achieved the topmost Simpson Index value (0.9). Nonetheless, the three HortaFCUL sites had more macroinvertebrate classes represented in their respective communities (5, 6 and 7). Moreover, 68% of the sampled individuals were captured in these three sites (FCULresta alone concentrated a third of all sampled individuals).

Table X Diversity metrics of FCUL's macroinvertebrate communities according to the Spring 2022 sampling work.

Site	Species richness	Shannon Index	Simpson Index	Number of classes
FCULresta	20	2.44	0.88	6 (Arachnida, Diplopoda, Insecta, Malacostraca, Maxillopoda, Ostracoda)
PermaLab's entrance	16	2.04	0.78	5 (Arachnida, Chilopoda, Diplopoda, Insecta, Malacostraca)
Permalab's Zone 0	14	1.98	0.76	7 (Arachnida, Chilopoda, Collembola, Diplopoda, Gastropoda, Insecta, Malacostraca)
Densely vegetated lawn	19	2.62	0.88	4 (Arachnida, Diplopoda, Insecta, Malacostraca)
Tree alley with no underlayer vegetation	14	2.52	0.9	4 (Arachnida, Insecta, Malacostraca, Myriapoda)
Lawn with sparse tree cover	1	0	0	1 (Insecta)

3.1.5. Carbon captured in compost

Between 2016 and 2023, an estimated 5287.2kg of carbon were sequestered in compost production, which is the equivalent to 1.3 times the average carbon emissions per capita in Portugal in 2022 **(Our World in Data, 2022).**

3.2. Regulation services

3.2.1. Amount of rainwater captured and Proportion of permeable surface

In 2022, HortaFCUL (Hortinha + PermaLab + FCULresta) harvested 2266.4m^3 of rainwater (2266373L), i.e. 4% of the total amount of rain that dropped at FCUL **(see Fig. 30)**. Regarding the greenhouse roofs, an estimated volume of 225.72m^3 of stormwater was retained in the reservoirs (225572L). Approximately 15785m^3 of stormwater fell over FCUL buildings' roofs.

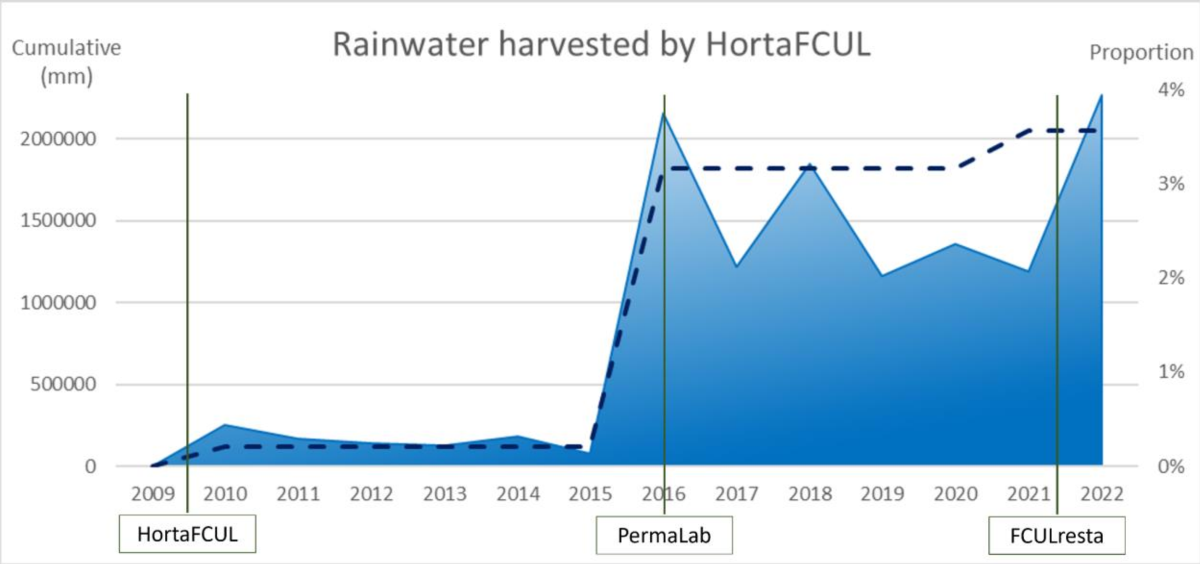


Figure 30 Plot describing the evolution of stormwater retention by HortaFCUL areas. Major increase between 2015 and 2016 correspond to the beginning of PermaLab's project.

As a case study in terms of stormwater management on the campus, recently HortaFCUL designed and implemented a small intervention in one of the sidewalks adjacent to FCULresta. Due to poor stormwater drain planning, a significant part of the waterflow in an area of around 650m^2 was being channeled to a single pavement walkway and then lost to the city drainage system. A group of students, facilitated by HortaFCUL guardians, created an obstacle perpendicular to the waterflow in that same pedestrian walkway, which successfully redirected the water into a FCULresta's swale area **(see Fig. 31)**. With this change, it was added an extra 650m^2 to FCULresta's retention basin (217% increase). During the same day of the intervention, an estimated 15770L volume of water was diverted to FCULresta from the sidewalks (total precipitation on that day was around 16mm). If we consider total annual precipitation, total stormwater volume could reach 536.4m^3 (536400L).

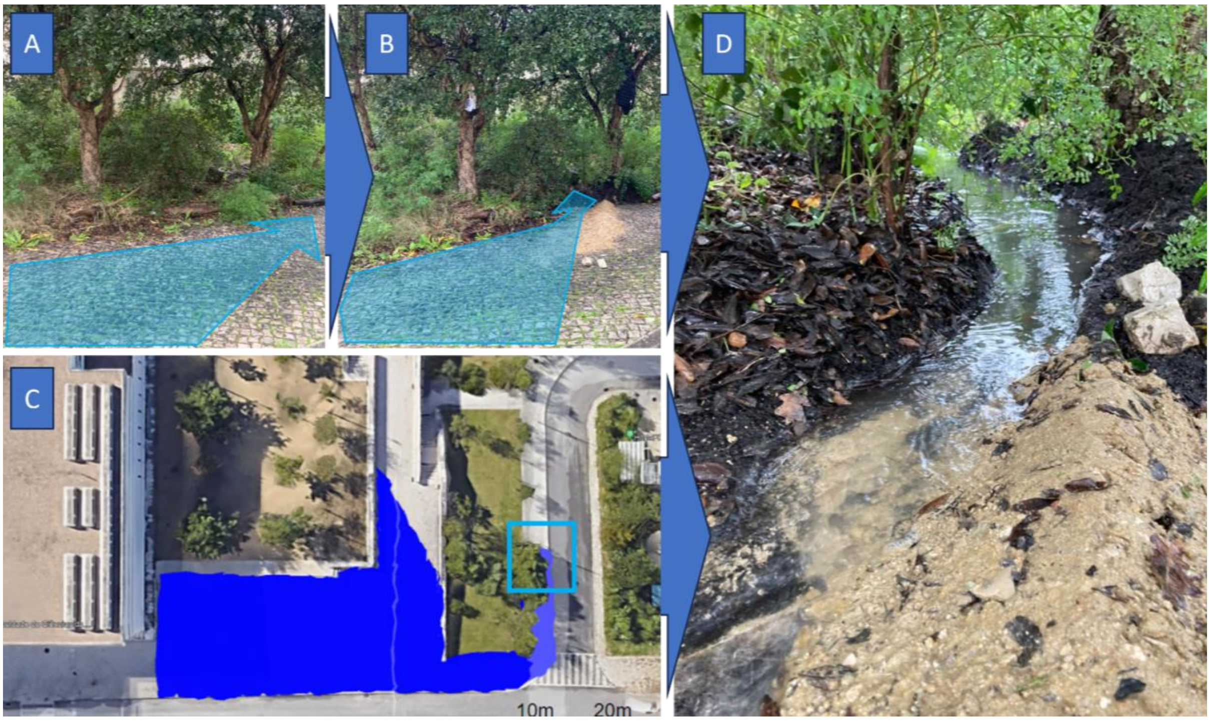


Figure 31 Mosaic figure showing the expansion of FCULresta's retention basin (in blue). (A) before intervention, (B) after intervention, (C) satellite image showing the intervention (square) and the expansion area, (D) the result on the 7th december 2023 after 4 mm of cumulative rainfall. FCULresta is located between the staircase and the road in the right part of the image (Source: Google Earth).

3.2.2. Tree cover as temperature regulator

In terms of structure, tree density in Hortinha was 0.44 trees / m^2 and tree cover per plot square meter was around 1.43m^2 (143$m^2$of tree cover per 100$m^2$of plot). Total bush cover was 52.7m^2 (31% of total area). As for PermaLab, tree density was 0.18 trees / m^2 and tree cover per plot square meter was around 1.26m^2 (126$m^2$of tree cover per 100$m^2$of plot). Total bush cover reached 170.63m^2(24% of zones 3 and 4 area). Regarding FCUL's main green areas, average tree density across plots was 0.03 trees / m^2 ($Dens_{min}$= 0 trees /m^2 ; $Dens_{max}$ = 0.09 trees /m^2) and average tree crown cover per plot square meter was 0.45m^2(45$m^2$of tree cover per 100m^2 of plot area; Cov_{min} = 0m^2; Cov_{max} = 1.99m^2). Average bush cover was 7.04m^2 per plot (3.5% of plot's area). A schematic illustration of relative tree cover is visible in **Fig. 32.**

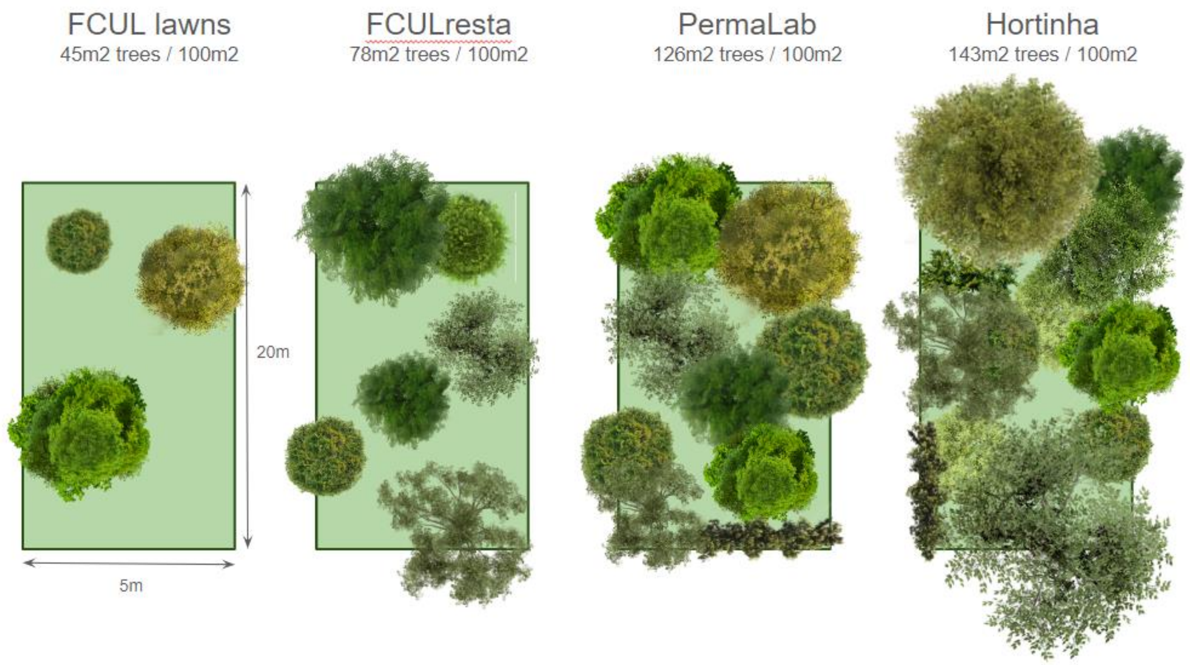


Figure 32 Visual scheme of the relative tree density of the four area types. Each plot has 100m². Trees do not correspond to the species present in the plots nor to their placement in each of the areas.

3.3. Provisioning services

3.3.1. Production volume of compost and vermicompost

3.3.1.1. Compost

Between 2016 and 2023, compost production yield was estimated at 47.95 metric tons (255m³).

3.3.1.2. Vermicompost

In two years (2021-2023), HortaFCUL produced 8.1 metric tons of vermicompost, which is the equivalent to 11.7m³ of material.

3.3.1.3. Volume of recycled organic residuals

At the FCUL campus, a significant part of the organic waste produced in cafeterias is orange peels and coffee grinds (no quantitative results were obtained). Other residuals detected include fruit peels (during spring and summer months mostly), lettuce leaves and tomato scrapes. An estimated 4247kg of organic residuals were sent to the vermicompost station during 2023, which is the equivalent to 4.6m³.

3.3.3. Number of plants provided to the campus community

From 2015 to 2019, and between 2022 and 2023, a surplus of 498 plants per year was provided to the faculty community. During the fall semester (from September to December), an average of 46 plants per month were put at the gift stand, while during the spring semester (January to June), the average was 60.

Figure 33 Picture series depicting HortaFCUL's gift table evolution from 2014 to 2023 (clockwise, starting upper left corner): 2014, 2016, 2017, 2019 and 2023.

3.3.4. Number of propagated plants

The plant propagation potential of the project is around 4110 plants a year. Based on the photographic record of the plant nursery, at least 30 species were propagated with reasonably successful outcomes (see Table XI). Based on the analysis of the surplus plants that were put at the Gift Stand, *Pelargonium sp., Plectranthus barbatus, Salvia elegans, Salvia officinalis, Rosmarinus officinalis* and *Lavandula sp.* were the six most propagated plants at the nursery.

Table XI List of the species propagated at regular basis in PermaLab, with some additional information. The species are in alphabetic order, thus it doesn't reflect an hierarchy in terms of production volume.

Species	Origin	Main property description
Artemisia absinthium	Native	Aromatic, medicinal properties
Lavandula sp.	Native	Aromatic, medicinal properties
Pelargonium citrodorum	Exotic	Pest control (mosquitoes)
Pelargonium sp.	Exotic	Ornamental, biomass provider,
Physalis peruviana	Exotic	Food provisioner, biomass provider
Plectranthus barbatus	Exotic	Biomass provider, medicinal properties,

Species	Origin	Main property description
		sound pollution mitigator
Ruta graveolens	Native	Aromatic, medicinal properties
Salvia elegans	Exotic	Aromatic, medicinal properties,
Salvia oficinalis	Native	Aromatic, medicinal properties
Salvia rosmarinus	Native	Aromatic, medicinal properties
Smallanthus sonchifolius	Exotic	Food provisioner, biomass provider
Solanum muricatum	Exotic	Food provisioner

3.3.5. Meals cooked

During 2023, HortaFCUL had 21 working days, which totals around 126 hours of voluntary work. On average, a 15 liter-pot of soup was cooked on each of these working days, which totals 315 liters of soup. All the food cooked in HortaFCUL had 3 sources (decreasing order in terms of relative contribution): Rizoma Coop (cooperative grocery store), HortaFCUL's own production and Herdade do Freixo do Meio (community-supported agriculture project). There is no quantitative data on food production **(see Fig. 34)**, but a qualitative analysis found that there were at least 18 crops used in soups: beans, chard, beetroots, tomatoes, aubergines, cabbages, broccoli, peas, mustard leaves, lettuce, parsley, garlic, onions, sweet potatoes, courgette, carrots, leeks and broad beans.

Figure 34 Pictures depicting part of a 20kg vegetable harvest which was donated to the faculty cafeteria. Donated vegetables were used to cook soup for the faculty community (May 2014).

3.4. Social-cultural services

3.4.1 General activity data

This analysis found a total of 439 registered events, which excludes informal working days organized by HortaFCUL's community. Estimates based on the best available sources (Facebook and email) indicate that the working days at HortaFCUL were at least 450 (1800 hours). Workshops and courses were the most represented activity type in the list (n=84, time invested = 709h), followed by talks, presentations and debates (n=74, time invested = 230h), guided tours (n=65, time invested = 209h) and articles, papers and media content (n=55). On the other hand, participation in fairs had the lowest number of contributions (n=23), followed by parties and official gatherings (n=29). The average activity pattern indicates that the busiest months for the project were October and March, whereas August and June had the lowest activity records **(see Fig. 35).** Between 2010 and 2023, the two years period before covid-19 pandemic were the most active (2018 and 2019), as a result of the steady increase of activity that started in 2014 **(see Fig. 36)**. Regarding the project's localisation, most of the activities were campus-based (60%). By adding the events that occurred in Lisbon to the latter, the percentage rises to 72% **(see Fig. 37).** If we exclude online events (n=77, 17%), locally based events represented 92% of total activity.

Concerning community members, at least 74 guardians were part of HortaFCUL's collective since 2009 and the highest number of active guardians was registered in 2019 (n=26). According to the activity output analysis, Simpson's Index (D) and Shannon-Wiener Diversity Index (H) showed that guardian contribution to project's activity was evenly distributed through its members in every year (D_{max} = 0.66 ; D_{ave} = 0.88 ; D_{max} = 0.93 ; H_{min} = 1.09, Hm_{ax}= 2.84; H_{ave}= 2.32). About 92.5% of the members of HortaFCUL's community integrated the project either as students, alumni or researchers from FCUL during the last 14 years. Considering the total number of guardians, 48.6% of the community is made of female guardians. Average percentage of active women in the project each year was 37.5% ($\%Women_{min}$ = 31.1% [2010,2011] ; $\%Women_{max}$ = 52.1% [2018] ; **see Fig. 38**). In the first 4 years of the project (2009-2013), the average percentage of women in the guardian community was 26% (more than 6 men in relation to total number of women), increasing to 44.1% from 2014 to 2019 (a little over 1 man in regard to the number of women), and then decreasing to 34.5% in the last 3 years (post-pandemic period). Using the number of mails sent to HortaFCUL's mailing list as proxy for guardian participation, women represented a little over a third of email's total activity (33.34%), with an average of 31.81% between 2009 and 2023 ($Women_{min}$ = 19.6% [2013]; $Women_{max}$ = 38.0% [2016]). Overall, the 15 (20% of the community) most active guardians, represented about two thirds of the total activity (66.3%). Average participation of the top 20% most active guardians between 2009 and 2023 was 59.8% ($Top20\%_{min}$ = 49.0% [2015]; $Top20\%_{max}$ = 79.9% [2022]).

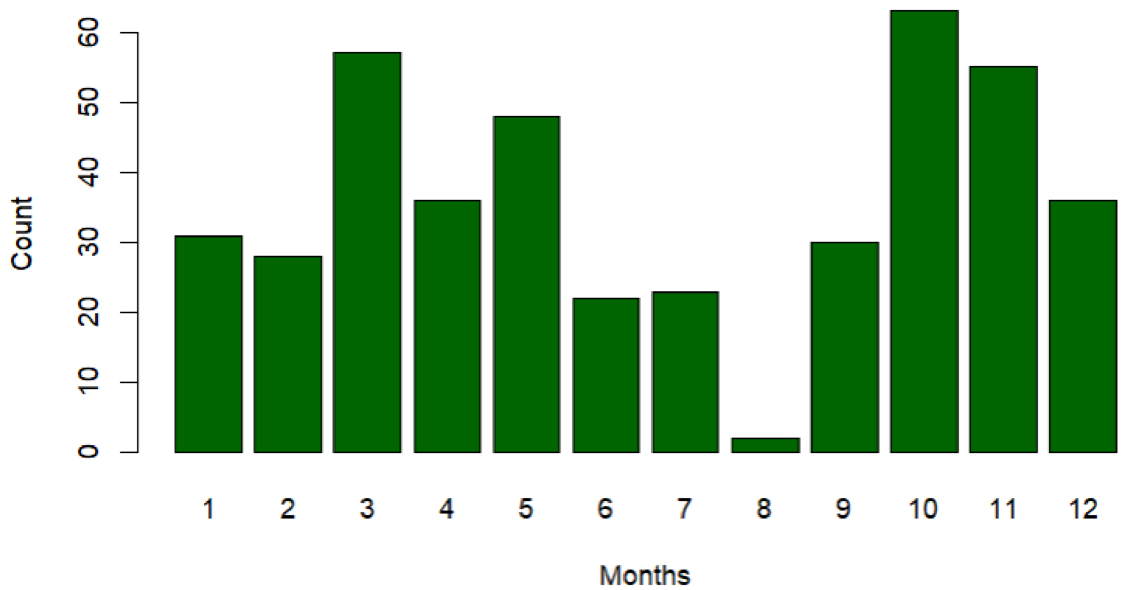


Figure 35 Cumulative number of events since the beginning of the project (in absolute values) for each month..

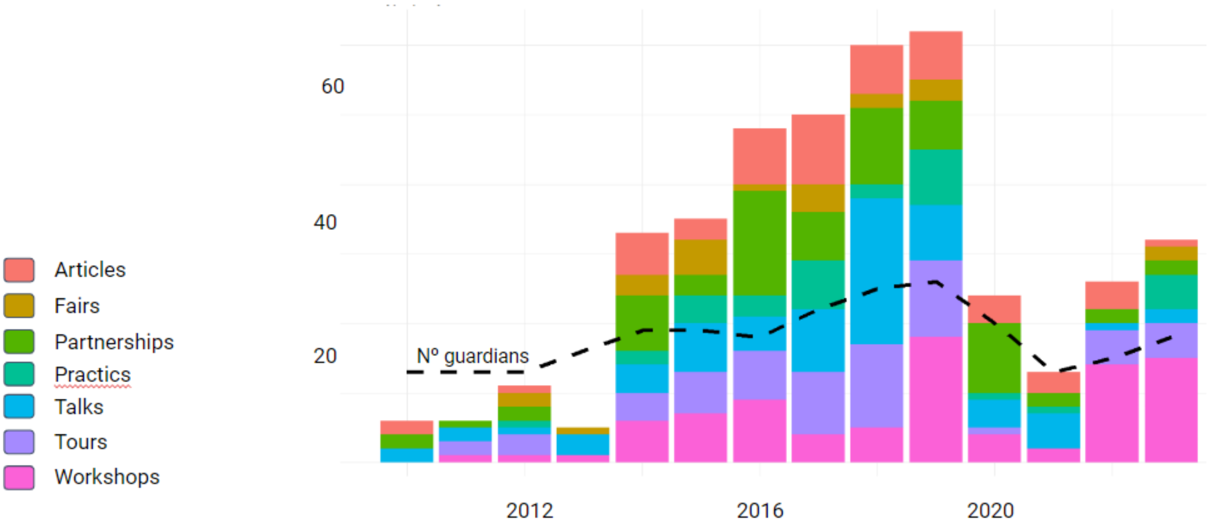


Figure 36 HortaFCUL's total activity from 2010 to 2023. Each color represents an activity type, as described in the side legend. Dashed line describes the variation in number of active community members (aka. guardians) for each year.

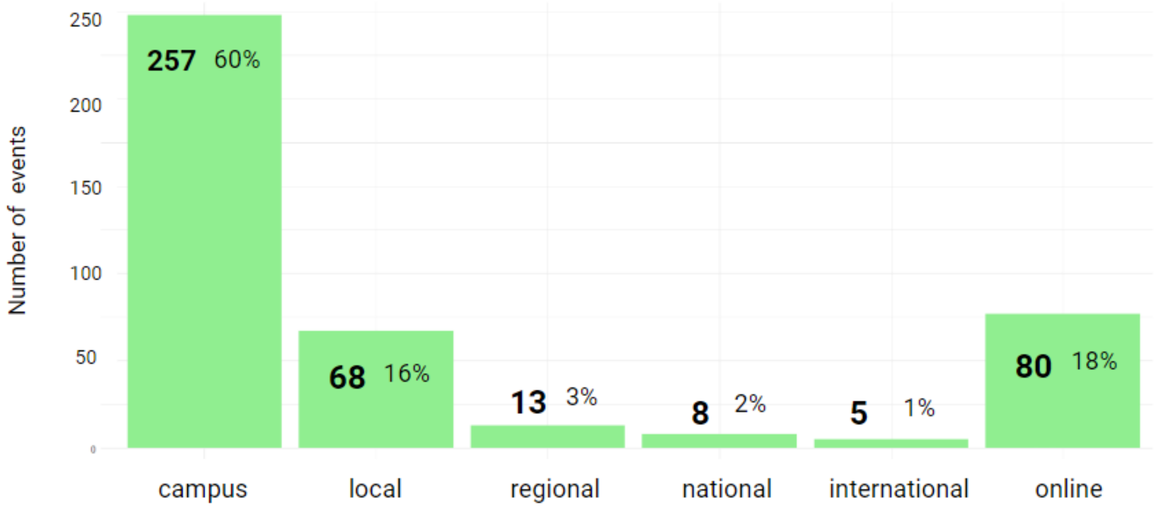


Figure 37 Localisation of HortaFCUL's activity, based on a categorical spatial scale. Local activity refers to the limits of Lisbon's municipality, while regional activity includes Lisbon's Metropolitan Area (50km radius). Online activity includes online published articles or media content as well as other online events such as talks. This section does not include social media posts.

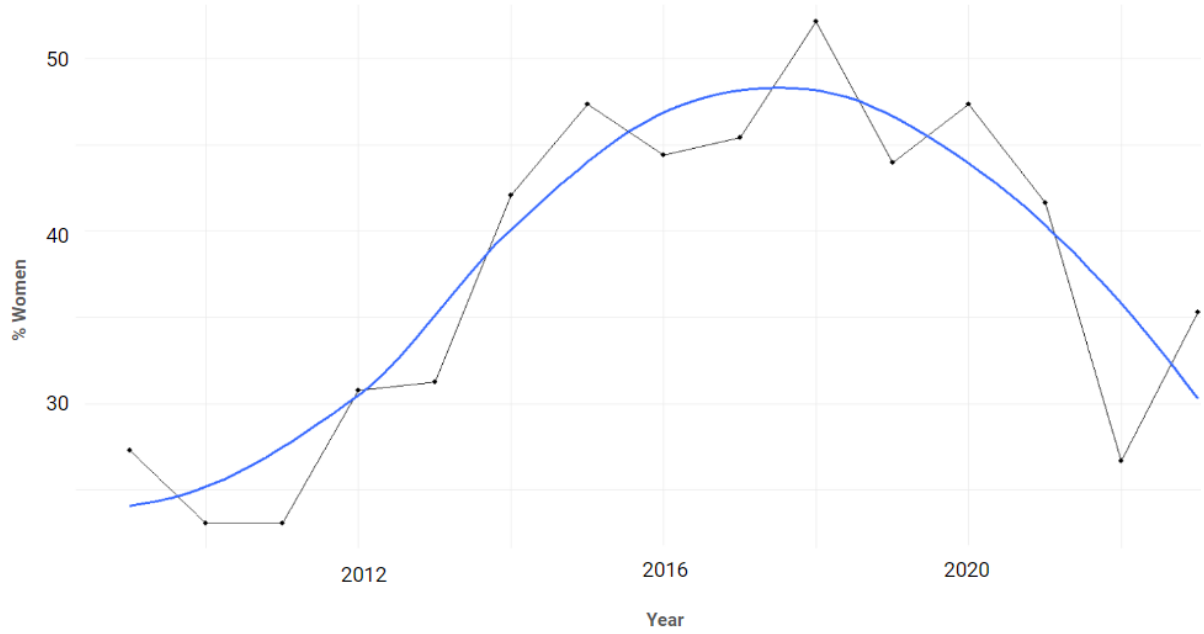


Figure 38 Gender balance expressed as percentage of female guardians each year from 2009 to 2023 (solid black line). A statistical smoothing technique was added to highlight underlying patterns without imposing strong assumptions (blue solid line).

Regarding the beta analysis, in general, turnover increased with time **(see Fig. 39).** Average turnover in the project was 0.1. When comparing the guardian community in 2009 (the founding community) and the community in 2013, turnover was 0.12. Between the 2013 community and the 2019 community, turnover was set to 0.34, whereas between the pre-pandemic community (2019) and today (2023), turnover was 0.31.

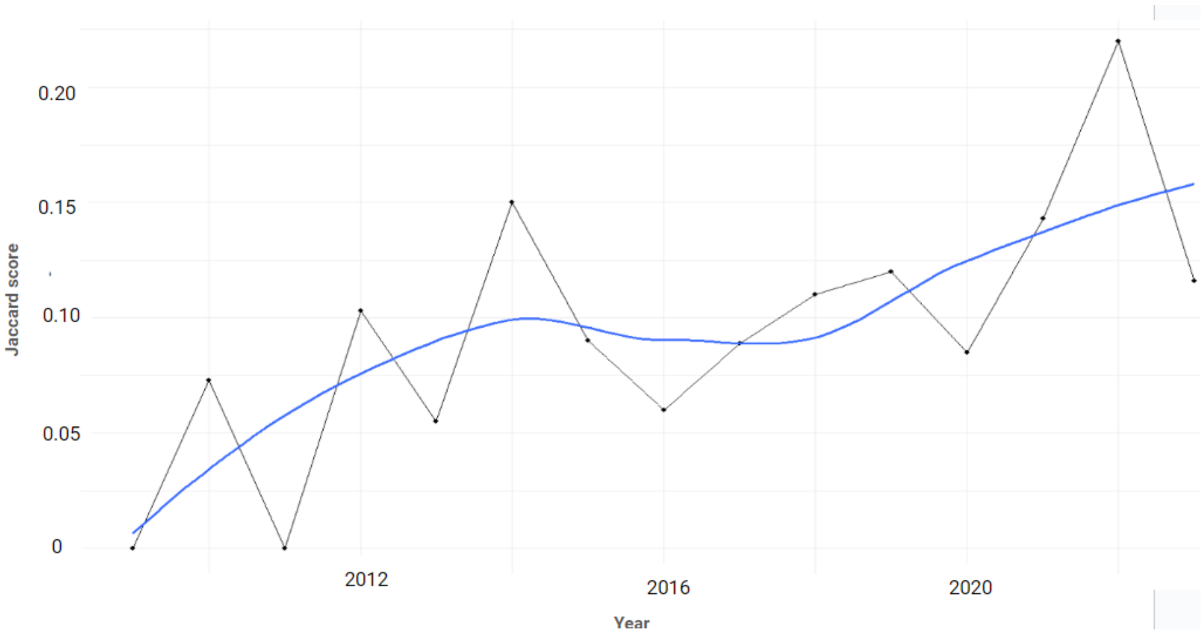


Figure 39 Community turnover expressed as the Jaccard Index score from one year community to the next between 2009 and 2023 (solid black line). A statistical smoothing technique was added to highlight underlying patterns without imposing strong assumptions (blue solid line).

As for the enquiry made to the guardian community (39 answers), main issues and weaknesses related to the project were: communication (12%), lack of commitment (11%), inclusiveness (11%), volunteer dependence (11%), personal conflicts (10%), unbalanced contribution (10%) and others (35%).

3.4.2 Activity type analysis

3.4.2.1 Articles, media content and research

HortaFCUL was directly and indirectly involved in 55 written or filmed content, which include scientific papers, news articles and outreach videos. Article's local outreach was more significant (65%), than national and international outreaches (22% and 13%, respectively). Within HortaFCUL's areas, there were a total of 5 scientific research papers developed, 8 minor scientific works and experiments **(see Appendix 8.1.)** and 10 official contributions to other scientific articles and works. The majority of the articles had PermaLab as the study site or subject.

3.4.2.2. Partnerships

HortaFCUL provided direct support to other projects on 87 occasions (20% of events). Concerning education for the younger public, there were 54 events (12% of total activity) that included activities with school children (total number of children involved was estimated at over 2000). In total, HortaFCUL has established partnerships with 197 unique partners. More than half of the partnerships with other projects, institutions and groups/communities) were local based (n=138, 54%), whereas 13% were international. About 80% (n=351) of the activity at HortaFCUL was conceived with other partners. However, it was not possible to infer the real impact of these partnerships in activity output. Examples of partner projects and their scope are summarized in **Table XII**.

Table XII List of some of HortaFCUL's partners that still develop their activity today complemented with a short description of their scope and partnership features with HortaFCUL.

Name	General description	Location	Partnership description
Colher para Semear	Association whose main goal is the preservation of native Portuguese agricultural varieties, by promoting their use in small-scale farming and by facilitating the access of these varieties to the public	Figueiró-dos-Vinhos, Coimbra, Portugal	HortaFCUL's is a collective associate of this project, and acts as a guardian of a local maize variety, through its cultivation in Permalab.
Bela Flor Respira	Community garden based in Lisbon inspired by syntropic agriculture principles. It was established near a social housing neighborhood, working closely with the local population.	Campolide, Lisboa	HortaFCUL provided logistic support in the first few months of the project, as well as some consulting expertise.
Horta do Alto da Eira	A social, environmental, cultural and experimental project, which is based on the construction and dynamization of a sustainable community garden	Penha de França, Lisboa	HortaFCUL participated in various activities related to open discussions as well as fairs.

Name	General description	Location	Partnership description
Rizoma Coop	Community-operated grocery store in Lisbon.	R. José Estêvão 4, Lisboa	Provides food for the community dinners. Participated in activities, some members are also HortaFCUL members.
Upfarming	Startup promoting vertical farming, urban farming and social entrepreneurship	Various, this moment in Alvalade, Rua das Murtas as well as at the primary school Dom Luís da Cunha. Seat at Tv. São Vicente, 15, 1D, Lisboa	Members of HortaFCUL are involved in various projects as advisors and consultants. PermaLab hosted various activities.
Com Calma Associação Cultural	Local cultural association whose role as community gatherer through diverse cultural activities is vital for its neighborhood	Benfica, Lisboa	HortaFCUL guardians have facilitated several cultural events in CC, and supported the creation of a local food garden (prior to the pandemic)
Biovilla	A project that has the vision of promoting a culture of regeneration that makes the ecosystem healthier, more harmonious and fair.	Palmela, Setúbal, Portugal	Both projects were born at the same time and since then have been cooperating, mainly through student exchanges and courses.
VIDA	NGOD with projects in Africa and Portugal whose main goal is to support local human development in poorer regions and communities	Almada, Portugal	VIDA and HortaFCUL partnered on the 1Planet4All project, which paved the way for the creation of FCULresta. Since then, VIDA has promoted the establishment of other micro-forests
Transição em Telheiras	Local association whose main mission is to develop and improve urban public space for communities, with a strong focus on permaculture ethics and sociocratic principles	Telheiras, Lisboa	HortaFCUL has organized presentations, guided tours and workshops with TeT to capacitate some processes of this association through permacultural dynamics.
Herdade do Freixo do Meio	Agricultural society founded in social economy principles, and one of the main references in regenerative agricultural practices in Portugal	Montemor-o-Novo, Alentejo, Portugal	HortaFCUL is food delivery point of Freixo do Meio's Community-Supported Agriculture programme in Lisbon and has co-organized talks, guided tours and events.
2adapt	A FCUL startup which provides services on climate change adaptation.	Lisbon, Portugal	HortaFCUL and 2adapt were partners during the implementation of FCULresta's project and are collaborating closely in other data-driven projects
Jardins Abertos	Biannual event which organizes activities, such as workshops and guided tours in less frequented gardens in Lisbon	Lisbon, Portugal	HortaFCUL is a partner-member of this event, organizing tours and workshops at PermaLab.

3.4.2.3 Workshops and Training Courses

Regarding events designed for practical knowledge transfer, such as workshops, courses and trainings (n=84), more than half (51%) integrated ecological management training (plantations, biomass management and permaculture techniques applied to the landscape, and others), followed by sustainable food production and urban agriculture practices (47%), social planning and permaculture design thinking (28%) and sustainable construction (8%).

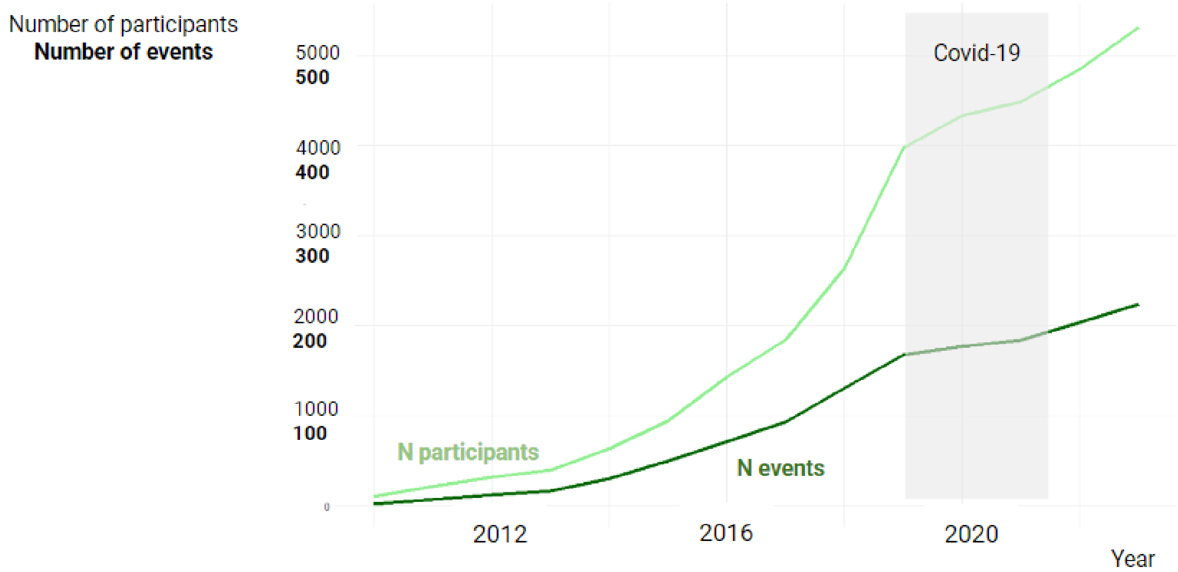


Figure 40 Cumulative participation in HortaFCUL events (as number of participants, light green line) and cumulative occurrence of workshops, talks and tours (dark green line; numbers in bold in the y-axis) from 2010 to 2023. The pandemic period is highlighted in gray.

3.4.2.4 Talks, Presentations and Tours

Talks, presentations, debates and guided tours to the project were main contributors for community outreach within the project activity. In total, outreach represented 29% of the project's energy investment. 39% of talks occasions were dedicated to the project's results and work, while 21% were conceived for other project's outreach within HortaFCUL's community. Workshops, talks and tours together attracted at least 5353 participants (225 events), which makes an average of 24 participants per event **(see Fig. 40)**.

3.4.2.5. Social/cultural services provided by FCUL

In 2019, FCUL - whose community has around 6400 people - organized and co-organized a total of 71 events related to sustainability (33 events), climate change (10 events) or nature conservation (28 events). Most of these events were talks, presentations, gatherings or conferences (60%), followed by workshops (14%). In the same period, HortaFCUL has organized a total of 59 events (22% of workshops, followed by 19% of guided tours and 10% of talks and presentations) and 26 working days, which renders a total of 85 occurrences in one year.

3.4.3. Event connection to permaculture cycle framework

When considering event contribution within the permaculture cycle framework, the knowledge cycle was the most represented by the event record, with 70% of the occurrences having a direct impact on knowledge transfer **(see Fig. 41)**. This result is mostly thanks to the educational initiatives promoted at workshops, talks and guided tours, which represent more than half of HortaFCUL's events. Production and social cycles were supported by 31% and 29%, as a consequence of the energy invested in food and compost production, on the one hand, and celebrations on the other. Cycles associated with regulation services such as the ecological (22%), organic (15%), materials (9%) and hydrologic (3%) were the least significant in this analysis.

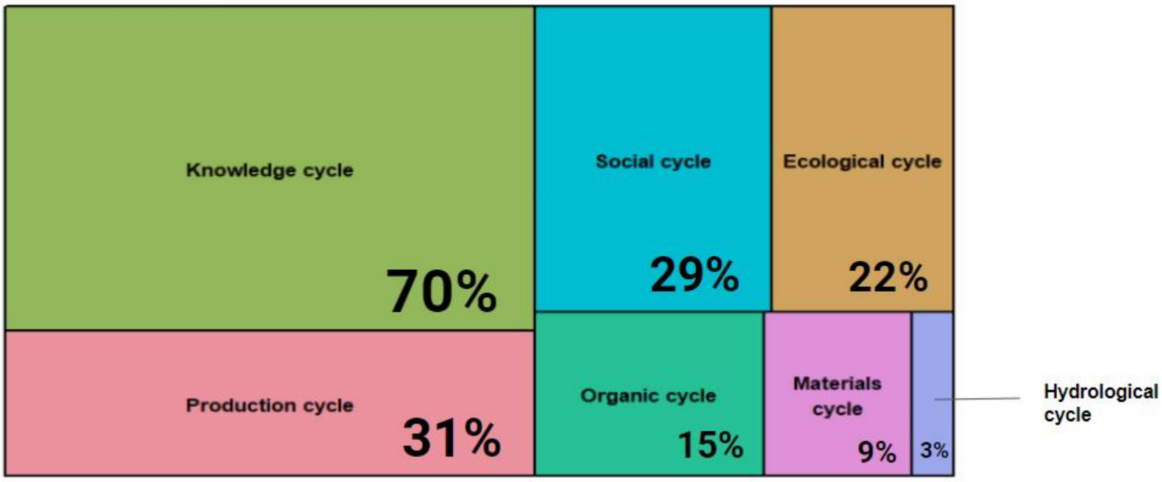


Figure 41 Mosaic plot depicting HortaFCUL's events relative contributions to the cycle framework **(Cassel & Cousineau, 2018)**, as it is described in permaculture design practices. A single event can address multiple cycles and, thus, the total sum of these relative contributions exceeds 100%.

3.4.4. Event connection to the ecosystem services framework

Regarding event outputs as ecosystem services for the community **(see Fig. 42)**, socio-cultural services were promoted in 85% of the events (n=370), with 50% of the events having solely social-cultural expression, followed by provisioning (n=131, 30% of the events) and regulation (n=90, 20% of the events). About 8% of the events had all three services represented.

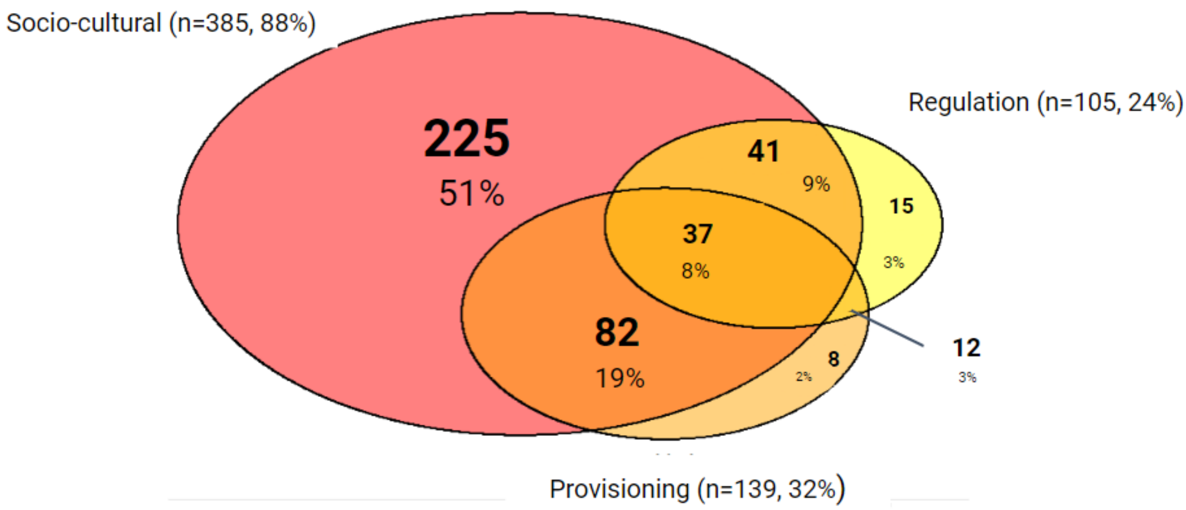


Figure 42 Venn diagram showing relative (in percentage) and total (in absolute values) event contributions to the three main ecosystem services described in literature (according to TEEB framework). Supporting services, per se, were discarded from this analysis because of their generalistic nature.

3.5. Ecosystem Service and Sustainable Development Goals interlinkage

Ecosystem service indicators selected for this study are interlinked with all the 17 SDGs proposed by the UN's 2030 Agenda, although with diverse contribution weights **(see Fig. 43)**. SDG 11: Sustainable Cities and Communities was the main goal approached by the project's activity, followed by SDG 4: Quality Education, SDG 13: Climate Action and SDG 15: Life on Land. Less significant SDG's included SDG 14: Life on Sea, SDG 5: Gender Equality and SDG 1: End Poverty.

Regarding the 169 UN's targets, HortaFCUL has a direct contribution to 17 of them and the indicators connection to these specific targets as described by the UN's framework is detailed in **Table XIII**.

Table XIII List of indicators used for the linkage between ecosystem services and Sustainable Development Goals. Targets addressed are specified.

Ecosystem service	Indicators	Main SDG	SDG Targets
Support	Above-ground carbon captured in biomass	13 (Climate Action); 15 (Life on Land)	Target 13.1 - Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters; Target 15.1 - Ensure the conservation, restoration, and sustainable use of terrestrial and inland freshwater ecosystems.
	Carbon captured in compost and vermicompost	12 (Responsible Consumption and Production); 15 (Life on Land)	Target 12.4 - Substantially increase the number of industries adopting sustainable practices; Target 15.9 - By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, and poverty reduction strategies.

Ecosystem service	Indicators	Main SDG	SDG Targets
	Biodiversity indices for plants and insects (shannon, spp. richness)	15 (Life on Land)	Target 15.1 - Ensure the conservation, restoration, and sustainable use of terrestrial and inland freshwater ecosystems; Target 15.5 - Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity, and protect and prevent the extinction of threatened species.
	Land cover features diversity	11 (Sustainable cities and communities); 9 (Industry, Innovation and Infrastructure)	Target 11.3 - Enhance inclusive and sustainable urbanization and capacity for participatory, integrated, and sustainable human settlement planning and management; Target 9.1 - Develop quality, reliable, sustainable, and resilient infrastructure to support economic development and human well-being.
Regulation	Amount of rainwater captured and proportion of permeable surface	6 (Clean Water and Sanitation); 15 (Life on Land)	Target 6.3 - Improve water quality by reducing pollution, eliminating dumping, and minimizing the release of hazardous chemicals and materials; Target 15.1 - Ensure the conservation, restoration, and sustainable use of terrestrial and inland freshwater ecosystems.
	Average relative temperature anomalies	13 (Climate Action)	Target 13.1 - Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters; Target 13.2 - Integrate climate change measures into national policies, strategies, and planning.
Provisioning	Number of soups cooked	2 (Zero Hunger); 12 (Responsible Consumption and Production)	Target 2.3 - By 2030, double the agricultural productivity and incomes of small-scale food producers; Target 12.3 - Halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses.
	Volume of compost and vermicompost produced and volume of organic residuals recycled	12 (Responsible Consumption and Production); 13 (Climate Action)	Target 12.4 - Substantially increase the number of industries adopting sustainable practices; Target 13.2 - Integrate climate change measures into national policies, strategies, and planning.
	Number of propagated plants	15 (Life on Land);	Target 15.3 - By 2030, combat desertification, restore degraded land, and strive to achieve a

Ecosystem service	Indicators	Main SDG	SDG Targets
		2 (Zero Hunger)	land degradation-neutral world Target 2.5 - Maintain the genetic diversity of seeds, cultivated plants, and farmed and domesticated animals and their related wild species.
Cultural/Social	Number of workshops, talks and tours; Number of participants in workshops, talks and tours	4 (Quality Education); 17 (Partnership for the goals)	Target 4.7 - By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development; Target 17.16 - Enhance the Global Partnership for Sustainable Development, complemented by multi-stakeholder partnerships that mobilize and share knowledge, expertise, technology, and financial resources.
	Partnership number, scope and outreach	17 (Partnership for the goals)	Target 17.17 - Encourage and promote effective public, public-private, and civil society partnerships, building on the experience and resourcing strategies of partnerships.
	Number of articles	4 (Quality Education); 17 (Partnership for the goals)	Target 4.7 - By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development. Target 17.16 - Enhance the Global Partnership for Sustainable Development, complemented by multi-stakeholder partnerships that mobilize and share knowledge, expertise, technology, and financial resources.
	Number of celebrations and gatherings	11 (Sustainable cities and communities); 17 (Partnership for the goals)	Target 11.4 - Strengthen efforts to protect and safeguard the world's cultural and natural heritage Target 17.16 - Enhance the Global Partnership for Sustainable Development, complemented by multi-stakeholder partnerships that mobilize and share knowledge, expertise, technology, and financial resources.

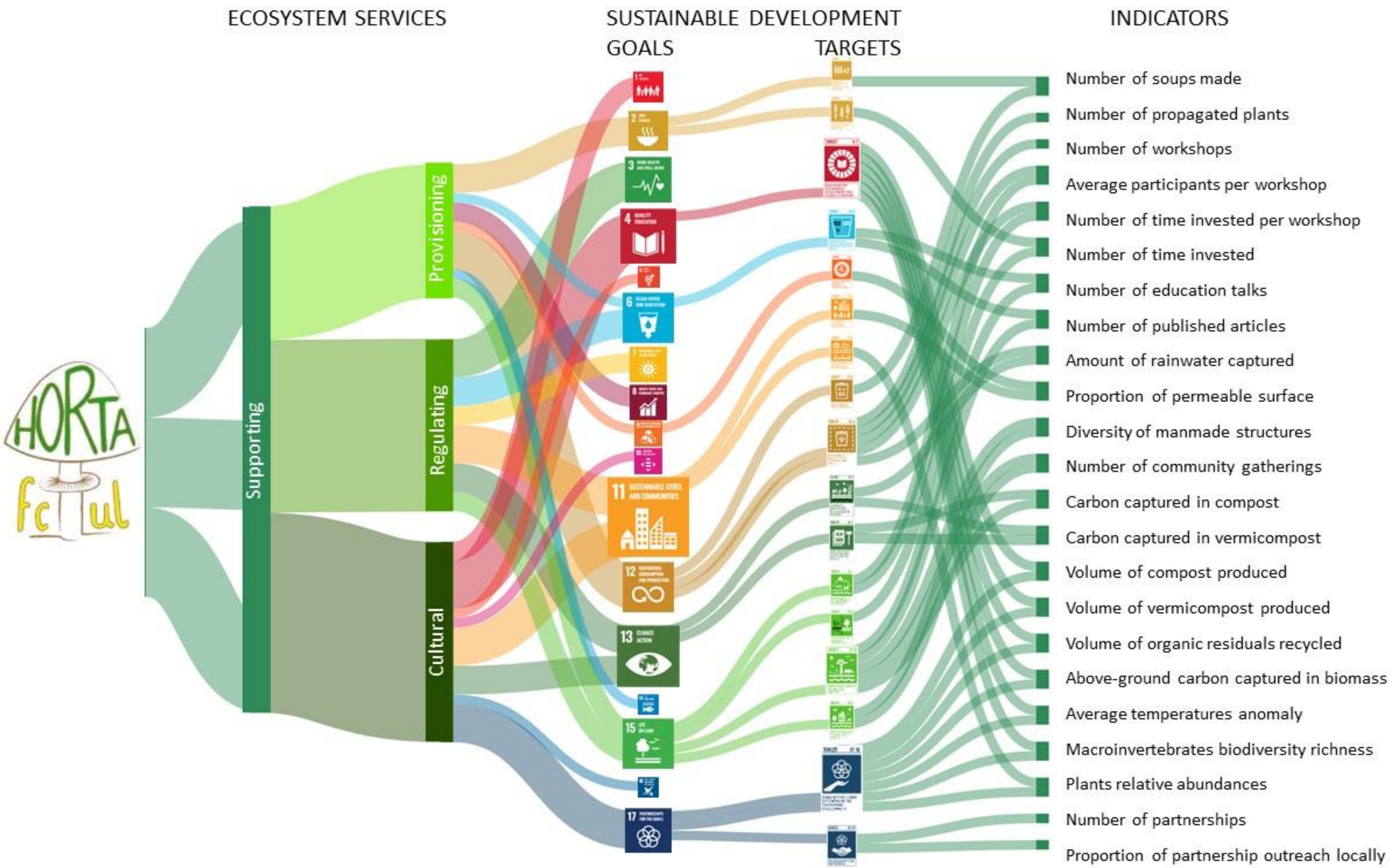
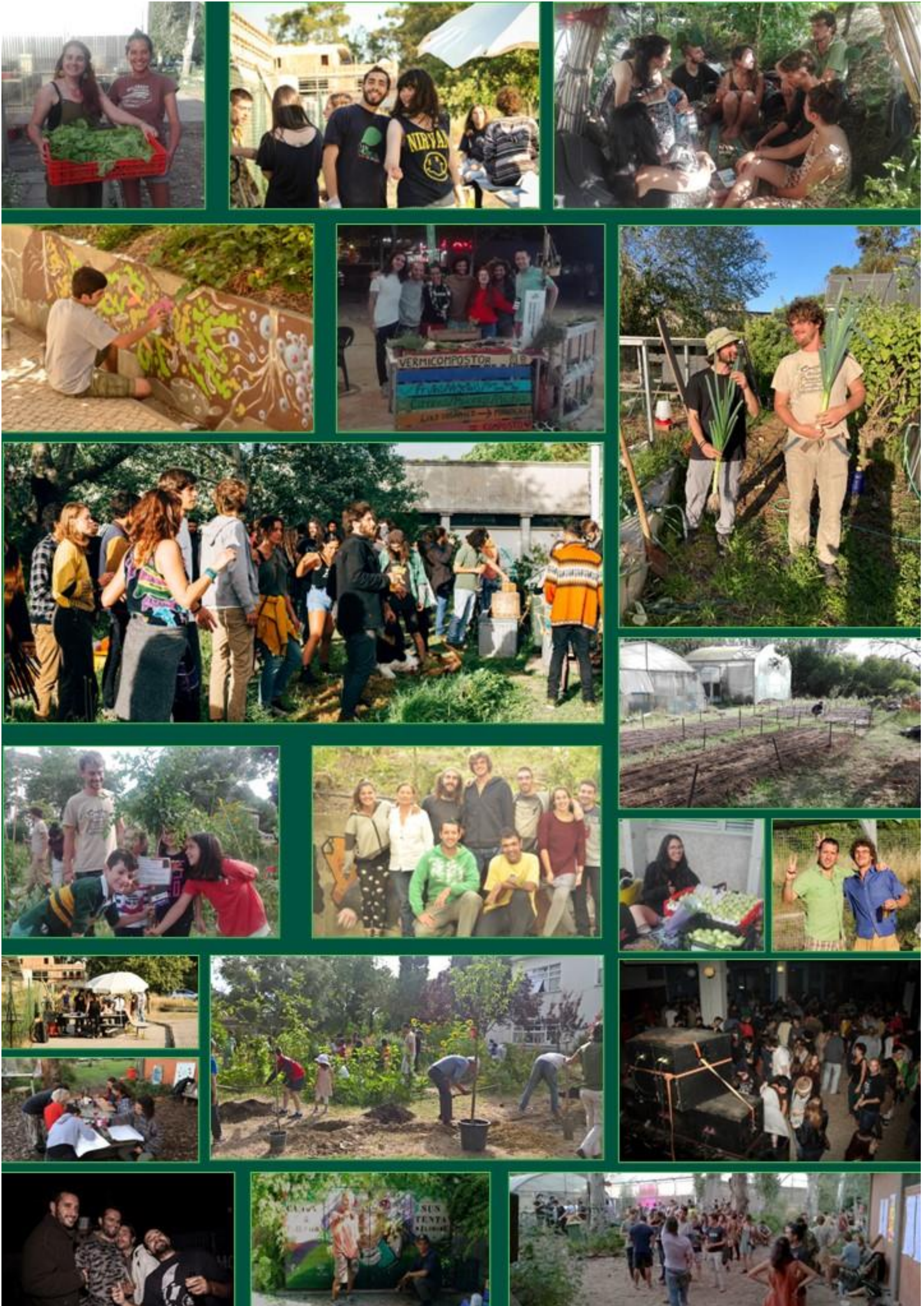


Figure 43 Sankey Diagram detailing the connections between HortaFCUL Ecosystem Services, Sustainable Development Goals and Targets and the indicators used in this study. Width of the links are proportional to the number of indicators and size of the SDG and target icon are correlated with the HortaFCUL direct contribution..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4. DISCUSSION

4.1. General considerations

Overall, HortaFCUL, as a community garden project, addressed in its 14 years of existence all the ES identified by The Economics of Ecosystems and Biodiversity - TEEB framework. The report outlined the achievement of sound results, especially concerning social and cultural services, however, indicators described for the remaining services were somewhat incomplete or limited to the sampling and data collection period, which was too short (between September and November). Therefore, some service groups can be considered under-explained due to resource limitations (instruments to measure some environmental parameters, for instance). Nonetheless, this study showed the potential of a deeper analysis into social and cultural services, since they are often qualitatively interpreted via enquiries to communities **(Riechers et al., 2016)**, and they are often left to a subjective examination.

Also, TEEB's ecosystem service framework was adapted to fit the purposes of this report. Exhaustive sectioning was simplified because of the finer scale in which HortaFCUL operates. If applied to other contexts and projects, the framework would possibly offer the same challenges in terms of interpretation and application due to scale and scope diversity **(Haines-Young & Potschin, 2018)** . Although the TEEB framework allows some flexibility in terms of use, efforts should be made to consider a framework adaptation depending on the ecosystem's scope.

4.2. Supporting services

4.2.1. Above-ground biomass

Above ground biomass accumulation in HortaFCUL's areas in terms of perennial crops (maize) was comparable to what can be expected from conventional agricultural practices (**Ulm et al., 2019**), highlighting the capacity of these high-input, high-output urban systems. In terms of tree-related biomass, all HortaFCUL areas exhibited more abundant cover, volume and biomass (**Table III**), however, the values presented need to be considered in context: For both the PermaLab and FCULresta, around 90% of the biomass was concentrated in already existing trees, not in new growth. On the other hand, many of the species growing in HortaFCUL's spaces did not have allometric equations available and the lack of volume-based allometric models makes biomass estimation of shrub-like trees not feasible (**Ulm et al., 2022**), therefore the values presented are gross underestimates of the real *in-situ* biomass. Thus, it is crucial to create more simplified allometric biomass models for these kinds of high-density, multi-strata ecosystems, especially in an urban context, where sample size and microclimatic conditions often make allometric model description difficult (**McPherson et al., 2016**). Nevertheless, using the data obtained here, it can be stated that the HortaFCUL systems created on campus exhibit similar, or even higher, biomass accumulation than typical, native, mediterranean shrublands (**Pasalodos-Tato et al., 2015**), highlighting the potential of these types of interventions.

In terms of NDVI and NDMI values, PermaLab exhibited comparable values to the lawn, which seems counterintuitive, considering the significantly higher biomass values measured via allometric models. Clearly, one constraint of remote sensing methods is the lack of three-dimensional resolution, which creates artifacts in terms of biomass indicators in these kinds of situations. Another important aspect of this data is the significantly higher annual NDVI and NDMI variation in the lawn (**Fig. 28)** contrary to the other observed sites. This highlights the lack of resilience of traditionally managed green spaces, which exhibit increased drought stress during the summer months, if not adequately irrigated. Lastly, the tendency of all HortaFCUL spaces was an increase in NDVI and NDMI along time, contrary to FCUL as a whole and lawn in particular, which showed no temporal trends over the time period measured.

4.2.2. Biodiversity indicators

Regarding the floristic communities analyzed in this report, HortaFCUL's areas clearly stood out in terms of diversity as compared to FCUL's conventional green areas. For instance, in terms of species richness, a single plot (Hortinha) had about three-quarters of the number of perennial plant species found in conventional green areas, which in total are about 64 times the size of the former (the richest FCUL's green plot had a maximum of 17 species). In terms of function and utility, while most of the species planted at FCUL were merely ornamental, in HortaFCUL the functional scope was more diverse, with more species providing habitat, food and general support to biodiversity. Green urban areas role as biodiversity harbors within a heavily disturbed matrix has been extensively documented in literature **(Aronson et al., 2017; Kowarik et al., 2020)**, while green areas as food provisioning landscapes are still in its first steps and pose challenging issues in terms of implementation and widespread application **(Wiskerke & Viljoen, 2012)**. Concepts such as urban foraging **(Hare & Peña del Valle Isla, 2021)** and edible gardens **(Russo & Cirella, 2020)** begin to attract some research attention, but more studies need to be developed in order to create a solid scientific basis to support these practices.

On the other hand, the fact that more than half of the plant species found in HortaFCUL were exotic reflects the role of urban ecosystems as harbors of exotic species and shows the availability and popularity of these species in urban contexts **(Gaertner et al., 2017; see Fig. 44)**. Tropical and sub-tropical species were clearly the most abundant given their advantageous traits in terms of growth (*P. barbatus* is the main biomass provider in Hortinha and Permalab), adaptation to local climate (Lisbon has mild winters and hot summers) and as resource providers (exotic fruit trees are very productive). None of the recorded species has reported any type of invasive behavior, which is also a concept up to debate in urban confined areas **(Zisenis, 2015)**.

Figure 44 Examples of abundant exotic species in HortaFCUL, that are often used in propagation by cuttings. These pictures were part of an initiative that intended to document the use and location of donated plants at the Gift Stand by donators ("Banca da Dádiva pelo Mundo", 2018).

Due to seasonal constraints, this report failed to describe the herbaceous layer of these ecosystems, which should be sampled (to provide rigorous results) during Spring **(Ristau et al., 2001)**. Still, *ad libitum* observations of FCUL's green areas have shown that the annual species richness in these areas can be potentially much lower than HortaFCUL's due to their maintenance routines and species dominance - exotic grass *Paspallum sp*. is the dominant species in most of the lawns, which severely hampers the development of other species belonging to the same structural niche **(Hassan & Mohamed, 2020).**

As for macroinvertebrate diversity, Spring sampling revealed the important role of HortaFCUL areas as biodiversity harbors for macroinvertebrates, mainly due to their habitat heterogeneity and investment in plant diversity, which attract many lifeforms within this group, from scavengers to pollinators, from filtrators to saprophytes. There is extensive research on macroinvertebrate diversity in urban areas especially for pollinating insects, due to the low-cost sampling and high-quality information extracted from these life groups' presence and abundance patterns **(Theodorou et al., 2020)**. Many studies highlight the maintenance of heterogeneous habitat mosaic patches as a tool to promote diversity and multifunctional communities **(McIntyre, 2000).** The Autumn sampling was not as conclusive as the Spring sampling due to seasonal and time constraints, and it should be repeated, with multiple capture methods to reliably represent the diversity of the macroinvertebrate fauna present at campus.

Nonetheless, studies conducted by students are always limited regarding time and resources available. In order to guarantee sound and solid results, sampling should be repeated every year in two seasonally different periods. Other approaches in this context, such as citizen science and BioBlitz events, could offer an alternative and complementary perspective on biodiversity within the campus **(Chozas et al., 2023)** and should be encouraged in future sampling efforts.

4.3. Regulation services

4.3.1 Amount of captured rainwater

In general, HortaFCUL's areas act as water harvesting areas, since all the areas occupied by the project (including the impervious surfaces) are by design retaining most of the water. However, it is important to state that the project's increasing water holding capacity was simply due to the occupation of past permeable surfaces in the campus that were already retaining rainwater. Although there is still no quantitative data on water holding capacity and water percolation rates in any of the areas (including FCUL's green areas), some scientific works found in literature highlight the importance of applying a different set of strategies (swale creation, organic matter input, increasing the complexity of vegetation layers, rain gardens and ponds) to improve the ecosystem's capacity to retain water **(Koiv-Vainik et al., 2022; see Fig. 45).** FCUL's green areas are morphologically and topographically very diverse, but lawn use by the community increases soil compaction and consequently water's runoff **(Corrêa et al., 2021)**. *Ad libitum* observations made during heavy rainfall clearly noticed runoff coming from lawns to pavements, given that no FCUL green area (besides HortaFCUL's) has had implemented a stormwater management strategy. More studies should be made to translate these observations quantitatively and promote a serious debate on green area management at local level. The intervention described at FCULresta is just an example of a small-scale, affordable and easy-to-implement solution that can have a major impact on regulation services for the community.

Figure 45 Swale building in PermaLab (2018). Lines are formed by accumulating organic matter at the same level on a slope (upper left picture), acting as an obstacle to water runoff. In these lines, there is an upstream depression (the swale) where more coarse organic matter is accumulated to incorporate biomass into the soil (upper right picture). Plants are planted at the crest of the 'mound' (bottom left and bottom right pictures).

Moreover, water harvesting at PermaLab's greenhouse roofs-level is another approach to increase water reserves at local level, which could be used in many services, such as lawns' irrigation systems **(Matos et al., 2012)**. The estimates produced in this report suggest that the amount of water lost in FCUL's roofs (in the 8 main buildings) was equivalent to the annual total volume of water invested in the irrigation of a 16.000m^2 garden in Lisbon **(Adriane Dummer, 2012, Masters thesis).** FCUL has over 9000m^2 of irrigated green areas. If water consumption patterns match the overall consumption in Lisbon Municipality when it comes to green areas management, it means that a little over half of this volume would be enough to irrigate FCUL's lawns and green spaces for the entire year. Campus potential to capture and store stormwater stresses the need to bring these solutions to the general public, particularly in severe drought scenarios, which are becoming more frequent in Portugal.

4.3.2. Tree cover as temperature regulator

Results show a significant difference in relation to tree cover at HortaFCUL's areas and FCUL lawns. For instance, in Hortinha, HortaFCUL's oldest subproject, tree cover level is more than three times higher than FCUL's average. Also, it should be mentioned that FCUL lawns and green areas in general are structurally simple and most trees and bushes serve ornamental purposes. The influence of green areas in the cooling island effect depends largely on vegetation's composition and structure, therefore, trees themselves cannot fully provide a significant cooling effect if the remaining vegetation layers are suppressed **(Ferrini et al., 2020)**. FCUL's lawns have only 3,5% bush cover as compared to, for instance, Hortinha (10 times more) and Permalab (8 times more). In order to enhance green spaces regulating services, species selection and garden design should be seriously considered by urban planners. Nonetheless, resources should be invested so as to monitor more rigorously the impact of green infrastructure on temperature regulation at campus level. Quantitative data will provide a valuable information baseline to decision-makers.

4.4. Provisioning services

4.4.1. Compost production

Compost production numbers clearly show HortaFCUL's significant impact concerning organic residuals management at local level. Volume produced at a community scale composting station reflects the resource abundance of urban areas and the potential to use these organic resources to feed sustainable and affordable practices **(Jara-Samaniego et al., 2017)**. Enriched organic compost is a valuable asset for food production and soil amelioration interventions **(Schröder et al., 2017)**, which are urgent given the context of intensive and harmful agricultural practices, as well as the human-led degradation of ecosystems.

Figure 46 Two different moments in compost production: initial residuals piling (left picture) and compost transfer from the second to the third stations (right picture).

In recent years, efforts have been made to promote compost production in Lisbon. Examples of city-scale projects include, for instance, “Lisboa a Compostar” or the initiatives of local waste management facilities, such as ValorSul **(Filipa Vaz, 2008, Masters thesis)**. However, most of these projects either aim to centralize city-level compost production by collecting organic waste “door-to-door” or to incentivize household-level composting. There are few examples of neighborhood-level composting initiatives like FCUL’s composting stations - **Madalena Horta’s Masters thesis (2020)** conducted in PermaLab remains the only reference in Portugal and most scientific papers on the matter were produced in the US **(Morrow & Davies, 2022; Pai et al., 2019).** Thus, more research should be conducted to evaluate the feasibility, the efficiency and the positive environmental impacts of this approach in community managed urban areas as compared to household and city-scale composting systems **(De Boni et al., 2022).** Nonetheless, HortaFCUL stands as a successful example of organic waste management **(see Fig. 45)**.

4.4.2. Plant propagation

In self-financed projects, it is crucial to create resource sources which represent little financial effort. Plant propagation through cuttings has been a central activity in HortaFCUL’s project to ensure living material to develop a denser and more diverse ecosystem **(see Fig. 47)**, but also to create a source of income based on plant surplus. Sharing the surplus is a way to remind the surrounding community that the project is active and functional and that its activity generates direct benefits provisioning-wise.

Figure 47 Picture depicting the plant propagation procedure in a workshop dedicated to plant propagation through cuttings (December 2023).

Numbers presented in this report are a rough approximation of reality, given that there hasn't been any consistent track of propagating routines, however, it reflects the propagation potential constrained by the survival rate of cuttings and their viability, which shouldn't lie far from the real number. As far as the research for this report is concerned, no article or scientific paper has approached the role of plant propagation within an urban agriculture or urban community garden context, which makes any attempt to compare results obtained in HortaFCUL difficult.

4.4.3. Meals cooked

Due to the absence of empirical data on food production, this indicator was selected as a proxy for the use of food resources for internal consumption. During the year 2023, all working days were succeeded by a dinner moment with a soup or equivalent dish. All these events had at least one main ingredient which was produced at HortaFCUL. Although the food produced is far from sufficient to amount to quantities that allow self-sustaining provisioning, its constant production underlines the ongoing capacity of this project to produce food at local level, which serves as an empowerment tool for similar projects. It is clear that the project has great potential in terms of scaling-up production, however, it should be recognized that this particular area is not central to the project's mission.

Moreover, food provisioning in this context has a social role, since it supports celebration moments, such as gatherings after a working day **(see Fig. 48)**. The energy invested in celebration and conviviality is vital to a project's continuity, as most community-based projects fail because of lack of investment in the social aspects of the project, especially internal communication **(De La Motte, 2022)**. Indeed, gatherings are opportunities to strengthen social bonds within a group by prompting discussions, talks and intimate connection between members, creating a democratic, free and communal space where new ideas can emerge **(Rutt, 2020)**.

Figure 48 Community meal preparation. The process is usually facilitated by the guardians (upper left picture) with the involvement of the volunteers (remaining pictures). Vegetables portrayed in these pictures were grown and harvested in PermaLab.

4.5. Social/Cultural services

4.5.1 General activity

Overall, HortaFCUL's activity pattern revealed some substantial information. In the first three years of the project, activity numbers were considerably lower - although this is also related to lack of recorded data prior to 2013. Nonetheless, those first years, when the project was still in its initial phase, were succeeded by a period of activity expansion (2014-2019), where the number of event outputs increased steadily throughout the years. Between 2020 and 2021, the impact of the pandemic was clearly visible, still with some repercussions on the recovery phase (2021-2023). The first phase can be regarded as the grounding phase, when the project focused its energy on the social structure and on small-scale interventions and partnerships. The expansion phase covers a period where the project consolidated its functioning basis, allowing it to welcome more members to its community and develop more activities. The lockdown phase, which was ubiquitous to every type of this kind of project, was fatal for the work developed in many communities, including Lisbon. HortaFCUL managed to recover from that impact, however, the recovery phase, which consists of the restoration of pre-pandemic dynamics and processes, has not been overcome yet. Turnover dynamics within the project reflect the shifts in the community as the project grew: not only there was a general increase in turnover (especially in the expansion phase), the pandemic coincided with the exit of an older generation, pushing the community to welcome new members. Moreover, overall monthly activity output followed the academic cycle. The periods of higher energy input from the guardian group corresponded to the initial months of each semester, when people are more prone to invest their time and effort. Also, it coincides with the moments in the school year when new people are more enthusiastic about integrating a group project, so it is important to summon that same enthusiasm **(see Fig. 49)**.

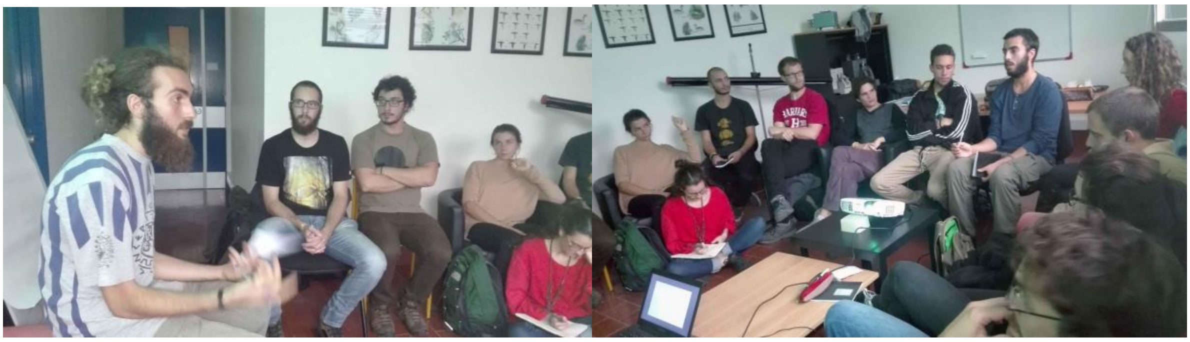


Figure 49 Pictures depicting an internal organization seminar to welcome and empower new guardians (October 2016). The expansion phase of the project demanded a continuous investment in terms of capacitation and empowerment due to the growing interest of newcomers in relation to the project.

Concerning the guardian community, this study found that a vast majority of guardians were from FCUL, entering the community as students, which shows the interdependence that connects HortaFCUL to the mother institution. In fact, this result can be explained by (1) the greater availability of students to commit to volunteering work and (2) the proximity factor, since most of the students can easily participate regularly in a project whose headquarters are close to their study place **(see Fig. 51)**. It should be highlighted that HortaFCUL's gender trends were male biased, although gender balance was reached and maintained between 2015 and 2019.

Figure 50 Guardian group picture commemorating the 10th year anniversary (2019). Group included both acting guardians and ex- guardians belonging to four different "generations", i.e. major guardian influxes.

Guardian contribution to event occurrence (traced by the Shannon and Simpson indices) didn't show any signs of dominance of a few over most of the processes, - dominance actually decreased with time

-, although this is not the general perception of the guardian community, where the unbalanced contributions of a few members were pointed out as a challenge. In reality, when using the number of emails sent per guardian as a surrogate for guardian activity, some unbalanced contribution was detected. The processes that lie behind the project's outputs are too complex to be translated in numbers and surrogates such as the ones retrieved in an email account should be regarded as rough approximations of reality. Nonetheless, community projects like HortaFCUL tend to fall in the Pareto rule **(Sanders, 1987)**, which, in few words, states that in collective initiatives 80% of the group's energy and work is invested by only 20% of the individuals. The promotion of active participation might be one of the most challenging issues of projects of this sort **(Drake & Lawson, 2015).**

Figure 51 Student welcome reception at the Gift Stand in FCUL campus (2018, left picture; 2023, right picture). As volunteering project mainly fueled by student contribution, HortaFCUL organizes every year a Q&A reception to introduce the project to students at FCUL.

Moreover, a significant percentage of events were organized at campus-level, reflecting the local dimension of the project's scope, despite the number of partnerships with national and international institutions and groups. This fact demonstrates in part that projects can become more efficient if they adapt their range of intervention wisely, since actions and events that happen close to the project's place are more easily managed and have greater positive local feedback. Indeed, energy can be less efficiently allocated if there is overdispersion in terms of project's activity input.

4.5.2. Activity type

In relation to the activity types described in this study, there are a few main ideas that should be highlighted:

The number of **partnerships** and events where HortaFCUL offered direct logistical, or expertise support reveals the importance of interdependence and cooperation between projects. Even though a great deal of initiatives failed to pursue its work, partnerships were essential to keep some projects alive and functional, including HortaFCUL. For instance, most of the events were co-organized with other entities or groups, which reinforces the idea of networking as a pillar for the project's fitness. However, a comprehensive study of how partnerships can effectively transform the partner projects is still lacking.

Regarding **workshops**, **talks**, presentations and **tours**, the energy invested in training and knowledge transmission underpins the centrality of people's empowerment and capacitation developed by the project, educating them to be autonomous enough to apply nature-based solutions to their own contexts. Moreover, the predominance of guided tours and presentations can be explained by the (1) growing interest of the public, especially schools, in creating opportunities for urban citizens to enjoy nature's proximity in urban areas and (2) the project's own outreach needs close to the local community.

Published **articles** also contribute to keeping the communication channel with the community as well as engraving knowledge that was accumulated in diverse experiments and processes. In reality, HortaFCUL stands out by its commitment to a "learning by doing" philosophy, which is the basis of guardian's and the general public's empowerment. Unsurprisingly, the Venn Diagram showing the relative and absolute weights of ES expressed in events supports the disproportional importance of social and cultural services rendered by HortaFCUL in the form of affordable, accessible and inclusive educational events along with community gatherings and **parties** to celebrate the project's accomplishments **(see Fig. 52)**.

Figure 52 One of the first HortaFCUL parties (2013, left picture) and a sunset party in PermaLab (2018, right picture)

FCUL, as a higher education institution, serves a very important role as education promoter in a wide range of scientific areas. Nonetheless, sustainability-related events have only become part of the main agenda very recently. The comparison made during the year 2019 corresponds to a time in which FCUL set its sustainability goals as a priority. This research underlined the predominance of theoretical approaches when organizing sustainability-related events in campus. Although there are lots of on-ground research projects conducted by the faculty research staff, at campus level it still lacks practical approaches involving the community. Nevertheless, the comparison methodology applied in the study presented here has some constraints, since FCUL's community is nearly one-hundred times larger than HortaFCUL's. There is a strong possibility that the research method did not record some events occurring at FCUL, artificially underestimating the role of the institution. Investment in communication should be increasingly incentivized by FCUL itself to properly describe the initiatives that are led by the faculty community.

4.6. ES connection to Permaculture

The permaculture closing cycles framework is an informal methodology which hasn't been applied to formal scientific works yet. In this report, we propose the use of this framework as a way to describe the activity of a community garden, or other sustainability-led projects. Overall, this framework is holistic, universal and objective, which makes it suitable to be applied in low-input, degraded, marginal and least-profitable areas **(Hirschfeld, 2021)**. Indeed, there is no rigid classification to define the cycles, as they should reflect ongoing processes and dynamics within the project itself. Contrary to the popular notion of promoting urban agriculture for food security, studies show that many agro-ecosystems in urban landscapes contribute more to supporting, regulating and cultural services **(Thiesen, 2021).**

In the case of HortaFCUL, the cycles illustrated in this report clearly show the project's transversal dimension. The knowledge cycle was the most represented in this framework because it was associated with any event in which there was some sort of knowledge transfer, educational practices and valuable information transmission. Tours, presentations, workshops and articles have a clear relationship with this cycle and their contribution to the overall event outcome is very significant.

Concerning the second most meaningful cycle - production -, this result exhibits that both compost and food production have the means to empower and capacitate projects and people. In reality, HortaFCUL, albeit the modest results in terms of food production, is sought by other projects that aim to develop production skills within their own context, especially compost. As for the cycle that follows production - social -, it is once again a quantitative expression of the investment made in social bonding and networking within this project, which is vital for its resilience in the long-term.

Nonetheless, the remaining less impactful cycles - materials, ecological, hydrological and organic - mostly reflect the energy allocated by the group regarding regulating services, which are essential for proper ecosystem functioning. For instance, the ecological cycle is represented by the development of the landscape in terms of biodiversity and habitat provisioning and the materials cycle supports most of the material needs of the project through inventive upcycling approaches.

4.7. ES connection to the SDG framework

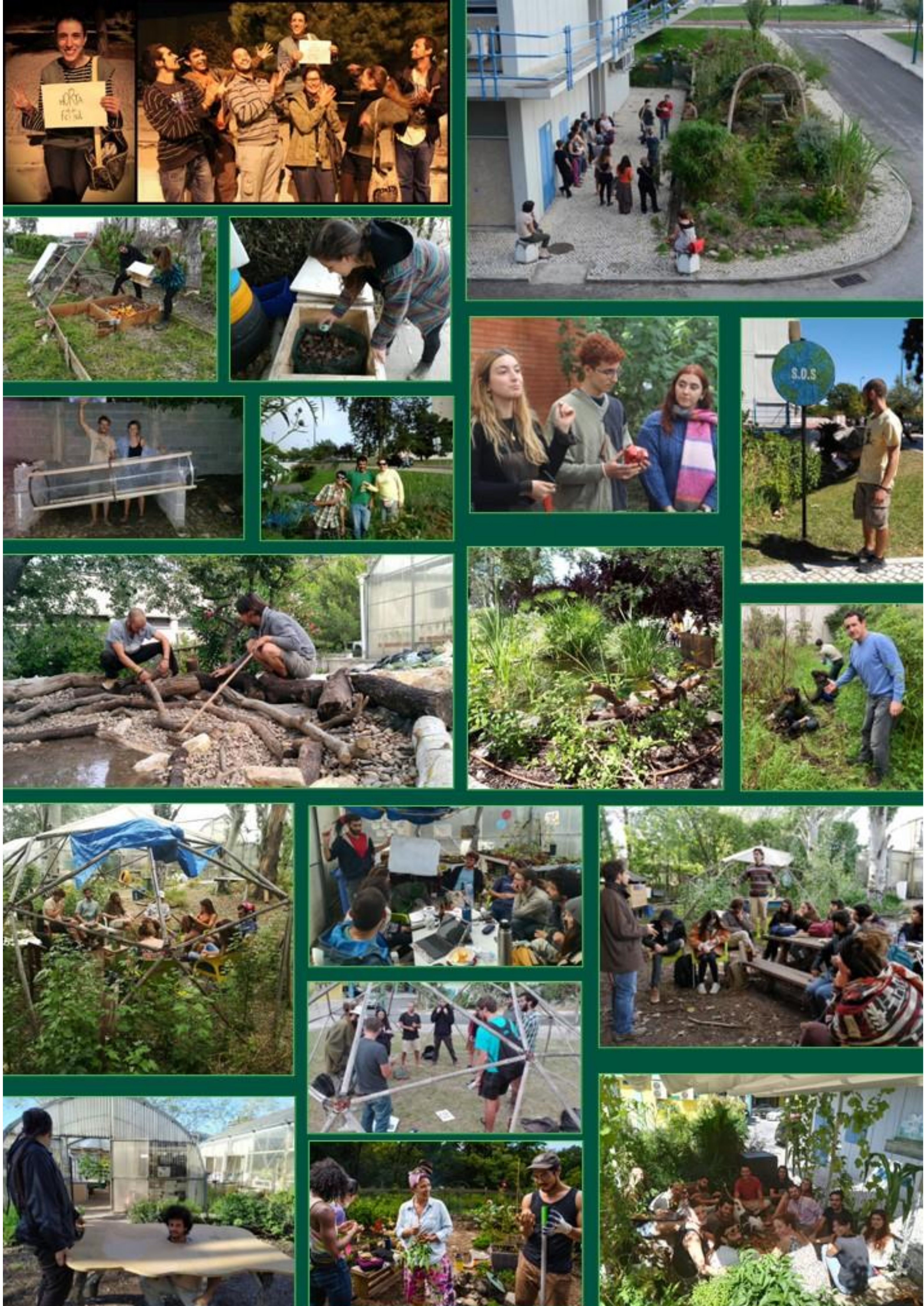
In September 2019, the UN Secretary-General called for a "Decade for Action" to ensure that the 2030 Agenda for Sustainable Development and the 17 SDGs become fully operational (**Biggeri, 2021**). To achieve this aim, new methods and frameworks for monitoring the SDGs are needed to fully realize the emerging 'subnational turn' in global policy (**Fox & Macleod, 2023**). In this report the indicators adaptation and connection with Ecosystems Services stresses the need to include this framework in studies of this sort, since it creates a common ground language to perceive each project's real impact on livelihoods.

HortaFCUL showed the potential to address all SDGs, although with diverse relative contributions. SDG 11: Sustainable cities and communities was the most represented SDG, thanks to HortaFCUL's work in addressing and promoting sustainability solutions and strategies within an urban context. Through partnerships with other entities, HortaFCUL has managed to implement in many contexts some of these solutions and foster its valuable social tools within other communities. Also, SDG 4: Quality Education has a substantial share of the activity's impact due to the investment made in educational events, not only through tours, presentations and courses, but also by means of articles and online information made available for the general public. The fact that HortaFCUL is integrated in (1) the university that has the education in the center of its mission and (2) in an urban context where both city and community are addressing sustainability.

Other significantly supported goals such as Goal 13: Climate Action, Goal 15: Life on Land, Goal 3: Quality Health and Goal 17: Promotion of Partnerships reflect the positive outcomes of HortaFCUL's mission in relation to (1) biodiversity promotion and harboring within degraded landscapes such as urban areas; (2) the commitment to prompt initiatives that decrease greenhouse gas emissions (via composting, for instance); (3) its central role in creating a safe space where people can be close to nature, impacting their mental health and well-being positively and (4) fostering networking between projects, strengthening bonds within groups to help them pursue their own goals.

Less evident, but also positively impacted are SGD such as Goal 14: Protect oceans and marine life are reflected in the amount of plastic and non-degradable waste which is intercepted during the composting process. In reality, organic waste arriving at PermaLab is often contaminated with waste left by people on the ground. Part of these polluting items would reach the ocean if there was no composting procedure to filter this waste **(see Fig. 53)**. Also Goal 5: Gender Equality is promoted within HortaFCUL since all its members have equal responsibilities, rights and decision-making power. Indeed, the inclusiveness principle plays an important role when it comes to fostering equality.

Figure 51 Plastic waste captured during compost sieving.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5. CONCLUSIONS

Based on the results compiled in this report, it becomes clear that projects like HortaFCUL have a regenerative and transformative impact in the surroundings via all 4 Ecosystem Service levels and contribute to all the 17 Sustainable Development Goals. Nonetheless, the project's evolution signature should be seen as a context specific example of localizing the SDG. HortaFCUL is integrated at the university campus in an urban context, which is reflected in its strong contribution to SDG 11 Sustainable Cities and Communities and SDG 4: Quality Education. Those positive impacts ought to be perceived at a local scale, because they are disproportionately transformative to the local communities. Scaling the impacts is critical not to overestimate the project's contributions. Permaculture may be particularly suited to fostering ecosystem services in low-input, degraded, marginal and least-profitable urban areas where effect sizes are most apparent. There is still a large knowledge gap when it comes to comprehending how the scale of the impact evolves if there would be more interconnected and interdependent initiatives in the same regional level.

Furthermore, projects like HortaFCUL should massively invest in their social tools to thrive and pursue their mission. Social services are by far the most important outcome of these projects, and it is very challenging to condense in numbers the scope of those services outside FCUL's context. However, efforts should be made to register and estimate objective social action, since it is crucial for decision-makers to clearly perceive these impacts. Regardless of top-down support, documented partnerships shed some light on the potential of a larger network of projects supporting each other in the pursuit of similar goals.

All in all, this report can be seen as a first attempt to scientifically summarize the added value of a community garden project in Portugal. Project's evolution documented here could be regarded as a learning curve for many initiatives still at their beginnings. Although the goals and the reference indicators for each community project may vary according to context-specific needs, the general matrix of this report may be used to monitor yearly benefits extracted from the activity of community gardens, given that it defines an objective and universal framework connection between ESF and SDG. This research effort should encourage further research endeavors in this area and make community gardens scientifically valid study subjects in academia.


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6. ACKNOWLEDGMENTS

This report wouldn't be possible without the tireless work and dedication of over 70 HortaFCUL guardians. Their names deserve to be engraved here as a recognition of their legacy and passion for sustainability, self-organized communities and nature. Together we prove that human beings, as active citizens, can actually have a meaningful impact in their surroundings. We give voice to the *motto*: *Act local, think global* in Lisbon and beyond. Hopefully, HortaFCUL's work will live on to inspire more projects in the future and restore some optimism in an age of radical change.

In alphabetical order, to all the guardians of this lovely community:

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To all the hundreds of HortaFCUL friends spread throughout the city, the country and abroad! You make sustainability possible, and you inspire us every day to pursue our mission. Thank you for dreaming, turning piles of compost, seeding crops, planting trees and celebrating with us. HortaFCUL would be much less than it is without your friendship.

Gratitude is the word we'd like to send to the Faculty of Sciences Directors Board for their logistical support and endless recognition through the Sustainability Living Lab. HortaFCUL went a long way in terms of institutional relationships with FCUL and the community is proud of their positive impression near the decision-makers at campus level as of today. HortaFCUL is unarguably one of the main engines of sustainability in the campus and that appreciation means the world to us.

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mother earth is pregnant again
the universe made love this time
there is no first couple
and the newborn is collective

from the space between the roots
[human] Nature is reborning

question makers
space creators

the soil as the womb

love is no longer a noun
and the earth penetration is not violent anymore
it comes with pleasure
in fact, penetration is not the center anymore

touch
decentralized love
attention
response over reaction

the role of the receiver is recognized
fear is not the fuel anymore
sadness can happen
and anger feeds creation

revolution

there is a feminine presence
balance
energy rather than gender

property became obsolete
individuality shows up only when needed

duality is an outdated concept

colors do not have names
and skin is no longer a border

knowledge is more than what can be said
and vision is just one of the senses

Nature-based science

trees continue to grow vertically
while we have more time to be horizontal

mother earth is pregnant again
the universe made love this time
there is no first couple
and the newborn is collective

Diogo Mendes
HortaFCUL guardian

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8. APPENDICES

8.1. Articles

8.1.1. Scientific articles/works developed at HortaFCUL

1. Ulm, F., Avelar, D., Hobson, P., Penha-Lopes, G., Dias, T., Máguas, C., & Cruz, C. (2019). Sustainable urban agriculture using compost and an open-pollinated maize variety. *Journal of Cleaner Production*, *212*, 622-629. Access here

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3. Horta, M. N. F. A. (2021). Does community scale composting produce a viable outcome? Some physical and chemical properties of green waste composts produced in the Faculty of Sciences campus. Master's thesis. Universidade de Évora. Access here

4. Mendes, D., Reynaud, R., Oliveira, F., Avelar, D., Ulm, F. (2017). Biobem-estar: Agrodiversidade e Bem-Estar Humano: Permacultura Urbana na HortaFCUL. Scientific poster. SPECO/FCUL. Access here

5. Silva, T., Avelar, D. (2015). Social Tools, structuring a university permaculture project. Permaculture Association. Access here

6. Ulm, F., Moreira, P., Alexandre, A., Santos, I., Mota, I., Teixeira, J., Gaspar, M., Ribeiro, M., Mateus, R., Monteiro, R., Moinhos, S., Avelar, D. (2014). Nurturing the plants the permaculture way: the HortaFCUL case study. Nutriplanta Symposium. Faculdade de Ciências da Universidade de Lisboa. Access here

7. Mateus, R. (2015). Ecosystem services of an urban gardening permaculture project. Masters report. Faculdade de Ciências da Universidade de Lisboa. Access here

8. Wulf, N. (2021) Time is money and compost brown gold." The Berkeley composting method compared with conventional composting with regard to the requirements of the Bundesgütegemeinschaft Kompost. Bachelor thesis. Bremen University. Access here

8.1.2. Articles with HortaFCUL's contributions or mentions

1. Matos, F. (2011). Pensando a resiliência e a sustentabilidade das cidades: experiências na Iniciativa de Transição em Telheiras (Lisboa). Doctoral dissertation. Universidade de Lisboa. Access here

2. Cabral, I., & Weiland, U. (2016). Urban gardening in Leipzig and Lisbon: a comparative study on governance and resilience. In Proceedings of the Conference «Growing in cities: Interdisciplinary perspectives on urban gardening», COST action TU1201: Basel. Access here

3. Oliveira, M.E.G. (2016). Hortas urbanas: desafios da sua implementação em contexto universitário. Masters thesis. Universidade de Aveiro. Access here

4. Paizinho, C. A. D. D. C. (2016). Práticas de economia solidária em iniciativas de agricultura: o caso das hortas urbanas de Lisboa. Master's thesis. Instituto Superior de Ciências do Trabalho e da Empresa. Access here

5. Teixeira, P. I. C. (2019). From degrowth to concrete actions: an exploratory study of the role of bottom-up and top-down initiatives in deep sustainability transitions. Doctoral thesis. Universidade Nova de Lisboa. Access here

6. Ramos, M. (2016) Contribuição para a conservação sustentável de ecossistemas dunares invadidos por Acacia longifolia. Masters thesis. Faculdade de Ciências da Universidade de Lisboa. Access here

7. Chaves, H., Vieira, I. (2020). Um laboratório ao ar livre para criar biodiversidade através do trabalho coletivo – o exemplo da HortaFCUL. Alimentar boas práticas: Da produção ao consumo sustentável, 104-108. Universidade Nova de Lisboa. Access here

8. Alexandre, A., Avelar, D. (Eds) (2023). Miniflorestas para MegaAprendizagens - Um guia para a integração da biodiversidade urbana no ensino. ONGD VIDA. Access here

9. Marques da Silva, J., Figueiredo, A., Cunha, J., Eiras-Dias, J. E., Silva, S., Vanneschi, L., & Mariano, P. (2020). Using rapid chlorophyll fluorescence transients to classify Vitis genotypes. Plants, 9(2), 174. Access here

10. Simon, S. (2022). 'Field work': drawing lessons from urban agriculture to facilitate transitions towards sustainable cities. Universidade Lusófona de Lisboa. Access here

8.1.3. General public published articles about HortaFCUL

1. Horta em 2013/2014 (2014)

A summary report of the main activities developed by HortaFCUL during the school year of 2013/2014.

2. Dragon Dreaming HortaFCUL (2014)

John Croft's dragon dreaming practice developed by the HortaFCUL guardians.

3. Universidade de Lisboa apoia a HortaFCUL – Domando os dragões (2014)

Announcement of a public fund granted to HortaFCUL by Lisbon's University to develop several projects and activities.

4. Mural HortaFCUL (2015)

Artistic intervention on the side wall of Hortinha depicting the evolution of matter and life, particularly the invisible parts such as soil life.

5. Banca da Dádiva da HortaFCUL (2016)

HortaFCUL's gift table located in between the faculty's main buildings, where the project tests on a continuous basis the gift economy model.

6. HortaFCUL 2.0 (2016)

Announcement of the results obtained in an enquiry made to the local campus community.

7. "Learning is an experience. Everything else is just information" (2016)

Travel testimony of an exchange program where two guardians participated in Newcastle.

8. Como está Ciências a melhorar a gestão dos resíduos orgânicos? (2017)

Report on the first year of composting activity in PermaLab

9. Projeto minhocário no Permalab da Faculdade (2017)

Worm nursery project: the construction process.

10. Laboratório Vivo de Permacultura (2017)

PermaLab's introduction: its mission, goals and first experiments.

11. Horta Pedagógica de Santo António (2017)

Testimony of a year-long partnership with a primary school in Lisbon.

12. A HortaFCUL em 2017/2018 (2018)

A summary report of the main activities developed by HortaFCUL during the school year of 2017/2018

13. Galinheiro móvel de Ciências (2018)

Introduction to the ChickenTractor: a mobile chicken house coupled to the food production plots.

14. Compostor FCUL (2018)

Composting station early results and transformative impact in the campus.

15. Dia Mundial do Solo (2018)

Article on World's Soil Day, commemorated at hortaFCUL with a series of practical activities, talks and community gatherings.

16. Um estágio na HortaFCUL (2019)

Marissa Verhoeven's testimony of her internship experience at HortaFCUL

17. Levar a permacultura para casa (2020)

Series of workshops for school children at Belem Cultural Center

18. CHILL: O que fazem as galinhas em Ciências? (2020)

Article explaining the functioning of the Chicken-Tractor at PermaLab, a mobile chicken house to improve soil quality for crop production.

19. Hortas urbanas. A ciência está a passar por aqui e o futuro também (2019)

Article introducing PermaLab's research framework in a national newspaper

20. Um pequeno oásis escondido na cidade. Na Horta FCUL, a ciência faz-se com as mãos na terra (2022)

Local newspaper article on HortaFCUL's work and mission.

21. Em vez de relvados, Lisboa pode ter miniflorestas no centro da cidade? (2021)

Introduction to the tiny forest concept, taking FCULresta as an example, in a national newspaper.

22. FCULresta, um ano depois

Celebration of FCULresta's first year.

23. Que florestas são estas a nascer no meio da cidade? Têm nome de um botânico japonês, Miyawaki, e trazem a natureza aos bairros (2023)

Local newspaper article on FCULresta's growing legacy as a role model for tiny forests in the Lisbon area.

24. Está a nascer uma mini-floresta mesmo à porta da FCUL (2021)

Local newspaper article on FCULresta's initiative.

25. Uma minifloresta é um livro que se escreve em conjunto

Podcast episode introducing the tiny forest guide for schools.

8.2. Video contents

1. RTP TV channel news piece on HortaFCUL (Portuguese, 2010), Part One and Part Two
2. 5 anos de HortaFCUL (2014)
3. *Horta*, directed by Inês Pina (Portuguese, 2014)
4. *Comunidade Baldia*, directed by Mariana Sanches (Portuguese, 2015)

Short film on Horta do Baldio community garden, an extinct sister project of HortaFCUL.

5. *O início da sopa da Horta* (2016)

The beginning of the community meals tradition at HortaFCUL (Sopas da Horta).

6. Um dia de trabalhos na HortaFCUL (2017)

A working day at HortaFCUL

7. O processo de compostagem em Ciências (2018)

Short account on the composting station experience at campus.

8. CHILL: Galinheiro móvel do PermaLab (2018)

Short video explanation of how PermaLab's chicken tractor functions.

9. #IGrowYourFood - Meet David Avelar from Portugal & hear what he has to say about Permaculture, IFOAM Organics International (English, 2019)

Urban permaculture explained by David Avelar

10. Cada Gota Conta (2019)

Witness account of the stormwater storage process

11. Video series introducing the HortaFCUL project at the 2020's online edition of Waking Life Festival (English, 2020)

a. Welcome to HortaFCUL
b. Gardening for biodiversity
c. Social tools
d. Compost and Soil regeneration

12. Podcast Caravana Agroecológica – HortaFCUL episode (Portuguese, 2020)

13. Conversas sobre microrganismos: Cristina Cruz fala com a HortaFCUL (Portuguese, 2020)

Short visual account of the presence and importance of microorganisms at HortaFCUL

14. Hortas de Lisboa, apresentação do projecto HortaFCUL (Portuguese with English subtitles, 2020)

    Short presentation of HortaFCUL's work as part of an exhibition about food gardens in Lisbon co-organized with Lisbon's municipality (Hortas de Lisboa)

15. Capacitation and climate action programme online series in partnership with 1Planet4All (Portuguese, 2021)

    a. *Permacultura urbana* with David Avelar
    b. *A História da HortaFCUL* with Rebecca Mateus e António Alexandre
    c. *A Hortinha* with Manuel Botelho
    d. *Intervenção na Hortinha - parte prática* with António Alexandre, Ivo Rosa e Tiago Silva

e. *Introdução ao PermaLab* with Florian Ulm
f. *A Zona Social (zona 0) do Permalab* com David Avelar
g. *O tampão verde e os swales (Zona 4) do Permalab* com Manuel Botelho
h. *A área de compostagem (Zona 1)* com Florian Ulm
i. *Introdução à FCULresta* com António Alexandre e David Avelar (5 video series) Part One, Part Two, Part Three, Part Four and Part Five

16. Workshop Permacultura Urbana (2022)

Practical workshop on urban permaculture techniques

17. Apresentação do projecto nas Jornadas de Engenharia do Ambiente (Portuguese, 2023)

HortaFCUL's history and mission

18. Plantação da Horta Solar (2023)

Practical workshop about plantation and seeding at Horta Solar

19. Workshop Bioilhas (2023)

Practical workshop on micro-forest planning and implementation as part of the Bioilhas project

20. *DocNomads point of view of HortaFCUL nature and gardening*, directed by Ana Barjadze & Feroza Gulzar (2023)

Short film on a working day at HortaFCUL

21. Compostagem e Vermicompostagem | Curtas de Produção e Consumo Alimentar Sustentável, Rede de Campus Sutentáveis (Portuguese, 2023)

Video explaining the composting process at HortaFCUL

22. *Compostagem,"* Acabou a hora de usar e deitar fora", by ADPM (Portuguese, 2021)

Good composting practices presented by Madalena Horta

HORTA FCUL

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