Technology
Arts Sciences
TH Köln

UASLP
Universidad Autónoma
de San Luis Potosí

UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ

FACULTADES DE CIENCIAS QUÍMICAS, INGENIERÍA Y MEDICINA

PROGRAMA MULTIDISCIPLINARIO DE POSGRADO EN CIENCIAS AMBIENTALES

AND

TH KÖLN - UNIVERSITY OF APPLIED SCIENCES

FACULTY SPATIAL DEVELOPMENT AND INFRASTRUCTURE SYSTEMS

INSTITUTE FOR TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

THESIS TO OBTAIN THE DEGREE OF

MAESTRÍA EN CIENCIAS AMBIENTALES

DEGREE AWARDED BY UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ

AND

MASTER OF SCIENCE

NATURAL RESOURCES MANAGEMENT AND DEVELOPMENT

DEGREE AWARDED BY TH KÖLN – UNIVERSITY OF APPLIED SCIENCES

PROPOSAL FOR AN URBAN GREEN INFRASTRUCTURE MANAGEMENT STRATEGY BASED ON ECOSYSTEM SERVICES.

THE UNIVERSITY PROGRAM OF BIODIVERSITY AT THE UASLP WESTERN CAMPUS

PRESENTS:

JUAN ANDRADE RIVERA

CO-DIRECTOR OF THESIS ITT:

PROF. DR. JOHANNES HAMHABER

CO-DIRECTOR OF THESIS PMPCA:

DR. MARCOS ALGARA SILLER

ASSESSOR:

DR. CARLOS RENATO RAMOS PALACIOS

COLOGNE, GERMANY AUGUST 2023

PROYECTO REALIZADO EN:

PMPCA

AGENDA AMBIENTAL

PROGRAMA UNIVERSITARIO DE BIODIVERSIDAD

UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ

CON EL APOYO DE:

CONSEJO NACIONAL DE CIENCIA Y TECNOLOGÍA (CONACYT)

NÚMERO DE APOYO: 806056

CVU: 619110

LA MAESTRÍA EN CIENCIAS AMBIENTALES RECIBE APOYO A TRAVÉS DEL PROGRAMA NACIONAL DE POSGRADOS

(PNPC - CONACYT)

Erklärung / *Declaración*

Name / *Nombre*: Juan Andrade Rivera

Matrikel-Nr. / *N° de matrícula*: 11151879 **(TH Köln)** / 348489 **(UASLP)**

E-Mail: juan.andriv@gmail.com

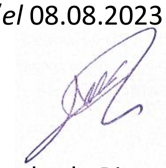
Ich versichere wahrheitsgemäß, dass ich die vorliegende Masterarbeit selbstständig verfasst und keine anderen als die von mir angegebenen Quellen und Hilfsmittel benutzt habe. Alle Stellen, die wörtlich oder sinngemäß aus veröffentlichten und nicht veröffentlichten Schriften entnommen sind, sind als solche kenntlich gemacht.

Aseguro que yo redacté la presente tesis de maestría independientemente y no use referencias ni medios auxiliares a parte de los indicados. Todas las partes, que están referidas a escritos o a textos publicados o no publicados son reconocidas como tales.

Die Arbeit ist in gleicher oder ähnlicher Form noch nicht als Prüfungsarbeit eingereicht worden.

Hasta la fecha, un trabajo como éste o similar no ha sido entregado como trabajo de tesis.

Köln /San Luis Potosí, den /*el* 08.08.2023



Unterschrift / *Firma*: Juan Andrade Rivera

Ich erkläre mich mit einer späteren Veröffentlichung meiner Masterarbeit sowohl auszugsweise, als auch Gesamtwerk in der Institutsreihe oder zu Darstellungszwecken im Rahmen der Öffentlichkeitsarbeit des Institutes einverstanden.

Estoy de acuerdo con una publicación posterior de mi tesis de maestría en forma completa o parcial por las instituciones con la intención de exponerlos en el contexto del trabajo investigación de las mismas.

Unterschrift / Firma: Juan Andrade Rivera

Technology
Arts Sciences
TH Köln

ITT
Institute for Technology and
Resources Management in
the Tropics and Subtropics

UASLP
Universidad Autónoma
de San Luis Potosí

AGENDA
AMBIENTAL

Proposal for an Urban Green Infrastructure Management Strategy based on Ecosystem Services

The University Program of Biodiversity at the UASLP ZUP campus

Master thesis presented by:

Juan Andrade Rivera

Köln, Germany, 2023.

ABSTRACT

Cities worldwide are currently confronted with significant social and ecological challenges arising from urbanization, climate change, biodiversity loss and resource scarcity. Urban green infrastructure (UGI) emerges as a critical solution to mitigate and adapt to these challenges by providing essential ecosystem services (ES) that contribute to human well-being and enhance the overall quality of urban life.

This work aims to propose strategies to achieve a sustainable and resilient provision of ES through the adaptive management of UGI within the specific context of the Universidad Autónoma de San Luis Potosí (Autonomous University of San Luis Potosí, UASLP) campuses.

The specific objectives of this research include: 1) defining priority ecosystem services, 2) evaluating their demand and provision, 3) identifying leverage points to maintain or enhance them where most needed, and 4) developing a management strategy for decision-makers concerning UGI on UASLP campuses.

To achieve these goals, a tool for developing adaptive management strategies for UGI based on ES was devised. The tool underwent a test through a pilot study on the Zona Universitaria Poniente (Western zone, ZUP) campus, enabling the identification of practical issues, challenges, and areas of opportunity. By analyzing ES provision and demand, a set of strategies was proposed in collaboration with a panel of experts to be implemented by decision-makers at the campus.

This work contributes to the broader understanding of UGI management at the local scale, showcasing its potential to address urban challenges effectively. The developed strategies offer guidance for decision-makers, fostering the creation of sustainable and resilient urban environments in line with the sustainable development goals (SDG) and principles.

Keywords

Urban Ecosystem Services, Urban Green Infrastructure, Urban Social-Ecological Systems, Adaptive Management, Sustainable Strategies.

Resumen

Las ciudades de todo el mundo se enfrentan actualmente a enormes desafíos sociales y ecológicos derivados de la urbanización, cambio climático, la pérdida de biodiversidad y la escasez de recursos. La infraestructura verde urbana (IVU) surge como una solución crítica para mitigar y adaptarse a estos desafíos proporcionando servicios ecosistémicos (SE) esenciales, que contribuyen al bienestar humano y mejoran en general la calidad de la vida urbana.

Este trabajo tiene como objetivo proponer estrategias para lograr una provisión sostenible y resiliente de SE a través del manejo adaptativo de la IVU dentro del contexto específico de los campus de la Universidad Autónoma de San Luis Potosí (UASLP).

Los objetivos específicos de esta investigación incluyen: 1) definir los servicios ecosistémicos prioritarios, 2) evaluar su demanda y provisión, 3) identificar los puntos de apalancamiento para mantenerlos o mejorarlos donde sea necesario y, 4) desarrollar una estrategia de gestión para los tomadores de decisiones con respecto a la IVU en los campus de la UASLP.

Para lograr esto, se diseñó una herramienta para el desarrollo de estrategias de gestión adaptativa para la IVU basadas en SE. La herramienta fue puesta a prueba mediante un estudio piloto en el campus Zona Universitaria Poniente (ZUP) de la UASLP, lo que permitió identificar problemas prácticos, desafíos y áreas de oportunidad. Mediante el análisis de la provisión y demanda de los SE, se propuso un conjunto de estrategias en colaboración con un panel de expertos, para ser implementadas por los tomadores de decisiones en el campus.

Esta investigación contribuye al entendimiento de la gestión de la IVU a escala local, mostrando su potencial para abordar eficazmente los desafíos urbanos. Las estrategias desarrolladas ofrecen orientación a tomadores de decisiones, fomentando la creación de entornos urbanos sostenibles y resilientes de acuerdo con los objetivos y principios del desarrollo sostenible.

Palabras clave

Urban Ecosystem Services, Urban Green Infrastructure, Urban Social-Ecological Systems, Adaptive Management, Sustainable Strategies.

ACKNOWLEDGEMENTS

To Zoey, as the guiding light of my life, your happiness and well-being drive my every move. May you continue to grow strong and proud, like the sunflowers you admire. I will always be close to take care of you.

To my mother María Antonia, thank you for dedicating your life to create an oasis where your four roses could bloom. I, your son of the desert, will be forever grateful.

To my sisters Claudia, Gema, and Ninel, thank you for the unconditional love and for always being my accomplices. I can only hope to return a fraction of it in my remaining life.

To my thesis committee, Dr. Algara, Prof. Dr. Hamhaber and Dr. Ramos, for your patience and guidance throughout this process.

And to my ENREM friends, who supported me when I struggled the most, even when you had your own battles to fight. You added the magic to this experience, and I wish you all the success in this life.

Dedicated to Zoey.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Abbreviations

SES	Social-Ecological System
USES	Urban Social-Ecological System
NbS	Nature-based Solutions
GI	Green Infrastructure
UGI	Urban Green Infrastructure
ES	Ecosystem Services
UES	Urban Ecosystem Services
EG	Ecosystem Goods
UEG	Urban Ecosystem Goods
ED	Ecosystem Disservices
UED	Urban Ecosystem Disservices
SLP	San Luis Potosí
UASLP	Universidad Autónoma de San Luis Potosí *Autonomous University of San Luis Potosí*
ZUP	Zona Universitaria Poniente *Western Zone*

1. INTRODUCTION

1.1. Background

1.2. Problem statement

1.3. Justification

1.4. Research questions

1.5. Objectives

1.1. BACKGROUND

Currently there is a great deal of interest on the importance of green spaces as support for a healthy life on urban areas. This is because the planet's population is growing at an accelerated rate with a clear tendency towards urbanization. It is expected that by 2030, more than 60% of estimated population (4.9 of 8.1 billion) will live in cities, areas characterized by their huge and complex environmental footprints (Endlicher et al., 2007). Due to global climate change, ample regions of the world will have to face multiple common challenges in the coming years like demographic explosion, temperature rising, food insecurity, water scarcity and increased risk of droughts and floods (Kim & Coseo, 2018).

Urban ecosystems, composed by highly modified landscapes, are a key element to sustain the environment and their inhabitant's wellbeing (Guillen-Cruz et al., 2021).

All ecosystems (including the highly urbanized) possess functions and provide services. The first ones refer to the properties or processes inherent to the system, while the second ones refer to the benefits that humans obtain directly or indirectly of said ecosystem functions (Costanza et al., 1997).

The publication of the Millenium Ecosystem Assessment in 2005 contributed to put the term of "ecosystem services" in the public eye, and related literature has grown exponentially ever since (Martínez-Guzmán et al., 2021). Afterwards it became consolidated in the international agenda in 2015, with the publication of the Sustainable Development Goals by the United Nations, by being included in the Objective 11. Sustainable communities and cities (Stahle, 2018).

1.2. PROBLEM STATEMENT

The World Health Organization makes use of the term "urban green area" to designate public green areas, and proposes an indicator based on accessibility (Stahle, 2018), specifically the population living within 300 m of a green area with a surface of at least 0.5 ha (Ward et al., 2016).

At local level, the extension of green areas is usually designated as a percentage of the total project and is commonly stipulated in the construction regulations of the city. As an example, according to applicable construction regulations in the city of San Luis Potosí, it is required that projects donate 10 to 15% of its extension to the municipality, from which the city must keep a minimum of 60% as green areas, resulting in 6 to 15% of any specific construction project becoming green space (Reglamento de Construcciones Del Municipio de San Luis Potosí, 1995).

To this day, there is no widely accepted urban green areas management strategy based on ecosystem services provision at the local or international levels.

1.3. JUSTIFICATION

According with the state-of-the-art review, made by Haase, Larondelle, et al. (2014), most studies revolving around ecosystem services in urban areas have been made for Europe, North America, and China, leaving a great need to generate information for developing regions, as is the case with Latin America.

Other important shortcomings detected in this review were a lack of vision towards the future or a synergies and tradeoffs analysis, no communication of results with stakeholders, the omission of ecosystem disservices, the absence of a systems perspective, and a disregard for the use of participatory or explicitly spatial methods to assess demand and offer of ecosystem services.

In addition, ecosystem services assessment is also an issue of environmental justice since it is necessary to ensure the equitable provision of these in areas where they are scarce (Croci et al., 2021).

A major problem in our view of urban ecosystem services is scale (Brzoska & Spaǵe, 2020). The little information available on their effect at small scale complicates their integration in the planning and decision-making processes of cities. Another problem is the lack of adequate methods to evaluate them at that level, since most of the common methodologies focus on regional level, generalizing most of the information analyzes. To obtain realistic results, studies should be conducted on smaller structures recognized by common planning tools such as parks, orchards, or gardens.

These problems give way to the fact that urban green infrastructure is not being strategically planned to provide ecosystem services to the population of cities; even though research has shown that vegetation can be managed to optimize the supply of desired services, utilizing the knowledge obtained from heterogeneous urban landscapes and human populations (Bodnaruk et al., 2017; Elliott et al., 2020; Wentworth, 2017; Wu, 2019; Zhao et al., 2020).

1.4. RESEARCH QUESTIONS

- Which are the ecosystem services of relevance provided by the urban green infrastructure of the UASLP campuses?
- How could the provision and quality of ecosystem services provided by the urban green infrastructure of the UASLP campuses be evaluated?
- Are there specific elements that can effectively impact the total quality of ecosystem services provision by the urban green infrastructure located inside the UASLP campuses?
- Which strategies should be applied in the management of the urban green infrastructure inside the UASLP campuses to enhance ecosystem services provision where they are most needed?

1.5. OBJECTIVES.

1.5.1. GENERAL OBJECTIVE

Design an urban green infrastructure management strategy based on ecosystem services that could be applied on the Universidad Autónoma de San Luis Potosí (Autonomous University of San Luis Potosí, UASLP) campuses.

1.5.2. SPECIFIC OBJECTIVES

Define the criteria for evaluation of priority ecosystem services provided by the urban green infrastructure located inside the UASLP campuses.

Evaluate demand and provision of priority ecosystem services for each urban green infrastructure located inside the case study; the UASLP Zona Universitaria Poniente (Western Zone, ZUP) campus.

Identify leverage points to maintain the provision of ecosystem services by urban green infrastructure located inside the case study; the UASLP ZUP campus in areas where they are demanded.

Create a strategy that proposes recommendations to decision makers to manage the UGI inside the UASLP campuses.

2. THEORY INTEGRATION AND CONCEPTUAL FRAMEWORK

2.1. THE URBAN ECOSYSTEM

2.1.1. ECOLOGY AND ITS ROLE IN CITIES

Urbanized areas and their huge and complex ecological footprints, considered as "urban ecosystems", are the field of study of the discipline known as "urban ecology", understood as "the integration of natural and social sciences in their basic and applied form to explore and elucidate the multiple dimensions of urban ecosystems" (Vogt & Cortez, 2020).

Several approaches to this discipline have been identified. First the urban sociological approach, which investigates human behavior and social organization in urban environments; second, the bio-ecological approach, which is interested in the distribution and abundance of animals and plants in and around cities; third, the urban systems or human ecosystem approach, which treats the city as a complete ecosystem, consisting of natural and socioeconomic components; fourth, the urban landscape approach, which views urban areas as dynamic, spatially heterogeneous, multi-scale patchwork systems; and finally, the urban sustainability approach, a recent view that treats cities as social-ecological systems, with an increasing emphasis on the relationship between ecosystem services and human well-being in urban areas (Wu, 2014). The present study makes use of the fifth approach in the analysis of the urban system.

2.1.2. CITIES AND URBAN CHALLENGES

The World Economic Forum (WEF) & Alexander von Humboldt Biological Resources Research Institute (2022), identified the main problems of urban social-ecological systems as increasing urban population and declining biodiversity, causing the natural layer on which society is built to be degraded through direct and indirect impacts of urbanization. This spatial footprint, the area from which residents extract resources for subsistence, is on average 36 times the size of a city.

These urban challenges have been expanded by stating that these types of ecosystems face a series of specific problems, referring to climate change adaptation and mitigation, water management, green area management, coastal management, air quality, urban regeneration, participation, planning and governance, social cohesion and justice, public health and well-being, and potential for economic opportunities, among others (Castellar et al., 2021). These are exacerbated by the increasing rate of urbanization, climate change, increasing pressure from resource scarcity, degradation of environmental quality, reduction in the availability of green spaces and rising global temperatures, leading to an increase in the frequency and intensity of various natural disasters (ICLEI - Local Governments for Sustainability, n.d.).

These urban challenges cannot be understood by separating the social and biophysical subsystems, so a synergy between natural and social science research is required when talking about the study of cities (Frank, 2017).

2.2. THEORETICAL FOUNDATIONS

2.2.1. THE URBAN SOCIAL-ECOLOGICAL SYSTEMS THEORY

Urban areas are characterized by abundant interactions between social, economic, institutional, and environmental variables, creating complex human-dominated landscapes that exert an enormous influence on ecosystems at local, regional, and global levels (Alberti, 2005).

For this reason, solutions to urban challenges, where nature and society often interact, require the use of a holistic perspective, integrating biophysical and human elements (Cumming, 2014). Urban Social-Ecological Systems (USES) are developed as a framework for studying and thinking about these relationships (Chapin et al., 2012).

Currently, there is no cohesive theory applicable to USES (Cumming, 2014; le Tourneau & Scott, 2020). Although multiple attempts have been made, most of them cannot bridge the gaps between theory and practice, or between ecology and sociology. For this reason, modern scientific work in the USES framework is based on the systems theory applied to an ecological system.

Taking this into consideration, it was decided to work with the most recent and generally applicable option, the "systems theory" understood as a specific and unified group of propositions, which have been put together for the purpose of achieving a general system understanding (Adams et al., 2014). However, due to the transdisciplinary nature of USES, this theory only functions as a general framework, within which elements of other theories that support the explanation of the various complex phenomena occurring within the system must be interrelated.

2.2.2. Relationship between USES and Human Scale Development

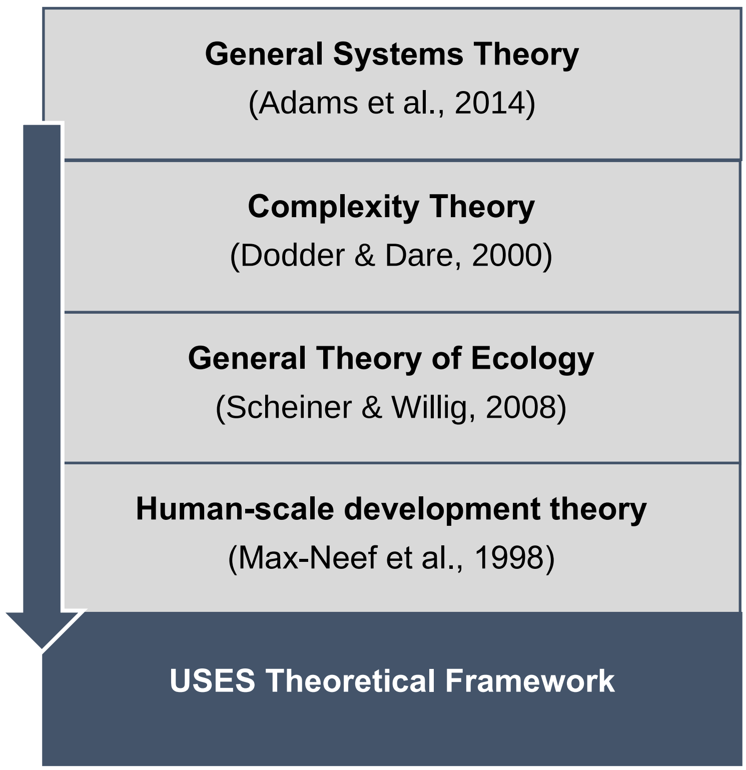
There is a need to link urban ecology studies, commonly focused on biodiversity, ecological processes, and ecosystem services, with urban sustainability studies, where the focus is on human wellbeing (Wu, 2014). This is consistent with more recent views stating that there is a problem in the analysis of USES when trying to understand the human roots of ecological changes, since we should first understand the forces that motivate human actions (Petrosillo et al., 2018). With this context, it is necessary to take concepts from the theory of human scale development (Max-Neef et al., 1998), which attempts to generate a paradigm shift in development, as it aims to focus development on the satisfaction of fundamental human needs, with the objective of improving people's quality of life, understanding quality of life as "the possibilities that people have to adequately satisfy their fundamental human needs".

Max-Neef understands fundamental human needs as: "human deficiencies at the physiological level, but to the extent that they engage, motivate and mobilize people, they are also individual and collective potentialities". On the other hand, he defines satisfiers as: "ways of being, having, doing and existing, of individual and collective character, conducive to the actualization of needs".

In addition, he categorized fundamental human needs, combining two disaggregation criteria: existential categories and axiological categories. The former refers to the needs of being, having, doing, and existing; while the latter are composed of subsistence, protection, affection, understanding, participation, leisure, creation, identity, and freedom.

To have sufficient theoretical background to understand and explain the USES, and given that currently there are no fully accepted theories, a comprehensive approach is needed, so keeping the “general systems theory” as a basis, concepts from the "general theory of ecology" (Scheiner & Willig, 2008); the "human-scale development theory" (Max-Neef et al., 1998), and the "complexity theory" (Dodder & Dare, 2000; Gare, 2000), are required to fill all the gaps and to understand the general properties of a complex system, explain the specific relationships that exist inside an urban social-ecological system, while emphasizing human wellbeing and satisfaction (Figure 1).

Figure 1. Theoretical framework



Note. Different theories required to construct the USES theoretical framework. The order shows the way they build upon each other.

2.3. CONCEPTUAL FRAMEWORK

2.3.1. ECOSYSTEM GOODS, SERVICES, AND DISSERVICES

The term ecosystem services (ES) refers to “functions, characteristics or processes that directly or indirectly contribute to human wellbeing, that is, the benefits that people derive from ecosystem functions” (Costanza et al., 2017). In the context of urban spaces, urban ecosystem services (UES) are defined as “those services that are directly produced by ecological structures inside urban or periurban areas" (Luederitz et al., 2015). The subset of UES that are tangible material products is identified as urban ecosystem goods (UEG), while the functions and structures that have a negative consequence on human wellbeing are denominated "urban ecosystem disservices" (UED) (Dobbs et al., 2011).

A great variety of ES have been identified, and they have been categorized using different criteria by multiple organizations (Croci et al., 2021). These diverse frameworks continue to co-exist with each other because they have a different focus, each useful for distinct objectives. Some of them are more suitable for economic valuation, others for ecological assessment, but the one that concentrates on SES and systemic effects is the Millenium Ecosystem Assessment from 2005, so this is the classification that will be used for this research project (The Economics of Ecosystems and Biodiversity (TEEB), 2012).

This framework differentiates services as provisioning, for those tangible products obtained from ecosystems, regulating for those that control ecosystem processes, cultural for non-material benefits that contribute to well-being, and supporting for those fundamental to produce all other ecosystem services (Millenium Ecosystem Assessment (MEA), 2005).

However, urban ecosystems are distinct in terms of the high coverage of impermeable surfaces, density of human population and levels of pollution, which makes cities highly dependent on the reduced green areas they have, to provide them of goods and services and manage their waste and residues. This results in a complex situation where deciding which ES are priority for a given city will depend completely on its environmental, social, and economic characteristics (Bolund & Hunhammar, 1999; Wentworth, 2017).

Table 1 shows a classification of common UES, UEG and UED, taken from a non-systematic literature review, and classified according to the Millenium Ecosystem Assessment framework.

Table 1. Common Urban Ecosystem Goods, Services and Disservices

Provisioning	Regulating	Cultural
Food production Freshwater provision Wood and fiber	Microclimate regulation Noise reduction Air quality regulation Carbon sequestration Flood regulation Pollinators Soil quality maintenance Waterflow regulation	Aesthetic pleasure Connection with nature Stress reduction Education Recreation Community creation
Water consumption Polluted crops	Pests VOC emission	Perception of insecurity Increased allergenicity
Supporting		
Biodiversity Habitat connectivity		
Non-native species invasion Habitat fragmentation		

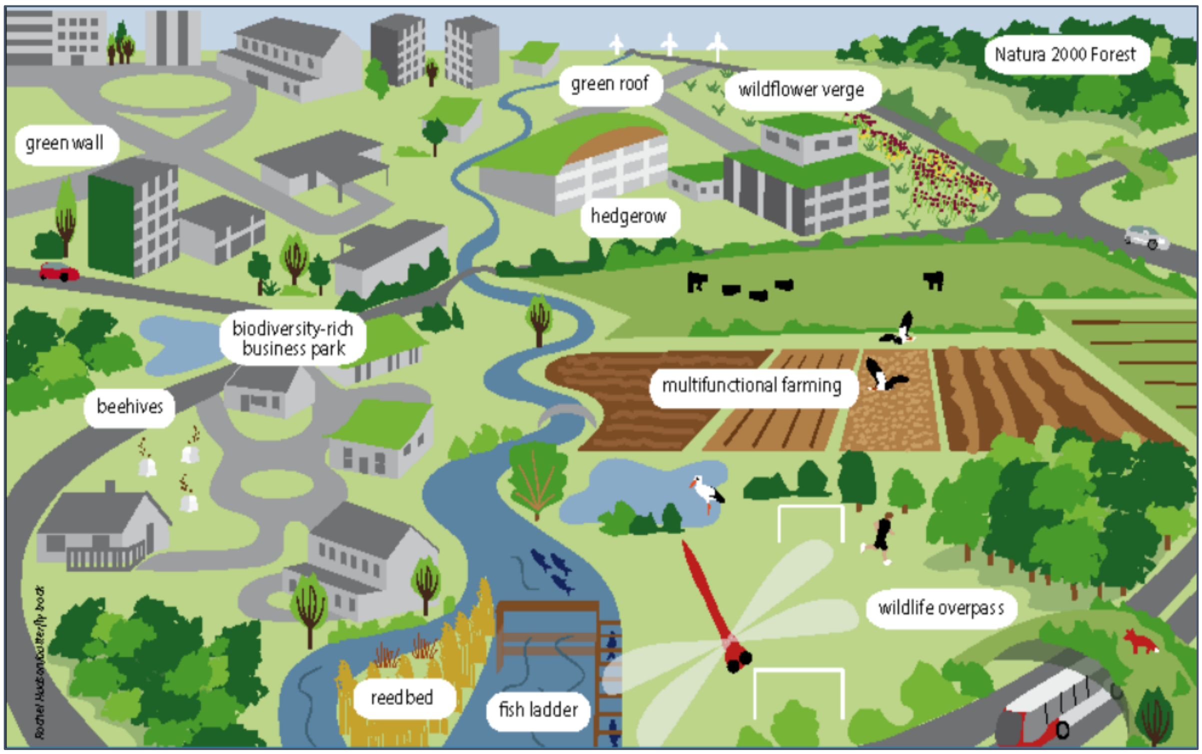
Note. Ecosystem good or service (green) Ecosystem disservice (orange)

Source. Bolund & Hunhammar (1999); Brzoska & Spaǵe (2020); Dobbs et al. (2011); Guillen-Cruz et al. (2021); Haase, Frantzeskaki, et al. (2014); Martínez-Guzmán et al. (2021); Millenium Ecosystem Assessment (MEA) (2005); Obalum et al. (2017); Pataki et al. (2011); Wentworth (2017)

2.3.2. Nature-based solutions and urban green infrastructure

The Mapping and Assessment of Urban Ecosystems and their Services (MAES) – Urban report (2015) conceptualizes urban green areas and urban green spaces as synonyms, referring to “urban areas partially or completely covered by vegetation”. Afterwards it defines green infrastructure as a “strategically planned network of natural and seminatural areas with other environmental elements, designed and managed to provide a wide range of ecosystem services. Including green areas (or blue, if involves aquatic ecosystems) and other physical characteristics on land and maritime areas. On land, it is present on rural and urban settlements". Finally, the concept is grounded on urban environments as urban green infrastructure (UGI), defined as "green infrastructure that is located inside urban or periurban areas" (Rocha et al., 2015). Different examples of UGI can be appreciated on Figure 2.

Figure 2. Examples of urban green infrastructure



Source. Deutsche Gesellschaft für Internationale Zusammenarbeit (2019)

Although a completely accepted categorization for different types of nature-based solutions (NbS) and UGI does not exist, Castellar et al. (2021) has developed a comprehensive and hierarchical classification that includes a wide array of different solutions. Besides, considering that the vegetation type and configuration have a critical effect on the provision of UES by a certain intervention (Zhao et al., 2020),

Table 2 presents a summary of the most common UGI categorized by type and configuration.

Table 2. Categorization of common nature-based solutions and urban green infrastructure

<table>
<tr><th colspan="4"></th><th colspan="3">Configuration</th></tr>
<tr><th colspan="4"></th><th>Punctual</th><th>Linear</th><th>Group</th></tr>
<tr><td rowspan="7">Type</td><td rowspan="4">Units</td><td rowspan="2">Spatial</td><td>Arboreal</td><td>Individual tree</td><td>Lined trees
Sidewalk trees</td><td>Urban forest
Orchards</td></tr>
<tr><td>Mixed vegetation</td><td>Small planter</td><td>Green corridor
Hedges.</td><td>Park
Urban garden
Botanical garden</td></tr>
<tr><td rowspan="2">Technological</td><td>Vertical</td><td>Vertical planter</td><td>Green wall
Green facade</td><td>Vegetated pergola</td></tr>
<tr><td>Horizontal</td><td>Infiltration basin</td><td>Bioswale</td><td>Green roof
Rain garden
Permeable pavement</td></tr>
<tr><td rowspan="3">Interventions</td><td colspan="2">Soil</td><td colspan="3">Compost
Soil improvement
Systems for erosion control</td></tr>
<tr><td colspan="2">Biodiversity</td><td colspan="3">Biodiversity habitats and shelters
Use of native vegetation.</td></tr>
<tr><td colspan="2">River</td><td colspan="3">Riverbank engineering
Blue corridor
Floodplain management
Diverting elements.</td></tr>
</table>

Note. Cross-matrix based on type and configuration.

Source. Zhao et al. (2020) and Castellar et al. (2021)

2.3.3. THE COMPLEX ROAD FROM URBAN GREEN INFRASTRUCTURE TO HUMAN WELLBEING

The links between biodiversity and ecological structures, to ecosystem services, and to human well-being has been commonly described through the “cascade model” (Haines-Young & Potschin, 2010) which, although useful for representation and conceptual means, falls into the trap of analyzing a social-ecological phenomenon, as complex and multidimensional as it is, from a reductionist perspective.

This happens since there is a lack of a systematic framework in which complex USES can be described, understood, and investigated in an integrated manner. Emerging opportunities for assessment lie in the incorporation of concepts such as system dynamics, resilience, and ecosystem services into their framework (Bowd et al., 2015).

Current tools that are frequently used to assess environmental attributes, range from checklists, matrices, networks, and quantitative methods. Of these, matrices are probably the most well-known for attempting to capture more complex relations, some of them try to quantify through a subjective assessment, like the Leopold and Peterson matrices. On the other hand, the Sorensen network was an approach developed explicitly to investigate higher order relations and impacts (Bowd et al., 2015).

Since networks are intended to provide a more structured way of linking causes and effects, when potential effects on complex, interrelated ecosystems are considered, they seem better suited to display, in an easily understood format, the intermediary links, present in the ecosystems to human well-being cascade that this research is focusing on, allowing the illustration and exploration of elements and their likely consequences (Mason & Moore, 1998).

It is possible to develop a Sorensen Network from known effects compiled through literature reviews of similar existing activities (Mason & Moore, 1998). Table 3 presents one example developed specifically for the provision of UES from UGI, connecting its effects to human well-being.

This was accomplished by adapting the classical cascade conceptual framework for ecosystem services (Haines-Young & Potschin, 2010), by interconnecting the concept of ecosystem functions (Szumacher, 2011) and landscape patterns (Alberti, 2005), to different types of UGI (Castellar et al., 2021), to the provision of UES (Costanza et al., 1997), and finally to their role as satisfactors of basic human needs (Aly et al., 2018; Max-Neef et al., 1998).

The resulting network effectively links UGI multifunctionality through a multilinear impact chain, where a single UGI generates multiple ecosystem functions, each of those functions impact on different UES, UEG or UED, which in turn can take the role of multiple satisfactors of human needs, so we do not look at solely one to one (1:1) interactions, but at one to many (1:n), many to one (n:1) and many to many (n:n) interactions, which better depicts the complex qualities of the UGI system.

As an example of how it should be read, taking an individual tree, and following its column we can see multiple marks, representing the different ecosystem functions that it can provide. Then follow a single function along the row, like biomass production, to the other side of the matrix, where it crosses with the UES, UEG or UED it regulates or provides. If we select one, like food production, and follow it to the next matrix, the multiple ways in which it can be a satisfactor are visible. Selecting one, like physical health and crossing to the final matrix, subsistence is the human need that can be fulfilled.

This exercise allows to represent in a clear manner the multifunctionality and complexity of the non-linear relations that exist between UGI and human well-being, thus avoiding a black-box effect.

Table 3. Sorensen Network linking human well-being to ecosystem services provided by common urban green infrastructure

Urban Green Infrastructure (Ecosystem structures)																																										
Spatial units								Technical units									Interventions																									
Individual tree	Lined trees	Mixed vegetation planter	Urban orchard	Urban garden	Botanical garden	Hedges	Green corridors	Green wall	Green facade	Vertical garden	Vegetated pergola	Infiltration well	Bioswale	Rain garden	Gren roofs	Permeable pavement	Composting	Soil improvement	Erosion control	Shelter for biodiversity	Use of native vegetation	Ecosystem functions																				
x	x	x	x	x	x	x	x	x	x	x	x		x	x	x					x	x	Trophic dynamics	Biotic	x					x		x											
x	x	x	x	x	x	x	x	x	x	x	x		x	x	x						x	Biomass production	Biotic	x	x				x	x								x		x		
x	x	x	x	x	x	x	x	x	x	x	x		x	x	x					x	x	Habitat availability	Biotic	x	x																	
	x					x	x															Noise barrier	Biotic				x									x						
x	x	x	x	x	x	x	x						x	x			x	x			x	Nutrients cycling	Edafo	x					x			x								x	x	
x	x	x	x	x	x	x	x						x	x		x		x	x		x	Soil stability	Edafo	x								x	x								x	
x	x	x	x	x	x	x	x	x	x	x	x		x	x	x				x		x	Air filtering	Climatic	x		x		x	x									x				
x	x	x	x	x	x	x	x	x	x	x	x		x	x	x						x	Temperature regulation	Climatic	x		x										x						x
x	x	x	x	x	x	x	x	x	x	x	x		x	x	x						x	Humidity regulation	Climatic	x		x										x						x
x	x		x		x	x	x				x											Shade projection	Climatic	x		x								x		x	x					
x	x	x	x	x	x	x	x						x	x		x					x	Water filtering	Hydro	x								x	x								x	
x	x	x	x	x	x	x	x					x	x	x		x		x	x		x	Water infiltration	Hydro	x								x	x								x	x
x	x	x	x	x	x	x	x					x	x	x	x						x	Runoff mitigation	Hydro	x								x	x								x	
x	x	x	x	x	x		x				x		x	x	x						x	Rainwater interception	Hydro	x									x									
			x	x	x										x						x	Social spaces	Conf				x								x	x	x		x	x		

Sociocultural																						
Comfortable spaces				x	x	x		x								x						
Aesthetic spaces	x	x	x	x	x	x	x	x	x	x	x	x				x						x
Interaction facilitation				x	x	x		x								x						
Participation facilitation					x	x										x		x	x	x	x	x
Product provision				x	x													x				
Products recycling																		x	x		x	

	Ecosystem services and disservices																		
	Sup		Reg								Cul						Pro		
Sociocultural	Biodiversity	Habitat connectivity	Microclimate regulation	Noise reduction	Air quality regulation	Carbon sequestration	Pollination	Pest control	Soil quality maintenance	Runoff regulation	Aesthetic pleasure	Connection with nature	Stress reduction	Creation of community	Allergens	Insecurity perception	Food production	Water infiltration	Water consumption
Comfortable spaces			x	x				x			x	x	x	x	x	x			
Aesthetic spaces	x	x									x	x	x	x		x			
Interaction facilitation			x	x				x			x	x	x	x		x			
Participation facilitation												x	x	x		x	x		
Product provision	x						x										x	x	
Products recycling						x	x		x								x		

	Ecosystem services and disservices																							
	Sup		Reg								Cul						Pro							
Satisfactors (Human benefits)	Biodiversity	Habitat connectivity	Microclimate regulation	Noise reduction	Air quality regulation	Carbon sequestration	Pollination	Pest control	Soil quality maintenance	Runoff regulation	Aesthetic pleasure	Connection with nature	Stress reduction	Creation of community	Allergens	Insecurity perception	Food production	Water infiltration	Water consumption					
Physical comfort			x	x	x					x					x		x			x				x
Physical health			x		x								x		x		x			x				
Emotional health			x	x							x	x	x	x		x				x				
Mental health			x	x							x	x	x	x		x				x				
Future subsistence	x	x	x		x	x	x		x								x	x	x		x			
Protection from natural hazards	x	x	x						x	x								x			x			
Environmental comfort	x	x	x				x	x	x	x								x	x		x			
Psycholgical comfort			x	x				x		x	x	x	x	x		x					x			
Active engagement														x			x						x	x
Passive engagement	x										x	x												x

																				Subsistence	Safety	Identity	Participation	Leisure
										x	x		x		x				Sense of belonging			x		
										x	x		x		x	x			Sense of place			x		
x	x					x	x			x									Aesthetic enjoyment					x
		x	x				x			x	x	x			x				Relaxation					x
		x	x				x			x	x	x			x				Tranquility					x
				x						x			x						Recreation					x
																				Human Needs (Value)				

Note. The Sorensen Network portrays the complex and multifunctional nature of the phenomenon, where interactions are not solely one-to-one (1:1). Instead, each 'x' mark represents an individual interaction, and the network illustrates various relationships, including one-to-many (1:n), many-to-one (n:1), and many-to-many (n:n).

2.3.4. SUSTAINABLE AND RESILIENT URBAN GREEN INFRASTRUCTURE

UGI plays an important role in addressing urban challenges due to their ability to provide a range of benefits and values for urban dwellers (Fors et al., 2021a). The work of McPhearson et al. (2015) effectively links the ideas of urban sustainability and resilience into the context of UGI management, by exposing the need to design and manage urban green infrastructure that is multifunctional and provides a wide range of urban ecosystem services to reach the persistence of these despite variability, disturbance and uncertainty, while seeking the planning of urban green infrastructure to develop in areas of high demand of urban ecosystem services, and reach resilience through them.

Despite constant development, there is still no consensus among researchers and practitioners regarding the best implementation approaches of UGI, which makes it difficult to develop a robust strategy to address them. Luckily, some basic principles to promote UGI sustainable and resilient planning and management have been identified (Monteiro et al., 2020). These are: connectivity, multifunctionality, applicability, integration, diversity, multi-scale, governance, and continuity, presented on Table 4.

Table 4. Basic principles for urban green infrastructure sustainable and resilient planning and management

Principle	Interpretation
Connectivity	Crucial to sustain values and services of natural systems. Aims to create a well-connected network that is useful for humans and other species.
Multifunctionality	UGI are capable to provide multiple economic, social, and ecological functions. A multifunctional UGI increases its resilience, synergetic effects, and effectiveness, especially when there is limited space.
Multiscale	UGI should consider local, landscape and regional perspectives to enhance interaction between scales.

Principle	Interpretation
Integration	Considers all connections and synergies between green and gray infrastructures.
Diversity	UGI emphasizes the quantity, quality and diversity of solutions presented to solve a specific issue.
Applicability	UGI planning must consider applicability, adaptability, and implementation of the project to avoid failing to achieve its goals.
Governance	Collaboration between the government actors and the citizens in the planning process. If the community does not feel integrated into the planning process, UGI will not succeed.
Continuity	To be effective, UGI require investment, management and updates, so a monitoring system with periodic reports should be implemented with the project.

Source. Monteiro et al. (2020)

2.3.5. MANAGEMENT OF URBAN GREEN INFRASTRUCTURE

The prevalent use of UGI as a concept in urban planning by local authorities have recently led to its intersection with management practices and, more recently, to the concept of governance as it pertains to management. Following the principles presented on Table 4, the first six ones relate mostly to the physical characteristics of UGI, however, the last two deal specifically with the governance of UGI.

Governance can be defined as "the constellation of stakeholders, institutions, rules, and processes of collective decision-making that allows stakeholders to influence and coordinate their needs" (Breen et al., 2020), however, UGI governance has little consensus with regards to its definition. It is common to treat UGI management as an umbrella term encompassing both traditional management practices and governance, understood as the involvement of actors external to the state.

This creates a spectrum with one side involving a diverse range of actors in decision-making processes, high participatory practices and "bottom-up" initiatives, and the other encompassing traditional, centralized, “top-down” government management (Breen et al., 2020).

Currently, a shift from government to governance in the management of UGI is slowly taking place, however in practice, governments still play an important role in the management and planning of UGI. There are multiple ways to govern over UGI, but a simple categorization based on the strongest actors is presented on Table 5, however, this is a non-comprehensive list, and as research and knowledge advances, new ideas for management emerge.

Table 5. Common types of urban green infrastructure management

Types of UGI Management	Description
Governmental led	Top-down management and soft participatory governance
Market-led	Where private actors adopt a leading role
Co-governance	Where multiple actors share more or less equally in the maintenance of the space
Self-governance	Initiatives that prioritize bottom-up decision-making from communities

Source. Breen et al. (2020)

UGI is generally developed through three consecutive phases: planning, design, and management. These practices typically apply a linear logic in which projects develop in a chronological and hierarchical order, from a plan set by authorities to more detailed designs realized through construction or planting, and with maintenance practices implemented at the end. However, and in line with the continuity principle (Table 4), a strategic approach to this linear logic requires reinventing it into a cyclic process, in which planning, design, construction and maintenance are viewed in a long-term perspective, where all phases are ongoing processes to better manage UGI (Fors et al., 2021a).

Managing for human well-being requires managing to enhance the production of ES, and is necessary even when there is uncertainty derived from incomplete controllability, complex internal feedbacks, non-linearity and insufficient understanding of nature and people (Birgé et al., 2016), Table 6 shows different management practices recommended considering the uncertainty and controllability inherent to a given system.

Table 6. Recommended management practices considering uncertainty and controllability

Uncertainty \ Controllability	Low	High
High	Scenario Planning	Adaptive Management
Low	Prepare	Apply best practice

Source. Birgé et al. (2016)

2.3.6. ADAPTIVE MANAGEMENT

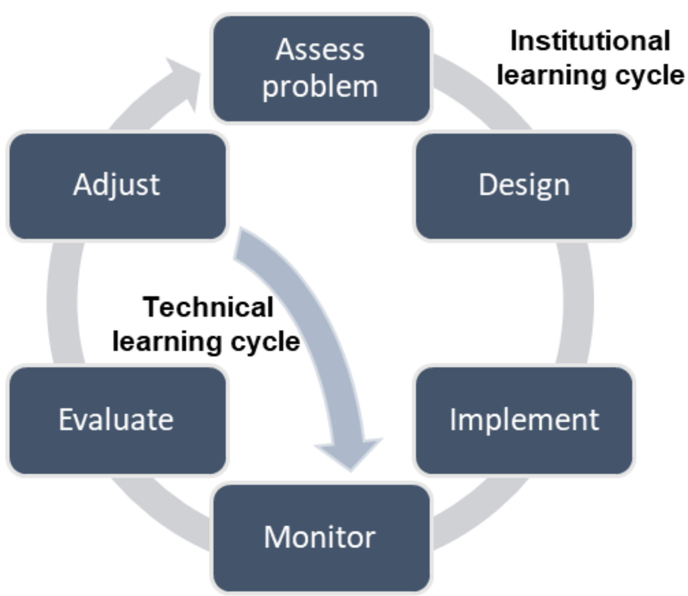
On the report of The Economics of Ecosystems and Biodiversity (TEEB) (2012) it is recommended to manage ecosystem services and biodiversity through cyclic and integrated management and planning and recommends that it consists of a baseline of appropriate information, participatory consultation to determine objectives, implementation of actions, monitoring, assessment, and results reporting. This results in a management methodology that is highly robust and responsive in the face of uncertainty.

These requisites are reunited in the term adaptive management (AM) defined as "to learn while managing, and to alter the management activities to reflect new information obtained" (Williams & Brown, 2016). This kind of management is applicable to systems where responsible people can't have a complete knowledge, either due to time, budget, or complexity constraints. AM allows the users to advance with a strategy that articulates and systematically reduces uncertainty.

This management style grew from Holling and Ostrom theories, precisely to tackle the challenge of managing complex, nonlinear, and dynamic ecosystems for which there was no data or experience. To do so, it introduced the idea of an adaptive cycle for learning and promoted the use of experimentation to gather information from the system (Figure 3).

The essential idea of AM is to recognize explicitly that management policies can be applied as experimental treatments, without pretense that they are sure to work, so that management becomes an active process of learning what really works (Hsu et al., 2020a). Some of the key elements of adaptive management are presented on Table 7.

Figure 3. Double loop adaptive management cycle



Source. Williams & Brown (2016)

Table 7. Adaptive management key elements

Key element	Description
Iterative learning	Emphasis on learning through the adaptive management cycle of ongoing monitoring, evaluation, and reflection. Knowledge gained on each iteration informs following decision-making.
Adaptability and flexibility	Should be able to adapt its structure to respond to uncertainty, changing conditions and new information gathered.
Experimentation	Testing different approaches, to expand the knowledge of the system through empirical evidence.
Stakeholder collaboration	Involvement of diverse stakeholders adds multiple perspectives to expand knowledge of the system through collective learning
Constant Monitoring and Evaluation	Systematic and rigorous monitoring and evaluation (M&E) of actions and outcomes to augment the knowledge of the system.

Source. Hsu et al. (2020b) and Razzaghi Asl & Pearsall (2022a).

A requisite for the proper implementation of AM, a specific institutional framework that deals with social and political dimensions that allow it to function is required. This framework is known as adaptive governance (Razzaghi Asl & Pearsall, 2022b). It integrates diverse formal institutions, informal groups and individual stakeholders in a collaborative manner that incorporates adaptive management principles in a nested, overlapping system. This network of stakeholders bolsters political, financial, and public support while also benefiting the process through horizontal and vertical information flow. This polycentric system enhances the capacity to manage the system by creating a collaborative structure for learning and experimentation, while providing a diverse source for ideas, expertise and informed decision-making while enabling broader levels of participation (Green et al., 2016a).

3. CASE STUDY: THE UASLP ZUP CAMPUS

3.1. A LEGAL CONTEXT FOR GREEN SPACES

Even when Mexican laws and regulations require a focus on human wellbeing that distillates from the Mexican Constitution itself, down to municipal regulations, and ecosystem services (ES) have the same final objective, there is no real connection between the two. These diffuse policies are reflected in deficient strategic and operational capacities at urban green infrastructure (UGI) management level inside the Latin America and the Caribbean region (Devisscher et al., 2022), resulting in an urban ecosystem management that does not comply with the good practices of promoting ecosystem sustainability and the provision of essential ES for society (Chapin et al., 2012).

A general overview of the legal framework currently governing over UGI in San Luis Potosí (SLP) is provided in Table 8.

Table 8 Overview of the legal framework governing over SLP urban green spaces

Level	Instrument
National	Mexican Constitution.
	General Law for Ecological Equilibrium and Environmental Protection.
	General Law on Climate Change
	General Law on Human Settlements, Land Use and Urban Development.
	National Development Plan
	National Program for Land Use and Urban Development
	Official Mexican Normative NOM-001-SEDATU-2021. On public spaces in human settlements.
State	Environmental Law for the State of San Luis Potosí
	Climate Change Law for the State of San Luis Potosí
	Law for the Protection and Conservation of Urban Trees of the State of San Luis Potosí.

Level	Instrument
	San Luis Potosi State Development Plan 2015-2021. The next one is in the process of approval.
	San Luis Potosi State Land Use and Urban Development Program.
Municipal	Construction regulations
	Ecology Regulation
	Parks and gardens regulations
	San Luis Potosi Municipal Land Use and Urban Development Program 2050

Source. Diario Oficial de la Federación (DOF) (1998, 2016); Ley General de Cambio Climático (2012); Plan Nacional de Desarrollo 2019 – 2024 (2019); Programa Nacional de Ordenamiento Territorial y Desarrollo Urbano 2021 - 2024 (2021); NOM-001-SEDATU-2021, Espacios Públicos En Los Asentamientos Humanos (2022); Reglamento de Construcciones Del Municipio de San Luis Potosí (1995); Reglamento de Parques y Jardines Públicos Del Municipio Libre de San Luis Potosí, S.L.P. (2002); Ley de Cambio Climático Para El Estado de San Luis Potosí (2015); Plan Estatal de Desarrollo 2015 - 2021 de San Luis Potosí (2016); Reglamento de Ecología Para El Municipio de San Luis Potosí (2016); Ley de Protección y Conservación de Árboles Urbanos Del Estado de San Luis Potosí (2017); Programa Estatal de Ordenamiento Territorial y Desarrollo Urbano de San Luis Potosí (2020); Programa Municipal de Ordenamiento Territorial y Desarrollo Urbano de San Luis Potosí, SLP 2050 (2021); Ley Ambiental Del Estado de San Luis Potosí (2021); Programa de Fomento a La Planeación Urbana, Metropolitana y Ordenamiento Territorial 2019 (2019); Poder legislativo (1917)

3.2. THE INSTITUTIONAL CONTEXT OF THE UNIVERSITY

At the Universidad Autónoma de San Luis Potosí (Autonomous University of San Luis Potosí, UASLP), the Agenda Ambiental (Environmental Agenda, AA) is an organization created with the explicit mission of articulating strategies to reach sustainability inside the university and society through the multidisciplinary integration of 4 pillars: education and research, institutional management, linkages and projects, and communication.

As part of its institutional management axis, the AA has implemented a Sistema de Gestión Ambiental (Environmental Management System, SGA), to improve the environmental performance of the UASLP in all its functions and transform it into a sustainable institution in conjunction with the community (Nieto-Caraveo & Medellín-Milán, 2004).

To reach its sustainable objectives, the institution has developed a set of programs, plans, procedures, and technical materials focusing on sustainability management. The main ones are presented in Table 9.

Table 9 UASLP institutional programs for sustainable management

Institutional Program	General Objective
Programa Universitario de Agua (University Program for Water, PUA)	Appropriate and integrated water management through technical aspects of efficiency, treatment, research, and innovation.
Programa Universitario de Energía (University Program for Energy, PUE)	Good use of energy, promoting sustainable urban mobility, electrical efficiency, and the strategy for the transition to renewable energies.
Programa Universitario de Residuos (University Program for Waste, PUR)	Create an institutional participatory culture of comprehensive and appropriate waste management.
Programa Universitario de Biodiversidad (University Program for Biodiversity, PUB)	Integrally manage the flora and fauna found in the spaces and gardens of university campuses in a sustainable and respectful manner.

Source. Universidad Autónoma de San Luis Potosí (UASLP) (n.d.)

3.3. The Program for Biodiversity

Strategic plans often regulate, orient, and coordinate the objectives and proposals of other plans, and thus, serve as reference for decisions taken at local level, including the implementation of UGI related projects (Grădinaru & Hersperger, 2019). Inside society, universities are a key element for the development and implementation of different actions and programs that foster the creation and habilitation of functional spaces to preserve biodiversity (Buendía-Oliva et al., 2021).

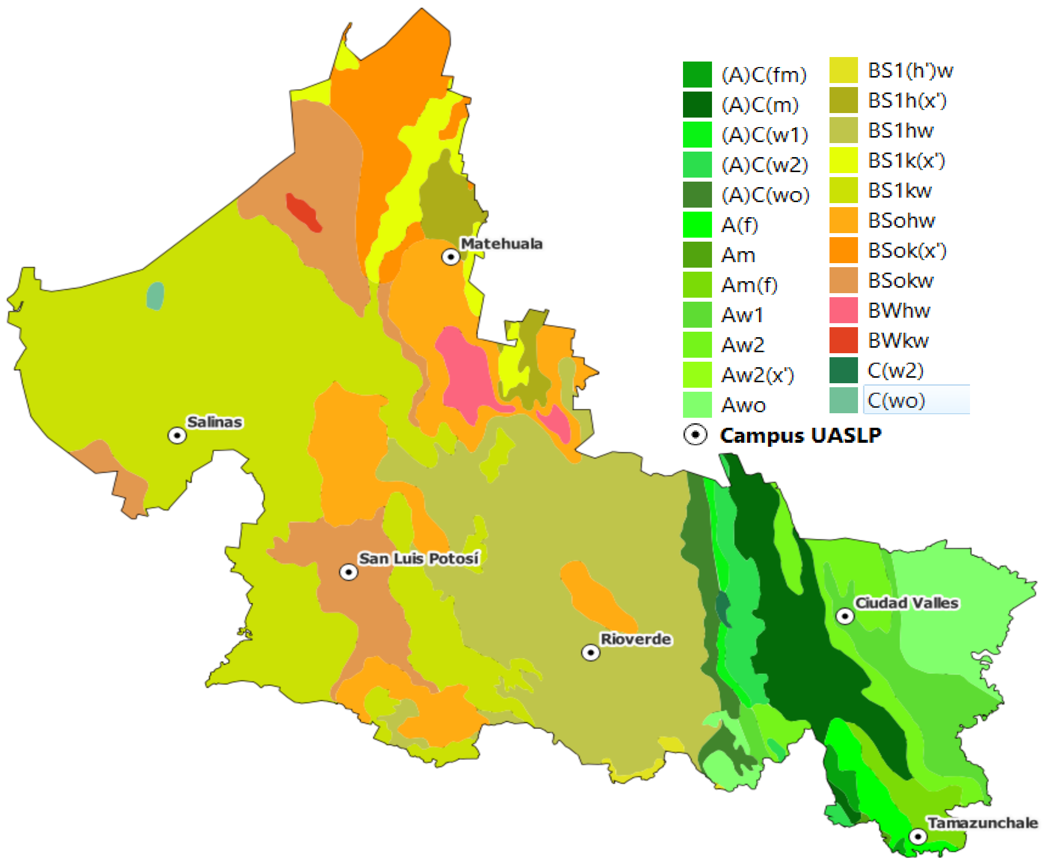
One of the many programs devised by the AA is the PUB, whose general objective is “to integrally manage the flora and fauna found in the spaces and gardens of university campuses in a sustainable and respectful manner”. (Universidad Autónoma de San Luis Potosí (UASLP), n.d.)

Considering that the UASLP has interest and capacity for action, shown by implementing these programs in all its campuses state-wide, and that as can be seen in Figure 4 as a whole they cover a vast number of social and ecological contexts, it needs to design a strategy that can be applied in urban areas with different geographical extent, population size and climatic conditions.

However, an internal baseline report shows that the management of green spaces inside the PUB is inefficient in its current form (Buendía-Oliva et al., 2021).

UGI is currently managed via the Guía de Jardines Universitarios (University Gardens Guide), which specifies some activities for gardeners and other workers, while assuring they have continuous education imparted by the AA and the University’s Civil Protection Department. Some tools like incident and accident reports have been implemented, but in general, it is concluded that there is a need to develop a yearly schedule and assessment of activities, which should consider phytosanitary vulnerability of each specimen, and to expand the roster of specialized personnel to attend the different problems that could potentially arise.

Figure 4. UASLP campuses and their climatic context



Note. Climatic classification adapted for Mexico by Köppen-García (1998).

3.4. The campus

The Zona Universitaria Poniente (Western Zone, ZUP) campus is located in the capital of the state: the city of San Luis Potosí, as can be seen on Figure 5, and it has been selected as a case study because it is the main campus of the institution, holds the majority of the student population, is located on the biggest metropolitan area inside the state, has the most information available, as well as a great variety of installed urban green infrastructure, as can be seen in Figure 6.

Figure 5. UASLP ZUP campus location

Figure 6. UASLP ZUP campus architectural plan

Note. Urban green infrastructure highlighted in green.

A basic ecological description for the ZUP campus is presented on Table 10 to provide a biophysical context for the research study.

Table 10. ZUP campus ecological description

Factor	Description
Type of climate	BS_0kw arid temperate, according to Köppen-García (1998)
Average annual temperature	17.4 °C
Average annual precipitation	392.1 mm
Geology	Alluvial / Acid extrusive igneous rock
Physiography	Province: "Central Mexican plateau" Subprovince: "Sierras and plains of northern Guanajuato" Topography system: "High steep mountain range with plateaus"
Altitude	1880 – 1900 m. s. n. m.
Slope	1.0 – 5.0 %
Edaphology	Phaeozem and Xerosol, of medium texture
Hydrography	Hydrological region 37 "El Salado", basin G "P. San José – Los Pilares y otras", sub-basin b "P. San José"
Runoff	10.0 – 20.0%
Acuifer	2411 San Luis Potosí: overexploited, in deficit and polluted
Geohydrology	Non-consolidated material with high yield
Land use and vegetation	Urban area

Source. Instituto Nacional de Estadística y Geografía (INEGI) (2023) and Servicio Meteorológico Nacional (SMN) (2023)

According to an estimation generated through geographic information systems (GIS) software, the campus has a total surface area of 162,635.9 m^2. Contrasting this information with a survey of the university's green spaces, the ZUP campus areas are allocated as shown in Table 11 (Picos-Benítez & Rodríguez-Robledo, 2010). For the 2022 – 2023 cycle, the campus holds a population of 13612 students, segregated on Table 12.

Table 11. ZUP campus green and gray areas

ZUP campus	Area (m^2)	Percentage (%)
Green areas	28,620.30	17.59
Gray areas	134,015.60	82.40
Total	162,635.90	100.00

Table 12. ZUP campus student population

School	Bachelor	Postgraduate	Total
Academic Coordination in Arts	153	0	153
School of Chemical Sciences	1802	182	1984
School of Nursery and Nutrition	1228	62	1290
School of Stomatology	979	114	1093
School of Engineering	4450	230	4680
School of Medicine	1013	678	1691
School of Habitat Sciences	2497	45	2542
Interdependency postgraduate	0	179	179
Total	12122	1490	**13612**

Source. Universidad Autónoma de San Luis Potosí (UASLP) (2022)

Selecting this specific campus as a case study has the additional advantage of having a robust information baseline, since either it or its surrounding area has been subject to a variety of studies, guides and technical reports, which provides this research project with information regarding urban agriculture, pollinators, water consumption and vegetation characteristics (Buendía-Oliva et al., 2021; Martínez-Guzmán et al., 2021; Montes-Betancourt et al., 2020; Picos-Benítez & Rodríguez-Robledo, 2010). This provides a unique opportunity to reframe this space as a resilient community against climate change, that is functional to help preserve the Mexican biodiversity (Buendía-Oliva et al., 2021).

4. METHODOLOGICAL FRAMEWORK

4.1. PROTOCOL DESIGN

As a social-ecological phenomena, ecosystem services management is subject to both, qualitative and quantitative assessment methods, so the devised tool must be created with a mixed-method approach in mind for it to be a robust instrument.

Mixed methods design can be done following different strategies depending on the timing of data collection, the weight given to qualitative and quantitative data, the way that the data will be mixed and the theoretical perspectives that surround it (Figure 7).

Figure 7. Key aspects for planning a mixed method design

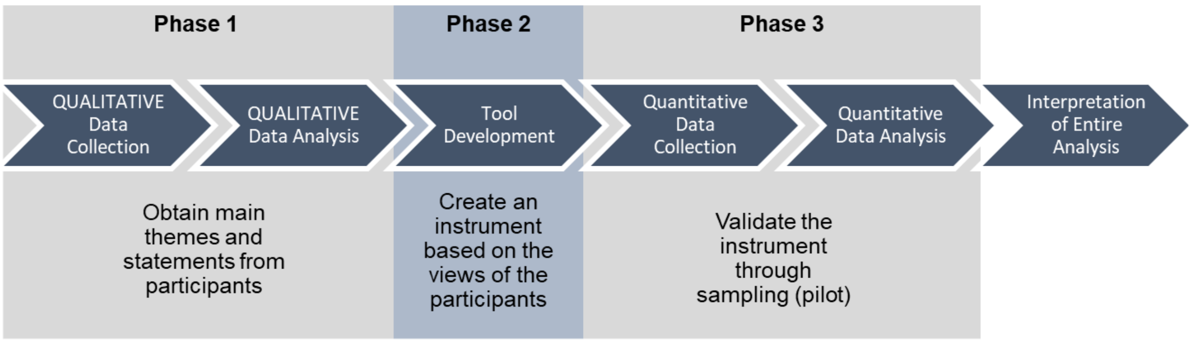
Timing	Weighting	Mixing	Theory
Concurrent	Equal	Integrating	Explicit
Sequential (qualitative first)	Qualitative	Connecting	Implicit
Sequential (quantitative first)	Quantitative	Embedding	

Source. Creswell (2009)

The sequential exploratory strategy is a common way to develop a new tool or instrument. Using a three phases approach, the first step is to gather and analyze qualitative data, the second step is identifying specific items or themes to develop the instrument, and the final step is quantitative validation and assessment (Creswell, 2009).

This strategy follows a sequential qualitative-first timing, giving extra weight to qualitative data. The way of mixing is through connecting, as each iteration of data gathering feeds the next one, and it may or may not be embedded into an explicit theoretical perspective.

Figure 8. Research design



Source. Creswell (2009)

Translating this design strategy into the context of a tool devised to manage urban green infrastructure (UGI) based on ecosystem services (ES), the basic structure of the protocol will be built on qualitative data, which will be used to design the main tool. Afterwards, it will be validated through a pilot run, where quantitative data will be gathered in the form of surveys and biophysical indicators. The interpretation will be carried out as a discussion on the applicability of the protocol (Figure 8).

4.2. PROTOCOL VALIDATION

Validation will be done through a pilot run for the case study: the Universidad Autónoma de San Luis Potosí (Autonomous University of San Luis Potosí, UASLP) Zona Universitaria Poniente (Western Zone, ZUP) campus.

4.2.1. DATA ACQUISITION AND SAMPLING

For the implementation of the pilot, some information needs to be acquired. For this, a few strategies have been selected to take advantage of the institutional capacities given by the case study.

- ***EXISTING DATABASES***

The UASLP's Agenda Ambiental (Environmental Agenda, AA), through their multiple Programs have developed some robust databases (Buendía-Oliva et al., 2021; Martínez-Guzmán et al., 2021; Montes-Betancourt et al., 2020; Picos-Benítez &

Rodríguez-Robledo, 2010), so they can provide specific information regarding the following aspects inside the ZUP campus.

1. Total annual food production at the Unihuerto.
2. Total annual water consumption for irrigation purposes.
3. Total vegetation census, considering some key characteristics like geographic location (lat, long), scientific name identification, total height, canopy cover, crown health and native ecosystem.
4. Study on the diversity of pollinators found in near parks (Morales Park, Tangamanga I Park and Tangamanga II Park) taxonomically identified by Family.

Mexico has a strong history of recording and releasing free robust online databases. The Instituto Nacional de Estadística y Geografía (National Institute of Statistics and Geography, INEGI) (2023), publishes thematic ecological raster and vector data, typically on a scale of 1: 50,000. Biophysical information on climate type, geology, physiography, topography, edaphology, surface hydrology, subterranean hydrology and land use will be retrieved and analyzed as needed for the study area using GIS software.

The Servicio Meteorológico Nacional (National Meteorological Service, SMN) (2023) provides a network of 5,400 meteorological stations, which preserve a historical record of annual average temperature and precipitation, among other variables. The values for the station 24111 SLP (SMN) will be retrieved and used, due to it being the nearest one to the study area.

- ***EXPERT CONSULTATION THROUGH THE DELPHI METHOD***

This method is composed of an iterative sequence of questionnaires distributed to selected experts and supervised by a coordinator. The first round usually is composed of open-ended questions to probe possible answers, subsequently the panelists are provided with anonymous feedback of all responses. Participants reflect on these opinions as they answer the next questionnaire, and this process is repeated until reaching a consensus.

The four defining elements of the method are: anonymity of participants which gives them freedom of opinion, the multiple iterations to allow panelists to reconsider previous answers, controlled feedback in the form of aggregated statistics of the responses obtained, and the statistically aggregated group responses. At the end of the exercise the group opinion is taken as the statistical mean of all the panelists opinions.

The process starts with the selection of the panel of experts. To do this, the competencies that qualify an expert must be defined and then the individuals that fill the required knowledge must be identified (Hirschhorn, 2019).

Due to the academic setting where the present study is being carried out, the desirable competencies for expert selection will be based on academic merit (graduate degree on the subject of interest), research merit (academic research on the subject of interest) and/or work experience (determined by work position and experience).

For the expert consultation, the ideal panel size is between 10 and 15 members, and a commonly used percentage to call “consensus” is 70% agreement. The criterion for selecting the experts is defined as: variety of roles, variety of academic disciplines and/or work positions, and prominence on the field (Olsen et al., 2021).

Identification and selection of individuals will be based on a sampling method based on “types of actors”, followed by “snowball sampling” to fill in potential gaps. The former seeks to meet representativeness in terms of different perspectives by selecting actors with a diverse range of experiences, while the latter is based on asking the first selected individuals for recommendations of other potential participants.

The first actors were pre-selected using the “types of actors” method based on their direct relation with the implementation of this pilot, namely the AA director, the SGA coordinator, and the PUB manager.

For the “snowball sampling” part, each of them will be asked to recommend experts based on variety of roles, variety of academic disciplines and/or work positions, and prominence on the field. Table 13 shows a list of related disciplines and positions that relate to the study of urban green infrastructure and ecosystem services that was presented to them as reference.

Table 13. Reference list for expert selection

Role		Discipline / Position	Prominence
Academic	1	Urban ecology and forestry	Manager of the PUB.
	2	Entomology and pollinators	To be determined
	3	Integrated natural resources management of arid zones	To be determined
	4	Integrated water resources management of urban areas	To be determined
	5	Water supply and irrigation infrastructure	To be determined
	6	Geology and soil quality	To be determined
	7	Climatology and atmospheric pollution	To be determined
	8	Architecture and urban design	To be determined
	9	Social participation, governance, and urbanization	To be determined
	10	Nutrition and health	To be determined
Administrative	11	AA representative	Director of the AA.
	12	SGA representative	Operative coordinator of the SGA
Operative	13	Urban garden representative	To be determined
	14	Green spaces maintenance services representative	To be determined
External	15	UGI Management expert	To be determined

The methodology will be adapted by offering a list of possible answers based on a previous literature review, which reduces the necessary rounds, and using electronic tools for communication, considering that all the participants are part of the UASLP and have an institutional e-mail account and free internet access inside the installations. This decision is made to create a process that can be easier and more convenient for all the involved participants (Olsen et al., 2021).

To expedite the discussion, a pre-selection of 19 UES and UED of interest was developed. Using this list as a basis, the first questionnaire was designed with the objective of identifying priority ecosystem goods, services and disservices or adding or removing elements of the list (Annex A).

The expected result is a list of relevant UES and UED for the specific area of study. This information will be compiled and analyzed both quantitatively and qualitatively. The summarized results will be forwarded as feedback to all participants.

Subsequently, a second expert consultation will be conducted to obtain a list of proposed urban green infrastructure (UGI) interventions. For this, a pre-selection of 27 UGI units or interventions was developed. Using this list as a basis, the second questionnaire was designed with the objective of identifying priority UGI interventions. An aerial image of the ZUP campus extracted from Google Maps was offered to the experts to obtain the proposed spatial allocation of their selected interventions (Annex A).

The expected result is a list of relevant and spatially localized UGI units or interventions for the specific area of study. This information will be compiled and analyzed both quantitatively and qualitatively to obtain the preferred interventions.

- ***PARTICIPATORY MAPPING THROUGH ONLINE SURVEYS.***

Considering that the target population of this study is mainly composed of students attending to the UASLP ZUP campus, that all of them have access to an institutional e-mail account provided by the University, and that the facilities offer free internet access, it was decided that the collection of geospatial information from the public would be done through a web platform.

The *Spraycan* platform available through the *Map-Me (mapping meanings)* website (http://www.map-me.org) is a free platform that allows the design and execution of participatory mapping using the Google satellite imagery view, as well as the download and management of the generated geospatial information in a simple manner (Huck et al., 2014).

Some UES and UED, mainly cultural ones, are appreciated by the population in a spatially diffuse manner. The aerosol-like interface used by this tool allows addressing this problem by eliminating the restrictions of defined spaces.

The participatory mapping survey was designed to be sufficiently simple, with a brief introduction and easy-to-follow instructions. The survey's design is presented in the Annex A.

The participatory mapping survey will be sent directly to the total student population enrolled at the ZUP campus. So, considering a completely randomized sampling for a total population of 13612 individuals, and following a simplified formula for sample size determination in survey research, where for continuous variables like open-ended questions it assumes a value of p=4 and e=0.03 (Adam, 2020), it follows that:

$$n = \frac{N}{1 + N\varepsilon^2}$$

Where:

n= minimum returned sample size

N= total population size

ε = adjust margin of error

$$\varepsilon = \frac{pe}{t}$$

Where:

p= number of standard deviations that would include all possible values in the range

t= t-value for the selected alpha level or confidence level at 95%

e= the degree of accuracy expressed as a proportion.

$$\varepsilon = \frac{4(0.03)}{1.96} = 0.0612$$

$$n = \frac{13612}{1 + 13612(0.0612)^2} = 216.8551$$

So, to get a result with a 95% level of confidence, we need to collect at least 217 valid student responses.

The survey will be sent electronically to the University's community, utilizing the official communication channels of the AA. A common minimum completion threshold of 70%, so only those surveys that reach this percentage will be considered as valid input data for the research.

4.2.2. DATA MANAGEMENT.

- ***DATA CLEANING AND ORGANIZING.***

Collected data will be checked for it to comply with certain basic standards to allow for easier processing and transformation.

- All collected data must be presented using metric units, species scientific names and geographic coordinates (lat, long).
- Surveys and consultation data must be identified per individual or participant.
- For the participatory mapping data, all answers will be compiled on a single MS Excel database, the responses that don't fulfill the 70% completion mark will be discarded.
- For the expert consultation data, all answers will be transcribed on a single MS Excel database, where response rate must be reported.
- For the instruments review, all data must be compiled on a single MS Excel database.
- Ensure that all databases share common headers and labeling terminology for easy processing and analysis.

All data that do not comply to these basic rules will not be considered for this research.

- ***DATA ANALYSIS***

Total vegetation census data will be uploaded into the i-Tree Eco software, as an MS Excel database. Following the requirements of its field guide (US Forest Service, 2019), the information collected should include as a minimum:

- species scientific name
- georeferenced location (lat, long)
- diameter at breast height (DBH)
- total height of the individual
- crown width (X and Y axis)
- height to crown base
- crown health

The software automatically calculates vegetation composition, change in air pollutants concentration, oxygen and VOC production, carbon sequestration, rain interception, evapotranspiration, avoided runoff and an allergy index, for each individual tree plotted. This data will be extracted from the software as a .CSV file and analyzed using GIS software to create point maps and interpolation maps (Burkhard & Maes, 2017).

Once compiled, all biophysical data regarding ecosystem services will be processed, and presented using maps, tables, or charts, depending on the specific service, to be analyzed both spatially and statistically (Liu et al., 2017).

For the participatory mapping data, and to assure equal weighting of all participants perceptions, the inverse of the total number of points allocated per user will be calculated. Each data point will then be scaled by this value, providing a unique scale for each participant's contribution. This approach guarantees that despite varying point allocations by individuals, each participant input carries the same weight.

This weighted data will be analyzed spatially using GIS software and heatmaps or density maps will be produced to identify areas of high interest or demand (Burkhard & Maes, 2017).

All expert consultation data will be transcribed into a single database, where response rate will be reported. For the data analysis two approaches will be used.

First, for quantitative data, descriptive statistics like mean, median, standard deviation, highest value, or total score will be calculated and reported, depending on the context and needs of the specific question (Hirschhorn, 2019). For qualitative data obtained from open questions, content analysis will be carried out to find recurrent topics and categories of interest (Erlingsson & Brysiewicz, 2017).

These results will be shared with the experts in a summarized manner, preserving the anonymity of each respondent opinion, prior to the next survey.

5. RESULTS

5.1. THE DESIGNED PROTOCOL

A non-exhaustive literature review for management protocols of urban green infrastructure, green spaces, or similar was carried out, and an existing framework developed specifically for the Mexican context was found. It was developed in coordination with high impact institutional stakeholders like the Secretaría de Medio Ambiente y Recursos Naturales (Ministry of Environment and Natural Resources, SEMARNAT), the Secretaría de Desarrollo Agrario, Territorial y Urbano (Ministry of Agricultural, Territorial and Urban Development, SEDATU) and the Deutsche Gesellshaft für Internationale Zusammenarbeit (German Agency for International Cooperation, GIZ) published in the report “Integrating ecosystem services on urban planning and management”, created inside the framework of the “Climate protection on urban Mexican politics” program between Germany and Mexico (Deutsche Gesellschaft für Internationale Zusammenarbeit, 2019).

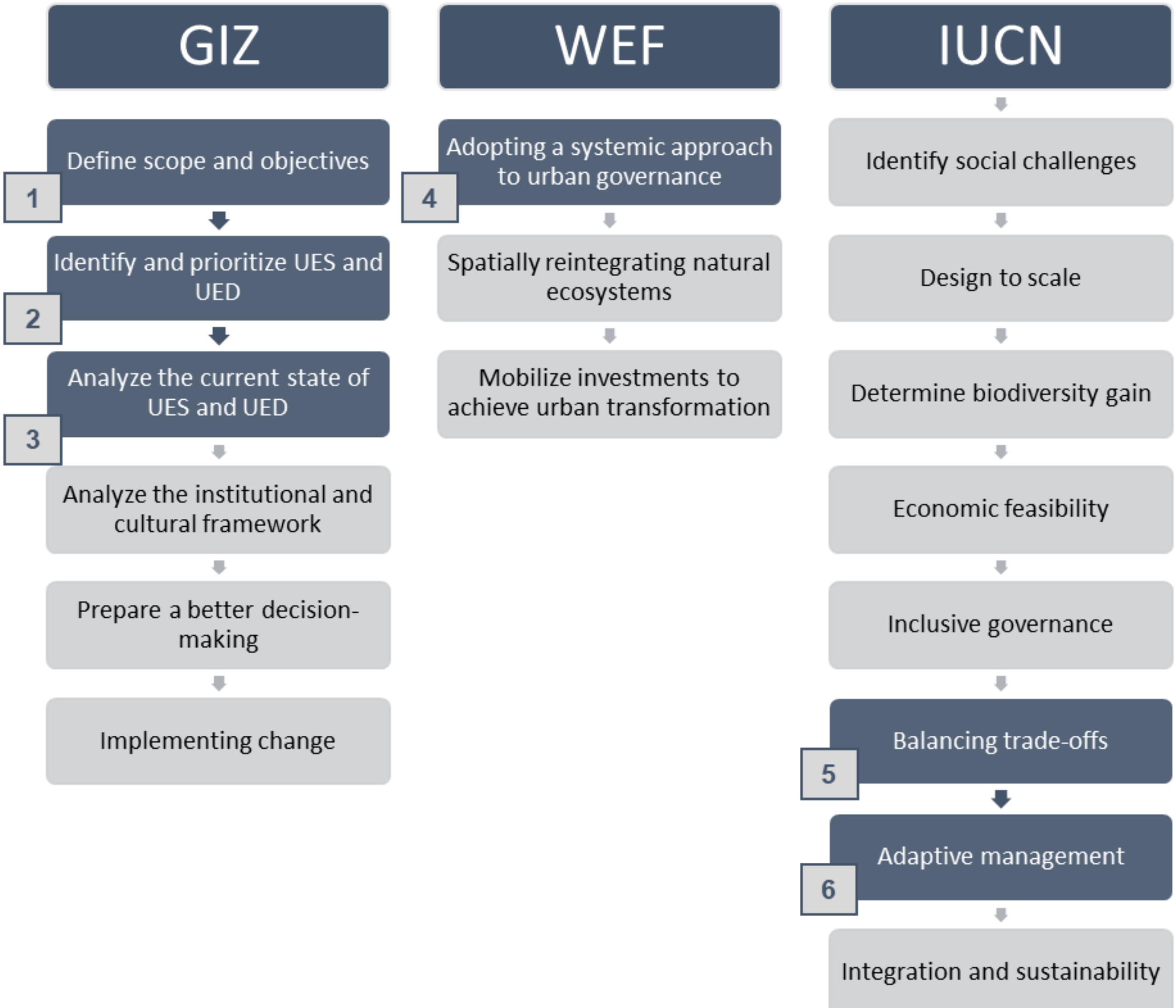
Due to these important characteristics, the existing document was selected as a basis for the development of this tool. However, since this method was developed to support political decision-making, its scope is not completely suitable for the context of this research and requires a few modifications.

The first adaptation originates in the framework of the “BiodiverCities by 2030” program developed for Colombia, which invites its users to adopt a systems approach to reach a coordinated and flexible urban transformation, spatially integrating natural ecosystems inside the Latin American context (World Economic Forum (WEF) & Alexander von Humboldt Biological Resources Research Institute, 2022).

The second adaptation was taken from the framework “Global standard for nature-based solutions”, which is a robust tool specific for nature-based solutions design and verification, focusing on adaptive management (International Union for Conservation of Nature and Natural Resources (IUCN), 2020).

Figure 9 presents the different instruments used and the steps that were selected for the development of the tool.

Figure 9. Instruments used for the design of the protocol



Note. every step for each instrument is displayed, but the ones selected for the protocol design are highlighted in blue.

Table 14 shows how the implementation of these modifications, namely a systemic vision, participatory approach, and adaptive management, provides a compelling framework for this tool, by incorporating the eight principles for sustainable and resilient urban green infrastructure (UGI) planning and management (Monteiro et al., 2020).

Table 14. Integration of the principles for sustainable and resilient urban green infrastructure planning and management into the design of the protocol

Principles	Integration
Connectivity Multifunctionality Multi-scale Integration	Systemic vision
Governance	Participatory approach
Diversity Applicability Continuity	Adaptive management strategy

Source. based on Monteiro et al. (2020)

The resulting tool integrates the previously mentioned characteristics in a logical sequence, adequate for its implementation on a small-scale, university campus context. Table 15 presents a general overview of each devised step and Figure 10 shows a general diagram of the protocol, highlighting its iterative nature through the adaptive management double loop. The full protocol can be found in Annex B.

Figure 10. Diagram of the designed protocol

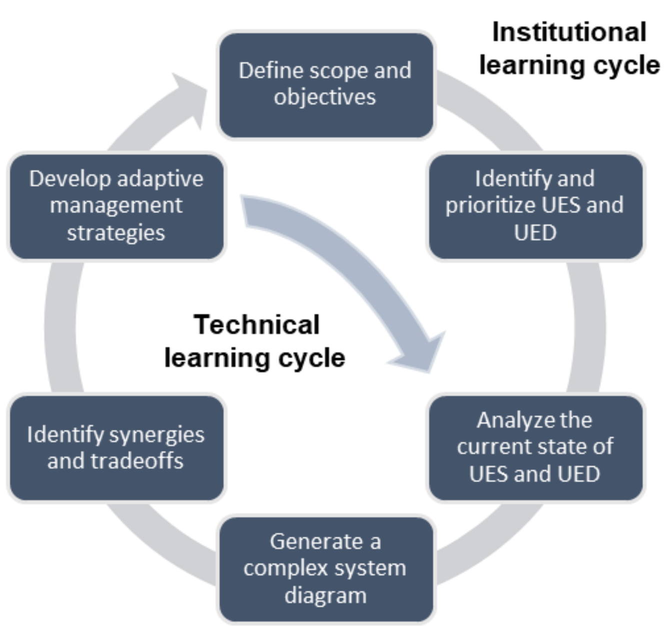


Table 15. Overview of the designed protocol

Step		Overview
Specific objective 1	Define scope and objectives	Objectives will be taken from the institutional agenda. Geographic scope will be done through the categorization of urban green infrastructure by configuration and type. Main actors will be identified and classified by interest and influence (Deutsche Gesellschaft für Internationale Zusammenarbeit, 2019). **Final product is the categorization of main components.**
	Identify and prioritize UES and UED	Based on e-Delphi methodology (Olsen et al., 2021) Selection of a group of experts through "type of actors" and "snowball" sampling, based on roles and experience. Data will be gathered and given to them based on a literature review. **Final product is a prioritized list of urban ecosystem services and disservices, their indicators and chosen methods of evaluation.**
Specific objective 2	Analyze the current state of the UES and UED	**Demand and provision** When possible, data gathering from literature review. When necessary, sampling or surveying using specific methodologies per ecosystem service or disservice. Indicators calculation. **Statistical analysis** (Liu et al., 2017) Correlation matrix comparing urban ecosystem services. Determination matrix comparing urban ecosystem services and urban green infrastructure. **Spatial analysis** (Burkhard & Maes, 2017) Elaboration of cartography for provision and demand of ecosystem services.

<table>
<tr><th colspan="2">Step</th><th>Overview</th></tr>
<tr><td rowspan="2">Specific objective 3</td><td>Generate a complex system</td><td>Identification of main components using a matrix based on key questions (Elia et al., 2020). Interrelations and goal of the system will be inferred.

Final product is a diagram of the complex system.</td></tr>
<tr><td>Identify synergies and tradeoffs</td><td>Identification of spatial shortfalls on the provision and demand of ecosystem services (Wong et al., 2018).

Creation of ecological production functions (EPF) through ordinary least square (OLS) regression.

Calculation of marginal values through regression coefficients.

Final products are spatial shortfall maps and ecological production functions for each urban ecosystem service or disservice.</td></tr>
<tr><td>Specific objective 4</td><td>Develop an adaptive management strategy</td><td>Based on the structured decision-making methodology (Robinson et al., 2016).

a) Problem statement. Taking the institutional objectives as basis.
b) Definition of objectives and management strategies. Use of e-Delphi to determine fundamental objectives, subobjectives and management alternatives based on identified shortfalls.
c) Consequences. Modelling of management alternatives using EPF.
d) Optimal decision. using e-Delphi to assign different weights to the assessed alternatives and calculating the expected utility value for each one, selecting the optimal. (Wong et al., 2018)
e) Monitoring. Develop a set of indicators for monitoring based on the methodology of (TWB. 2009. Making Monitoring and Evaluation Systems Work. A Capacity Development Toolkit, n.d.)
f) Learning. Through the application of a double loop of learning.

Final product is an adaptive management strategy.</td></tr>
</table>

5.2. THE VALIDATION OF THE PROTOCOL

The tool will be validated at the Universidad Autónoma de San Luis Potosí (Autonomous University of San Luis Potosí, UASLP) Zona Universitaria Poniente (Western Zone, ZUP) campus to identify practical issues, challenges, or areas of opportunity. Due to time and resources constraints, it is impossible to run the whole protocol for this first iteration, so some adjustments need to be done.

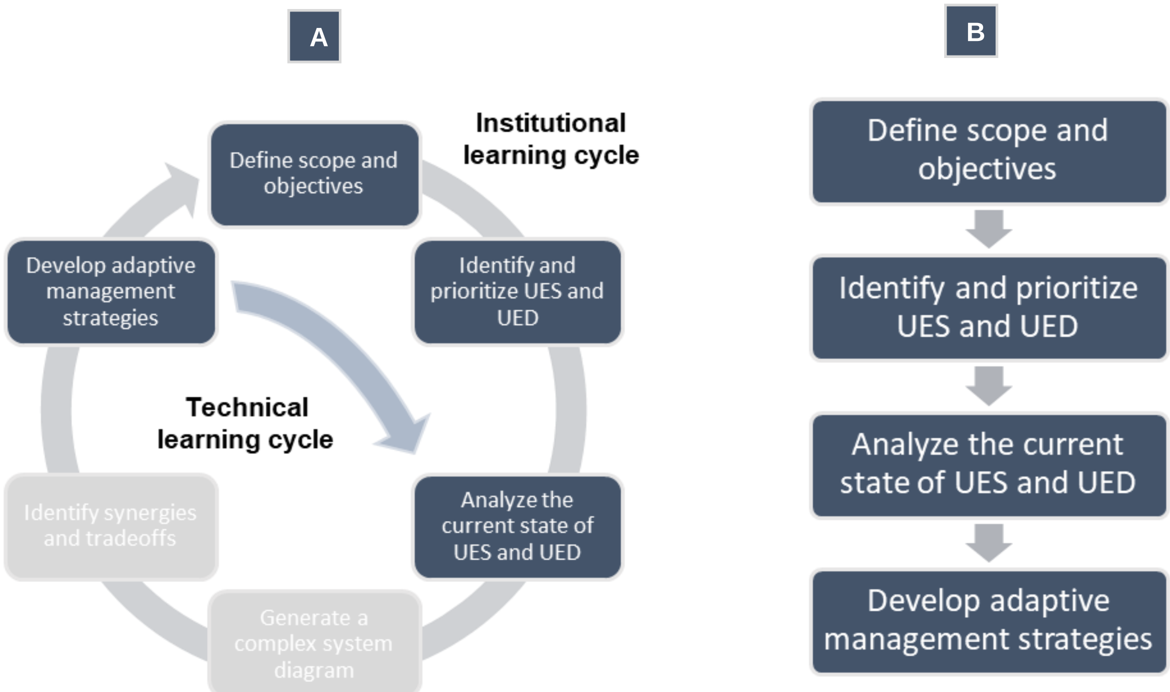
Considering that creating a baseline is a key step in developing a successful strategy, the focus of the pilot will be the identification, prioritization, and analysis of the urban ecosystem services (UES) and urban ecosystem disservices (UED) provision and demand. Steps 4 and 5, namely the complex system diagram and the synergies and tradeoffs analysis won't be carried out due to time and budget constraints, so the final expert consultation will be done with this reduced information.

According to this, the adaptive strategies will be developed by contrasting the information on UES and UED provision and demand provided by experts and students and supported by a literature review.

It is understood that due to the adaptive nature of the tool, it will develop and change through iterative technical learning cycles to better adapt to fulfill its objective, so this pilot test will be considered as the first iteration of the institutional learning cycle, and the information gathered will serve as a basis for its future development.

Figure 11 presents a diagram showcasing the steps of the protocol that will be carried out. Figure 11-A demonstrates that the pilot is embedded inside an adaptive management strategy that is intended to be continuous, and how the developed strategies will be implemented on a technical cycle of constant monitoring and learning, with periodical cycles of institutional learning. Figure 11-B highlights the standalone project nature of the pilot run, as a research project for the development of this thesis.

Figure 11. Diagram of the pilot test



Note. (A) = Pilot run steps to be carried out, shown as part of a continuous adaptive management strategy; (B) = Pilot run steps to be carried out, shown as a standalone project, for this research.

5.2.1. Defining Scope and Objectives

The objective, obtained from the Programa Universitario de Biodiversidad (University Program for Biodiversity, PUB) is to integrally manage the flora and fauna found in the spaces and gardens of university campuses in a sustainable and respectful manner.

The main actors were identified by informal conversations with Agenda Ambiental (environmental agenda, AA) personnel and are presented on Table 16. The geographic scope is limited to the UASLP ZUP campus green spaces, as seen on Figure 6. Different urban green infrastructure (UGI) was identified inside the campus and is categorized on Table 17.

Table 16. Identification and categorization of main actors at ZUP campus

	Low interest	High interest
High influence	Researchers and academics	Administratives Operative workers
Low influence	Disengaged students	Engaged students

Table 17. Identification and categorization of urban green infrastructure at ZUP campus

UGI	Type	Configuration
Individual tree	Spatial arboreal unit	Punctual
Lined trees	Spatial arboreal unit	Linear
Sidewalk trees	Spatial arboreal unit	Linear
Small planters	Spatial mixed vegetation unit	Punctual
Hedges	Spatial mixed vegetation unit	Linear
Park	Spatial mixed vegetation unit	Group
Urban garden	Spatial mixed vegetation unit	Group
Green roof	Technological horizontal	Group
Use of native vegetation	Biodiversity Intervention	
Biodiversity shelter	Biodiversity Intervention	
Compost	Soil intervention	

5.2.2. Identification and Prioritization of UES and UED

The panel of experts was asked to select what they consider as priority ecosystem services or disservices inside the ZUP campus, along with indicators and specific methods for monitoring.

15 experts from an interdisciplinary background were selected, the types of actors were kept the same as presented in the methods section. Only 8 out of the 15 answered the survey, giving a 53.33% response rate. The summary of the first round on expert consultation is shown on Table 18.

Table 18. Expert prioritization of urban ecosystem goods, services, and disservices, with proposed indicators and methods

UES / UED	Score	Selected Indicator(s)	Selected Method(s)
Biodiversity	**7**	Species richness and diversity or Native species percentage.	Species composition list or Shannon-Weiner Diversity Index or Percentage of native species.
Air quality regulation	**6**	Change in air pollutants concentration (ppm).	Dry deposition of contaminants mathermatical model.
Pollinators	**6**	Pollinators diversity.	Shannon-Weiner Diversity Index.
Connection with nature	**6**	Incidence of experiences.	Participatory mapping.
Stress reduction	**6**	Incidence of experiences.	Participatory mapping.
Water infiltration	**6**	Infiltration capacity (m/h).	Infiltrometer or Estimation derived from soil texture.
Carbon sequestration	**5**	Carbon sequestered in biomass.	Allometric equations.
Microclimate regulation	**4**	Change in air humidity and temperature.	On-site sensors or Direct measurement at variable distances.
Noise reduction	**4**	Noise reduction in dB.	On-site sensors or Direct measurement at variable distances.
Soil quality maintenance	**4**	Percentage of soil organic matter.	Loss of mass through ignition.
Community creation	**4**	Incidence of experiences.	Participatory mapping.

UES / UED	Score	Selected Indicator(s)	Selected Method(s)
Water consumption	**4**	Water used above irrigation sheet (m3).	Install water flow meters in irrigation pipes or Calculate irrigation sheet.
Habitat connectivity	**3**	Structural connectivity index.	Calculate structural connectivity index.
Pests	**3**	Incidence of experiences.	Participatory mapping.
Waterflow regulation	**3**	Rain interception (m3) or Water runoff reduction (m3).	Rain interception mathematical model or Curve number mathematical model.
Aesthetic pleasure	**3**	Incidence of experiences.	Participatory mapping.
Food production	**3**	Number of products harvested (kg).	Annual production.
Allergens	**1**	Incidence of experiences.	Participatory mapping.
Perception of insecurity	**1**	Assessment for accidents caused by trees.	Participatory mapping.

Note. Ecosystem good or service (green) Ecosystem disservice (orange)

5.2.3. Analysis of the current state of UES and UED

The next step was the quantitative assessment of prioritized UES and UED. Due to time and budget constraints some of these couldn't be assessed. Even so, the majority of them could be evaluated to create a baseline of provision and demand. Table 19 presents a summary of the results.

Table 19. Baseline of urban ecosystem goods, services, and disservices the UASLP ZUP campus

UES / UED	Data source	Provision	Demand
Biodiversity	Total vegetation census	Number of trees and shrubs: 1,541. Natives 504 (32%). Species Richness: 62 Shannon-Wiener Index: 2.30 IVI and species composition	Spatial analysis of areas with low vegetation density (Figure 12)

UES / UED	Data source	Provision	Demand
		(Figure 13) Spatial analysis of areas with high vegetation density (Figure 12)	
Air quality regulation	Modelling through the i-Tree Eco software	Removal of 482.9 kg of pollutants annually. Production of 7.98 ton of oxygen annually. Production of 337.8 kg of VOC annually. Spatial analysis of areas with high pollutant removal, high oxygen production and low VOC production capacities (Figure 14)	Spatial analysis of areas with low pollutant removal, low oxygen production and high VOC production capacities (Figure 14)
Pollinators	Institutional report	Families Richness on near parks: Morales Park: 13. Tangamanga I Park: 15 Tangamanga II Park: 10 (Table 20)	Couldn't be assessed. *(Data inside campus missing)*
Connection with nature	Participatory mapping	Spatial analysis of areas with high density of responses (Figure 15)	Spatial analysis of areas with low density of responses (Figure 15)
Stress reduction	Participatory mapping	Spatial analysis of areas with high density of responses (Figure 15)	Spatial analysis of areas with low density of responses (Figure 15)
Water infiltration	*NA*	Couldn't be assessed. *(Soil texture data missing)*	Couldn't be assessed. *(Soil texture data missing)*
Carbon sequestration	*NA*	Couldn't be assessed. *(DBH data missing)*	Couldn't be assessed. *(DBH data missing)*
Microclimate regulation	Participatory mapping	Spatial analysis of areas with low density of responses (Figure 15)	Spatial analysis of areas with high density of responses (Figure 15)

UES / UED	Data source	Provision	Demand
Noise reduction	Participatory mapping	Spatial analysis of areas with high density of responses (Figure 15)	Spatial analysis of areas with low density of responses (Figure 15)
Soil quality maintenance	*NA*	Couldn't be assessed. *(Soil texture data missing)*	Couldn't be assessed. *(Soil texture data missing)*
Community creation	Participatory mapping	Spatial analysis of areas with high density of responses (Figure 15)	Spatial analysis of areas with low density of responses (Figure 15)
Water consumption	Institutional report	Considering a consumption of 5 l/m2 per day, the ZUP campus consumes 143.1 m3 of water every day for irrigation purposes. This is 52,232.04 m3 of water annually.	Couldn't be assessed *(data on water consumption per UGI missing)*
Habitat connectivity	*NA*	Couldn't be assessed. *(Satellite images missing)*	Couldn't be assessed. *(Satellite images missing)*
Pests	Participatory mapping	Spatial analysis of areas with low density of responses (Figure 15)	Spatial analysis of areas with high density of responses (Figure 15)
Waterflow regulation	Modelling through the i-Tree Eco software and the Curve Number Method	366.48 mm of runoff annually (96.77%) 1,233.9 m^3 of water intercepted annually. 213.2 m^3 of avoided runoff annually. Spatial analysis of areas with high water interception and avoided runoff capacities (Figure 14)	Spatial analysis of areas with low water interception and avoided runoff capacities (Figure 14)
Aesthetic pleasure	Participatory mapping	Spatial analysis of areas with high density of responses (Figure 15)	Spatial analysis of areas with low density

UES / UED	Data source	Provision	Demand
			of responses (Figure 15)
Food production	Institutional report	37.87 kg produced in 2021. 55.22 kg produced in 2022.	Couldn't be assessed *(data on food per UGI missing)*
Allergens	Modelling through the i-Tree Eco software	Allergy Index 5.4/10.0 (Medium class) (Table 21)	Couldn't be assessed *(data on allergenicity per UGI missing)*
Perception of insecurity	Participatory mapping	Spatial analysis of areas with low density of responses (Figure 15)	Spatial analysis of areas with high density of responses (Figure 15)

Note. Ecosystem good or service; Ecosystem disservice

Figure 12. Location and origin of trees and shrubs inside the UASLP ZUP campus

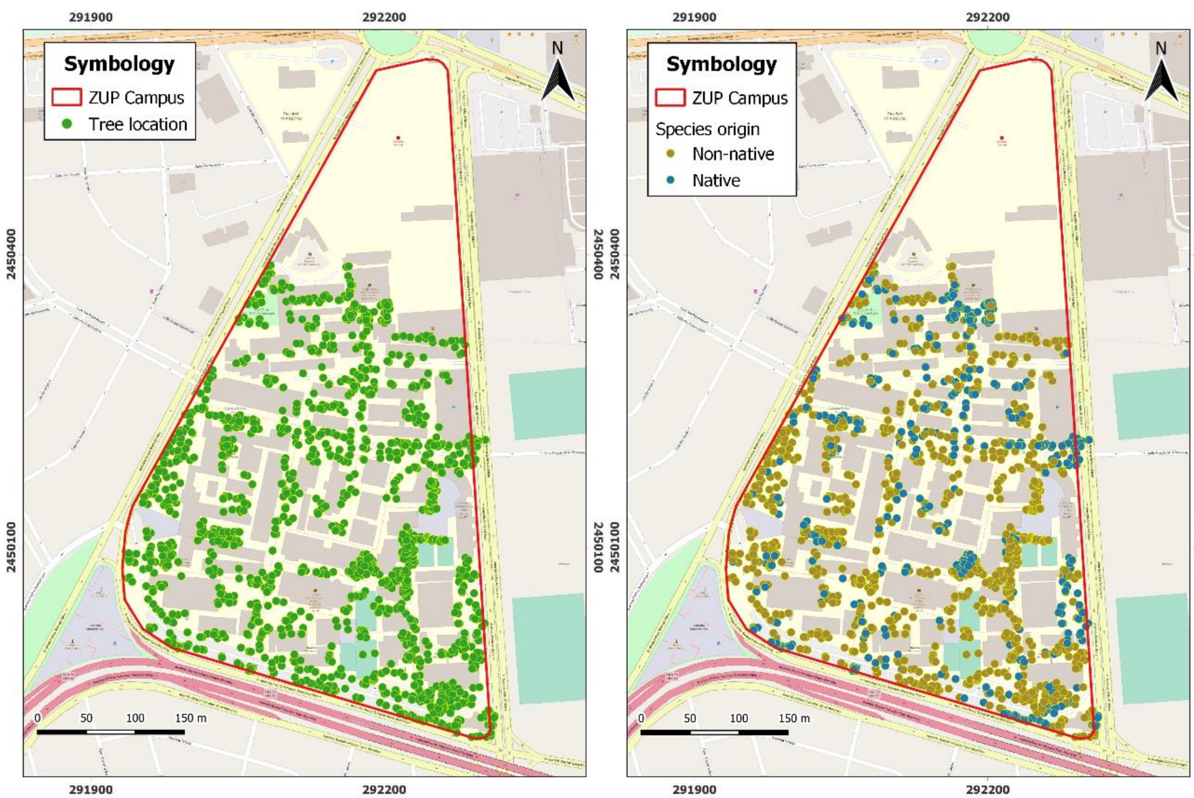
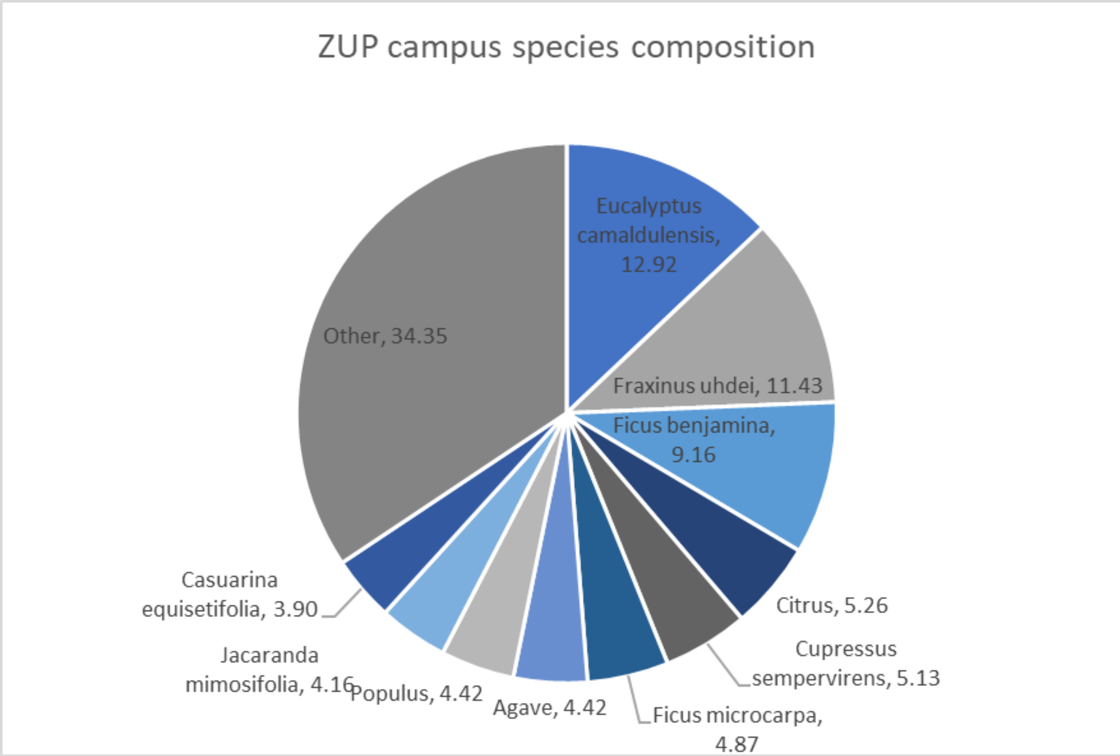


Figure 13. ZUP campus importance value index and species composition



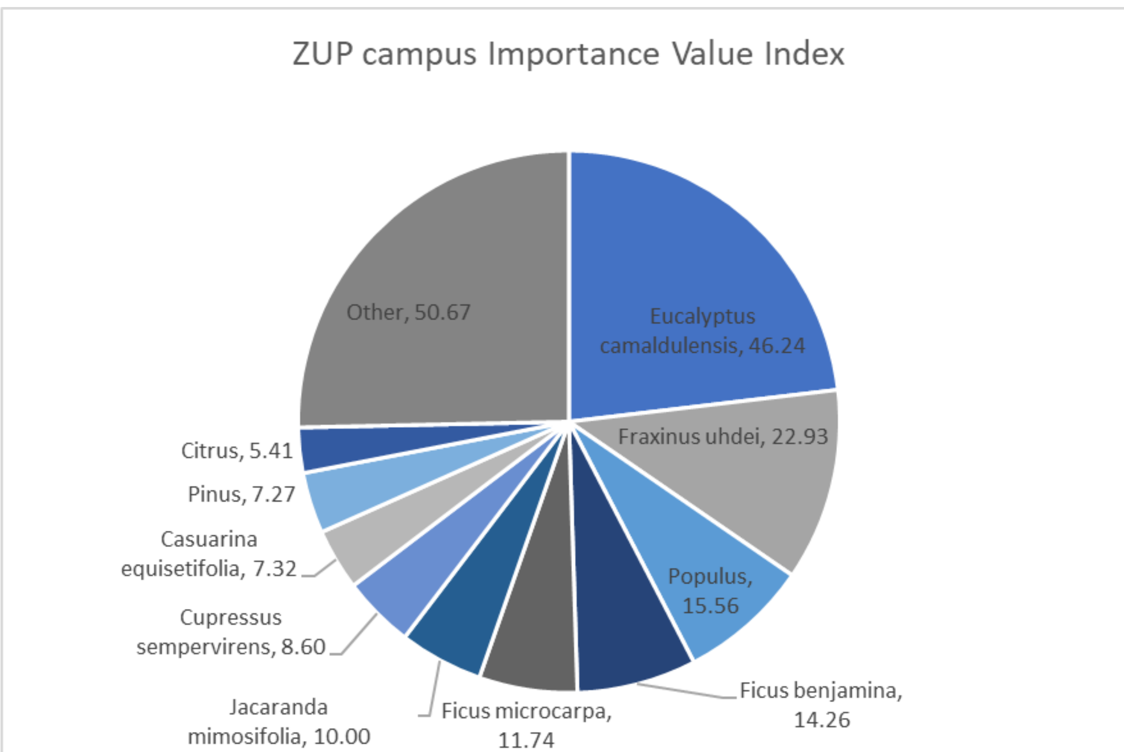


Table 20. Composition of pollinators found in parks near the ZUP campus

Morales Park	Tangamanga I Park	Tangamanga II Park
Dipetra		
Muscidae, Ulidiidae, Tephrifidae y Drosophilidae.	Muscidae, Ulidiidae, Tephrifidae y Drosophilidae.	Muscidae, Ulidiidae, Tephrifidae y Drosophilidae.
Hymenoptera		
Formicidae, Apidae y Vespidae.	Formicidae, Apidae y Vespidae.	Formicidae y Apidae
Coleoptera		
Coccinellidae y Scarabeidae.	Latreille, Correidae, Cerombycidae, Coccinellidae y Scarabaeidae.	Scarabeidae.
Neuroptera		
Chrysopidae	Chrysopidae	Chrysopidae
Blattodea		
Battidea		Battidea
Hemíptera		
Pentatomidae y Largidae	Pentatomidae y Largidae	Pentatomidae

Note. Taxonomic identification was only possible for Family and Order.

Source. Montes-Betancourt et al. (2020)

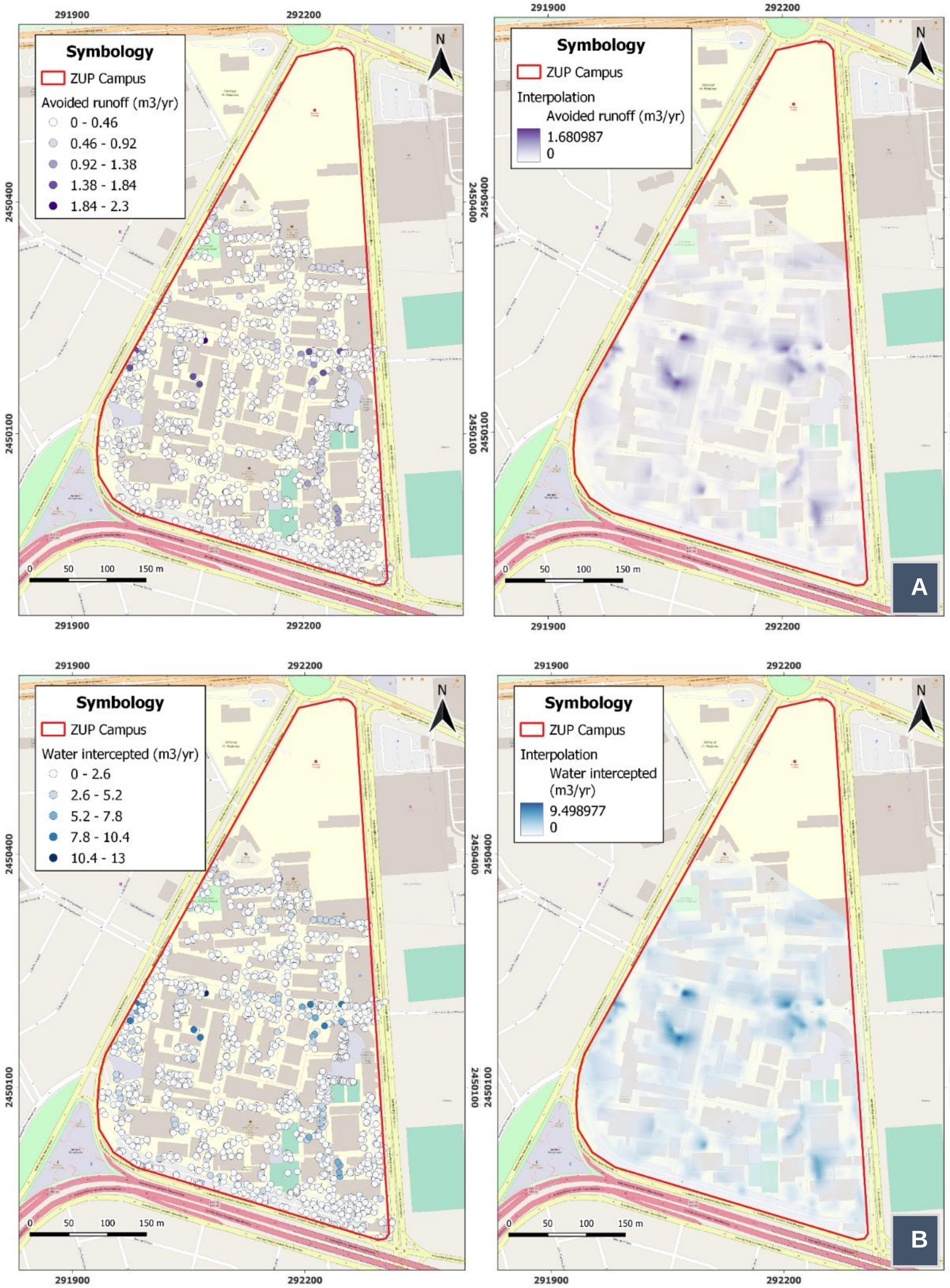
Table 21. ZUP campus allergy rating

Low (%)	Medium (%)	High (%)	Unknown (%)	Allergy Index	Allergy Class
6.1	72.63	11.43	9.85	5.4/10.0	Medium

Note. Allergy Index based on the OPALS scale (1-3 = low, 4-7 = medium, 8-10 = high).

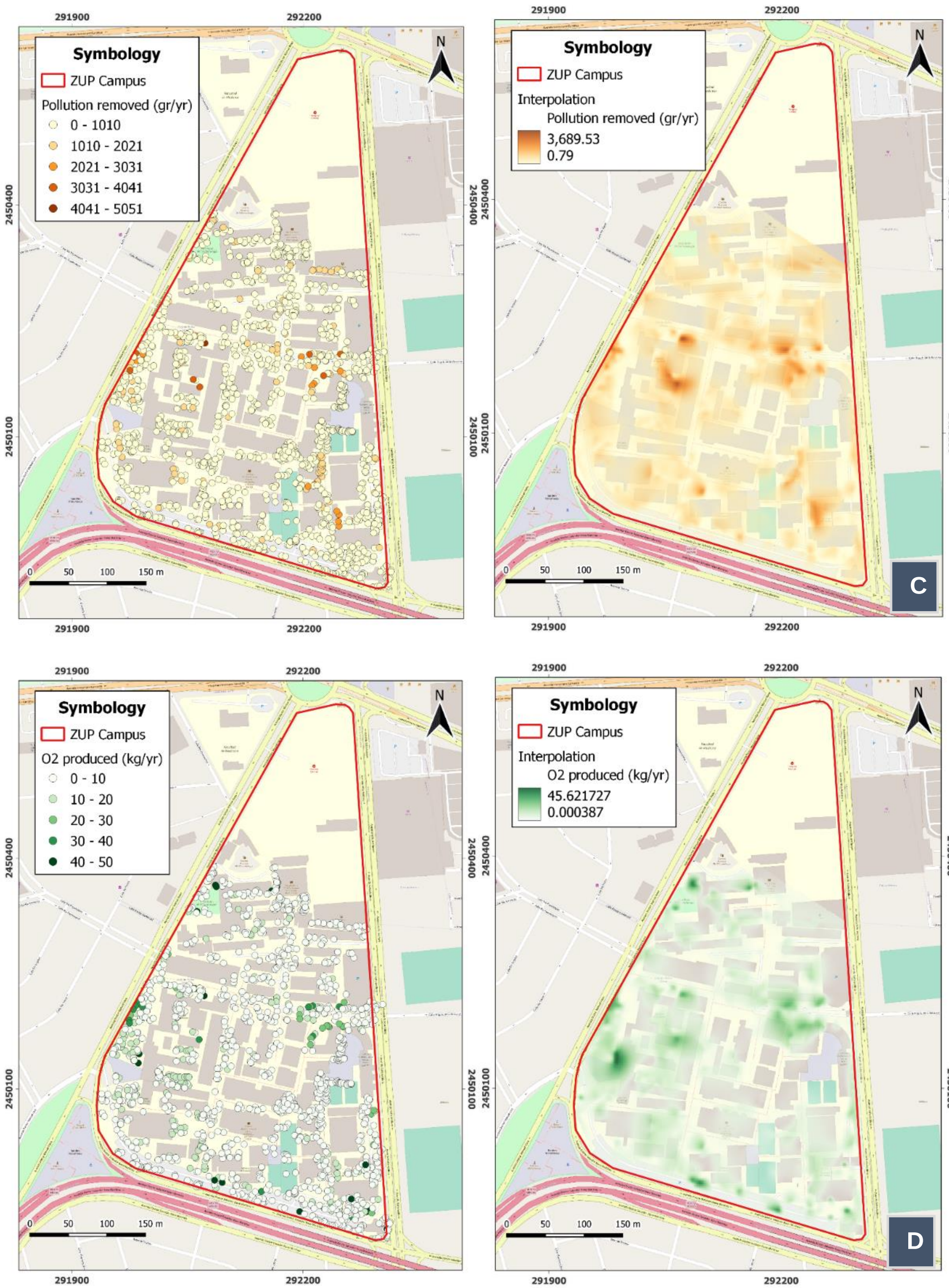
Figure 14. Distribution of ecosystem services provision inside the ZUP campus

Note. As points in a thematic map (left) and as gradients in an interpolation map (right).



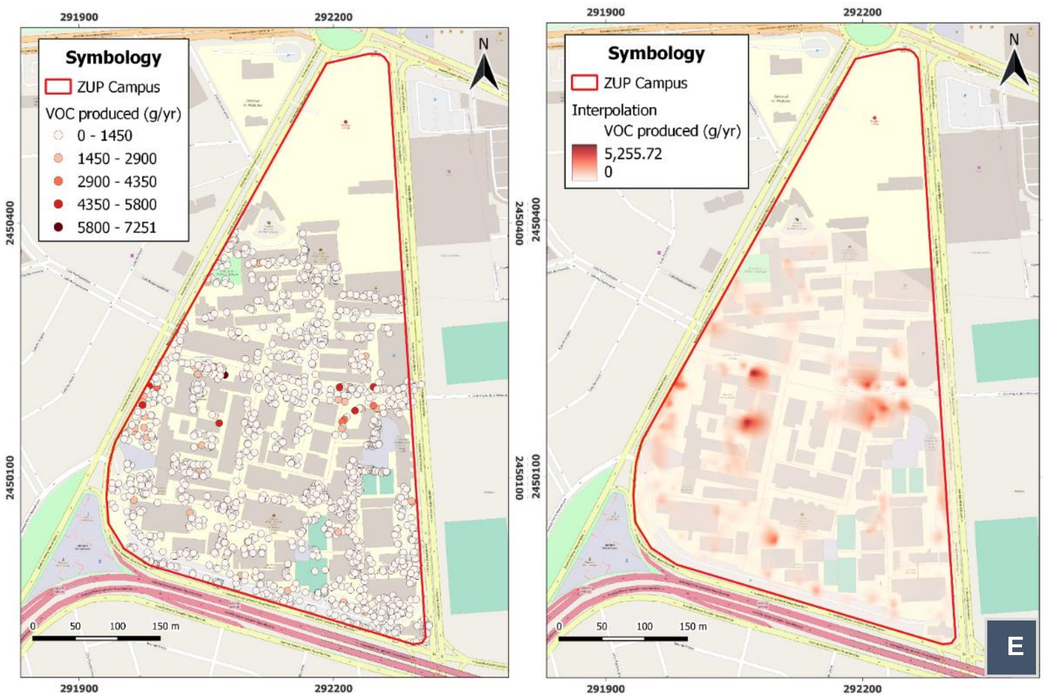
(A) = Avoided runoff, (B) = Water intercepted

Continued on the next page. Pages 63-65



(C) = Total pollution removed, (D) = O2 production.

Figure 14 (Continued)



(E) = VOC production.

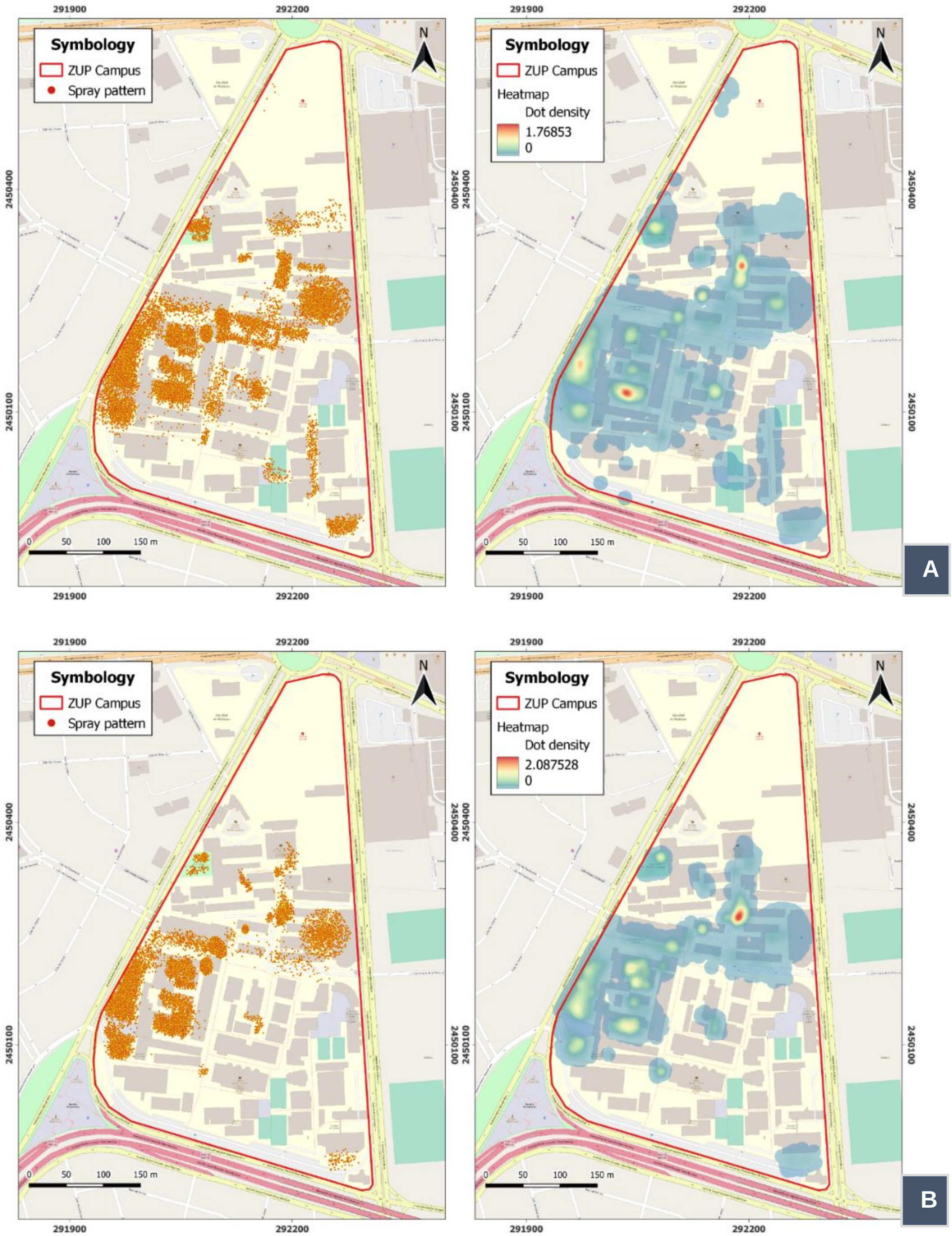
Figure 14 (Continued)

For the participatory mapping exercise, only 52 surveys were considered for inclusion in the analysis. Since 217 was the minimum number required for it to be considered a representative sample it is imperative to state that the data acquired is not a representation of the total student population, and should be taken with caution.

The results are presented both as the raw blobs of data obtained, and as heatmaps, to show both the hotspots of high dot density and maintaining the visual representation of the whole set of answers.

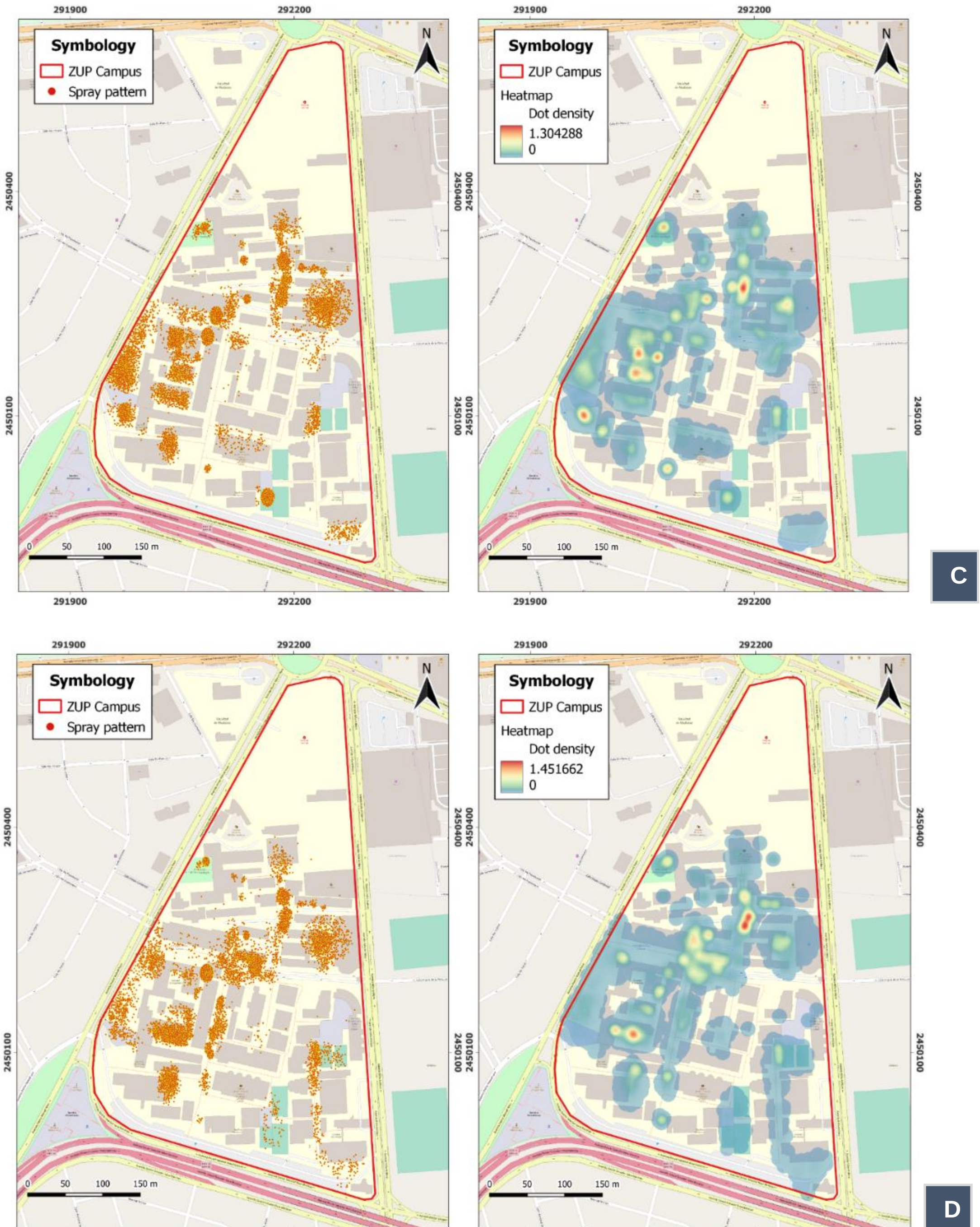
Figure 15. Distribution of ecosystem services demand inside the ZUP campus

*Note. A*s points in a thematic map (left) and as a density map (right).



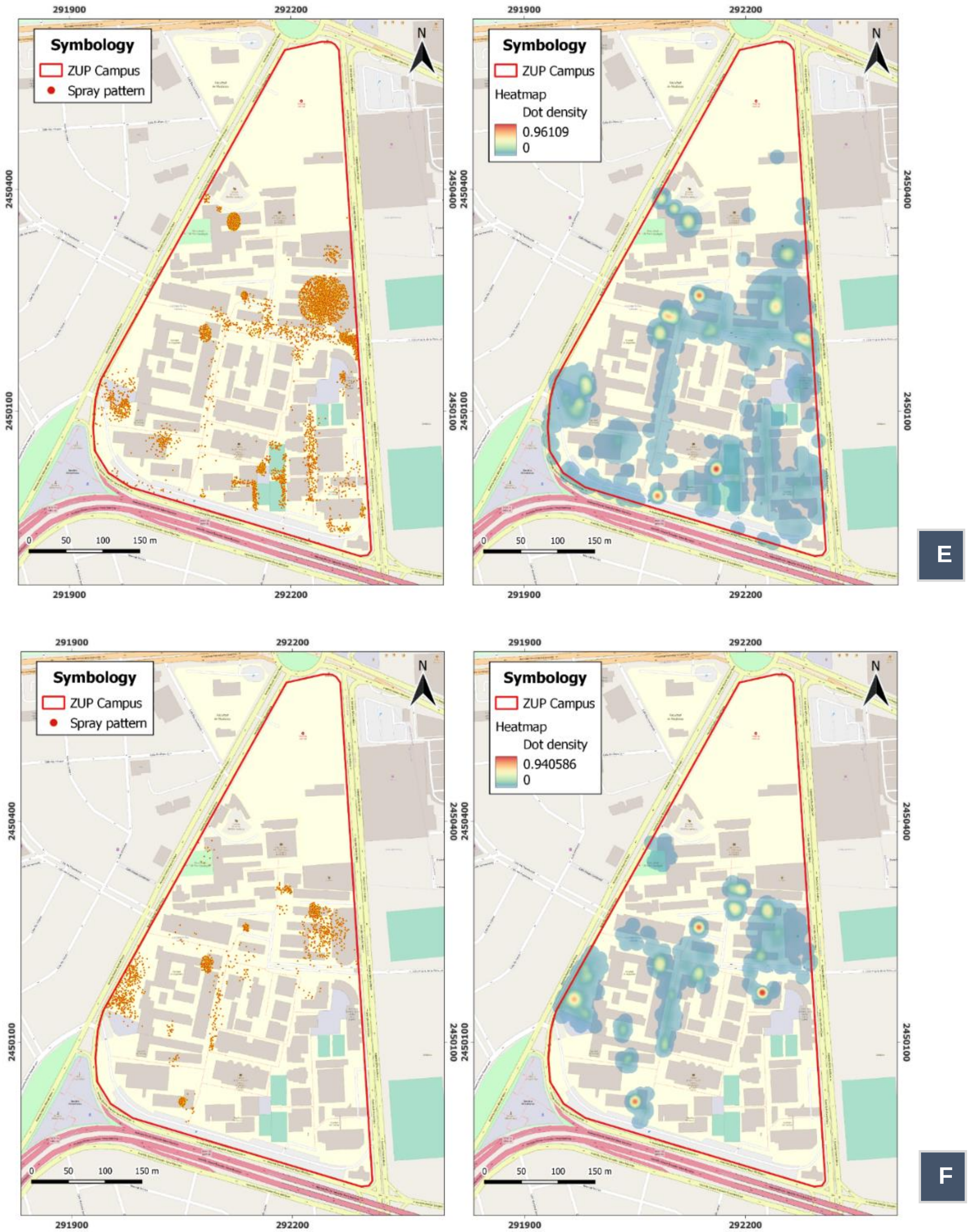
(A) = Aesthetic pleasure, (B) = Connection with nature

Continued on the next page. Pages 66-70



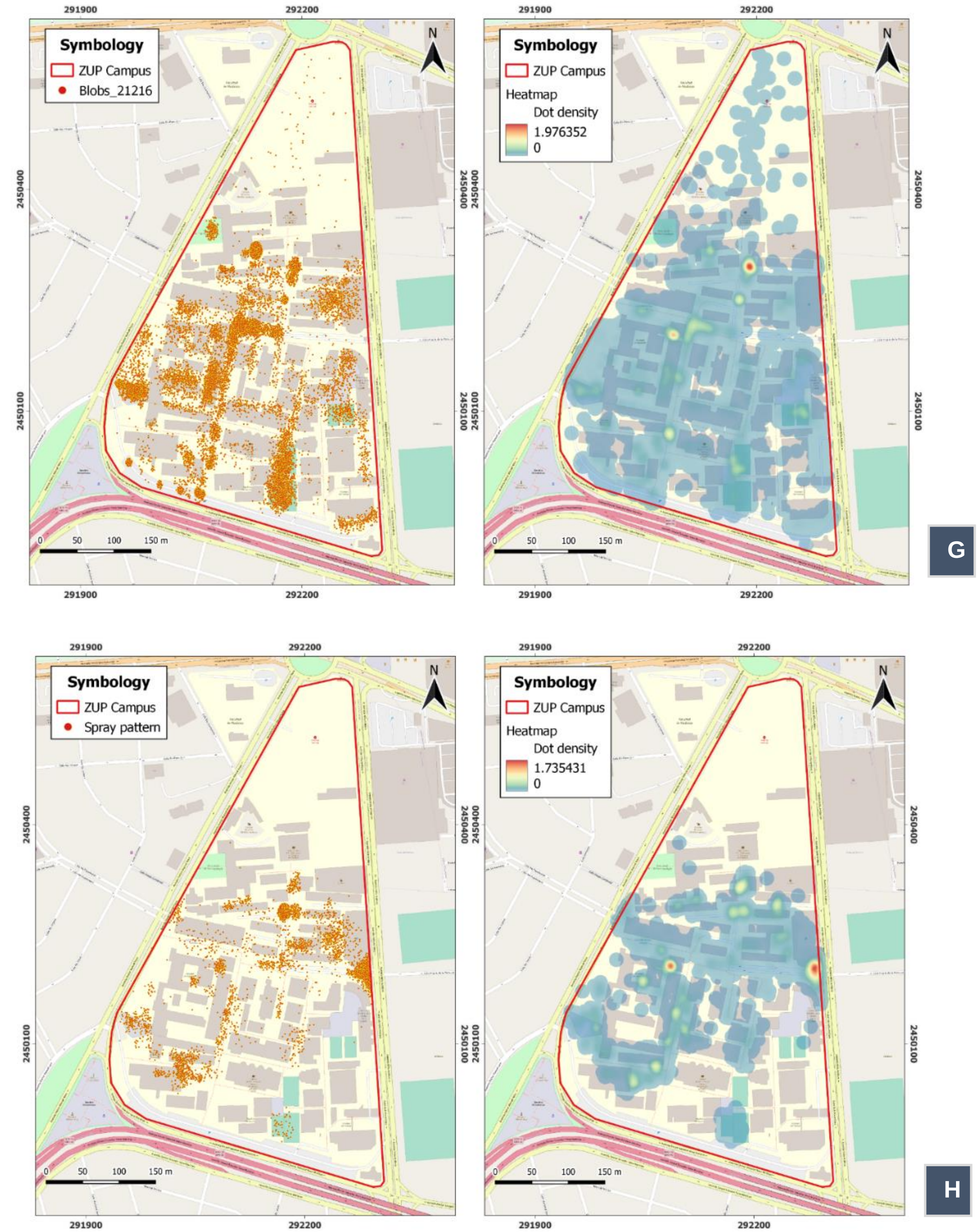
(C) = Stress relief, (D) = Community creation

Figure 15 (Continued)



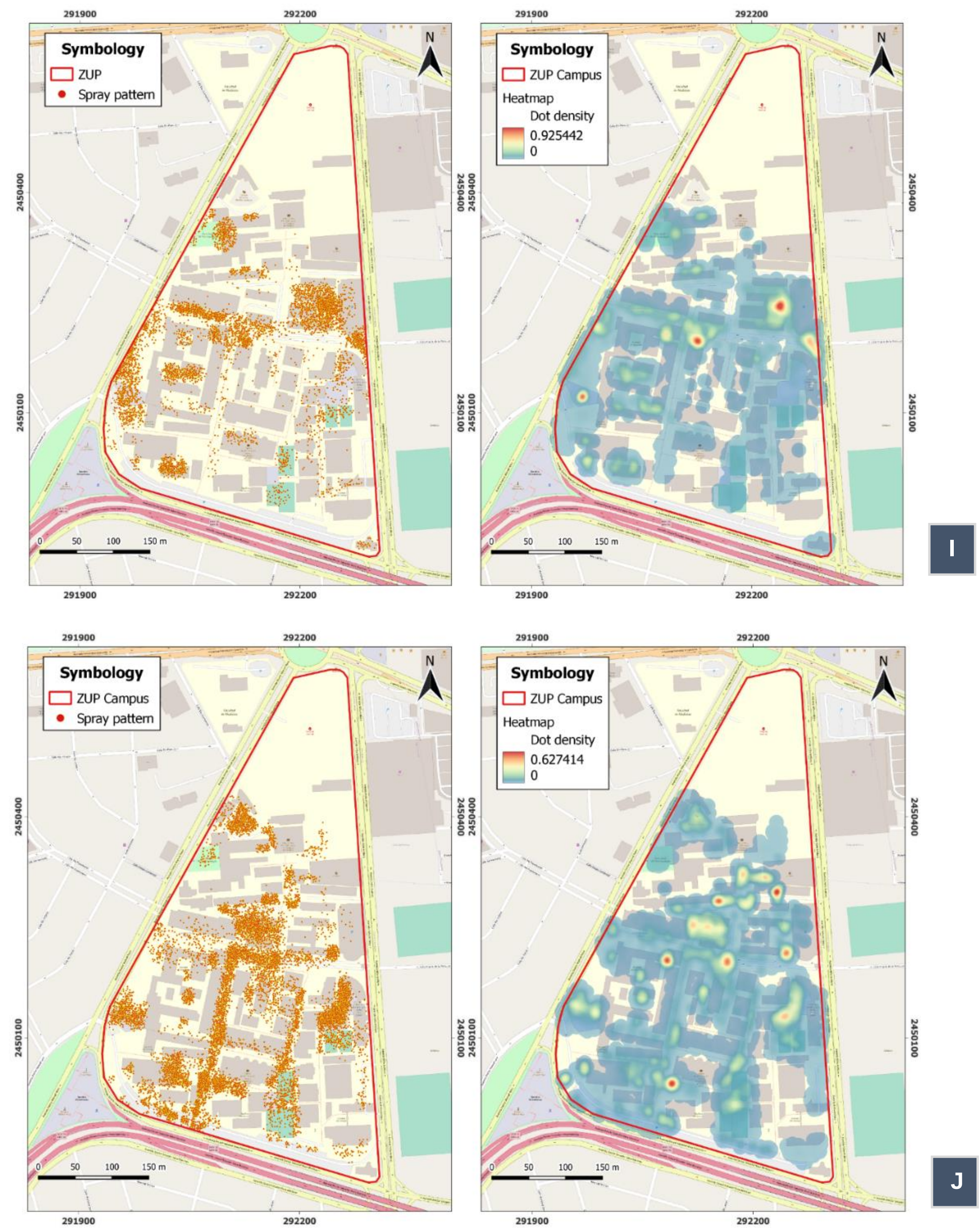
(E) = Perception of insecurity, (F) = Pests

Figure 15 (Continued)



(G) = Microclimate regulation, (H) = Waterflow regulation

Figure 15 (Continued)



(I) = Noise reduction, (J) = UGI installation

Figure 15 (Continued)

5.2.4. Development of adaptive management strategies

Some steps were bypassed for the pilot run. Specifically, the generation of a complex system diagram and the identification of synergies and tradeoffs, due to certain limitations.

On an ideal scenario, the complex relations between UGI, UES and human well-being would have been presented to the experts as a Sorensen Network, similar to the one presented on Table 3, but adapted for the specific case study of the ZUP campus, however, due to a low participation effort and a delayed response from important stakeholders, the time given for consultation was not enough.

For the synergies and tradeoffs analysis, the total vegetation census should have had each individual tree categorized inside a certain UGI. Since this was not considered in the provided database, and considering the time and resources required, this step was also bypassed.

The development of the strategies was done with this reduced amount of information.

- ***Prioritization of interventions***

The experts were given all generated data on UES and UED demand and provision to look for their opinion on specific strategies or actions that could maximize the provision of ecosystem services on the areas that the students need them the most. Response rate was 4 out of 15 participants, which equals 26.67% participation rate. The summary of this second round on expert consultation is shown on the following tables. Table 22 display selected interventions with their corresponding UEG, UES and UED; Table 23 presents selected interventions weighted considering the priority given by the experts and the number of UES provided, considered as a multifunctionality value, then the ranking of UGI units done by considering the frequency to generate the UGI total weighted value is presented in Table 24. Lastly, the results from the qualitative content analysis made for the open answers provided by the experts is depicted in Table 25.

Table 22. Urban green infrastructure interventions prioritized by experts and their corresponding ecosystem goods, services and disservices provided

		Main UES Provided	BD	AQR	PO	CWN	SR	WI	CS	MR	NR	SQ	CC	WC	HC	PC	WR	AP	FP	AL	POI	Multifunctionality score
Urban Green Infrastructure	Units	Food garden	x		x	x							x						x			5
		Floral garden	x		x	x	x								x			x				6
		Botanical garden	o	o	o	o			o				o		o							7
		Etnobotanical garden	x	x		x			x				x		x							6
		Hedges / Barriers	x	x			x		x	x	x	x					x	x				9
		Lined trees	x	x			x		x	x	x	x					x	x				9
		Green corridor	o	o			o		o	o	o				o		o	o				9
		Green wall	x	x			x			x	x							x				6
		Green facade	x	x			x			x	x							x				6
		Vertical garden	x				x			x								x				4
		Vegetated pergola	x				x			x								x				4
		Green roof	o				o	o		o							o	o				6
		Infiltration well						o														1
		Bioswale	x					x	x			x					x					5
		Rain garden	x					x				x					x					4
		Permeable pavement						o									o					2
	Interventions	Use of native species	o		o	o								o	o	o						6
		Shelter for biodiversity	o		o										o	o						4
		Biodiversity monitoring	o		o	o									o					o		5
		Integrated pest management														x			x			2
		Nature-based art installations					x						x					x				3
		Seasonal management			x		x							x				x		x	x	6
		Composting										x	x									2
		Soil improvement practices										o										1
		Erosion control										x										1
		Rainwater harvesting												o								1
		Efficient irrigation systems												o								1
		Summatory of ES for selected interventions	**6**	**2**	**4**	**3**	**2**	**3**	**2**	**2**	**1**	**1**	**1**	**3**	**5**	**2**	**3**	**2**	**0**	**1**	**0**	

Note. BD = biodiversity, AQ = air quality regulation, PO = pollinators, CWN = connection with nature, SR = stress reduction, WI = water infiltration, CS = carbon sequestration, MR = microclimate regulation, NR = noise reduction, SQ = soil quality maintenance, CC = community creation, WC = water consumption, HC = habitat connectivity, PC = pest control, WR = water regulation, AP = aesthetic pleasure, FP = food production, AL = allergens, POI = perception of insecurity.

Table 23. Weighted urban green infrastructure units or interventions

UGI unit or intervention	Multifunctionality	Priority	Weight
Green corridor	5	4	9
Green roof	4	5	9
Use of native species	4	5	9
Green corridor	5	3	8
Shelter for biodiversity	3	4	7
Biodiversity monitoring	3	3	6
Efficient irrigation systems	1	5	6
Green corridor	5	1	6
Green roof	4	2	6
Infiltration wells	1	5	6
Botanical garden	4	1	5
Rainwater harvesting	1	4	5
Soil improvement	1	4	5
Efficient irrigation systems	1	3	4
Permeable pavement	2	2	4
Soil improvement	1	3	4
Permeable pavement	2	1	3
Rainwater harvesting	1	2	3
Rainwater harvesting	1	2	3
Infiltration wells	1	1	2

Note. Multifunctionality = number of main ES provided per action (1 = 0 -1, 2 = 2 - 3, 3 = 4 -5, 4 = 6 - 7, 5 = 8 - 9); Priority = 1 is the lowest, 5 the highest.

Table 24. Final selection of urban green infrastructure units or interventions

UGI unit or intervention	Frequency	Total value
Green corridor	3	23
Green roof	2	15
Rainwater harvesting	3	11
Efficient irrigation systems	2	10
Soil improvement	2	9
Use of native species	1	9
Infiltration wells	2	8
Permeable pavement	2	7
Shelter for biodiversity	1	7
Biodiversity monitoring	1	6
Botanical garden	1	5

Note. The total value is used as the indicator of total importance given by experts, as it considers priority, multifunctionality and frequency.

Table 25. Results from the content analysis done for the second expert consultation

Code	Category	Theme
Species inventory	Species inventory	Biodiversity conservation
Bioconstruction guidelines	Implement sustainable guidelines	Green spaces and urban design
Participatory approaches	Monitor ES	Monitoring and evaluation
Rehabilitation of pedestrian areas	Rehabilitate existing UGI	Green spaces and urban design
Rainwater harvesting	Invest in infrastructure	Infrastructure for sustainable water management
Use of planters	Recreational activities	Green spaces and urban design
Efficient water use	Saving water	Infrastructure for sustainable water management
Use of native species	Rehabilitate existing UGI	Biodiversity conservation
Repurpose unused areas	Expand UGI	Green spaces and urban design
Improve water infiltration	Saving water	Infrastructure for sustainable water management
Rainwater harvesting	Saving water	Infrastructure for sustainable water management
Improve ecological interactions	Improve ecological quality	Biodiversity conservation
Climatic confort	Expand UGI	Green spaces and urban design
Composting	Improve ecological quality	Soil improvement
Increase green areas surface	Expand UGI	Green spaces and urban design
Improve ecological interactions	Improve ecological quality	Soil improvement
Install infrastructure for irrigation	Saving water	Infrastructure for sustainable water management
Monitor biodiversity	Monitor ES	Monitoring and evaluation
Increase green areas surface	Expand UGI	Green spaces and urban design
Rainwater catchment	Saving water	Infrastructure for sustainable water management
Rainwater catchment	Saving water	Infrastructure for sustainable water management
Improve water infiltration	Water infiltration	Infrastructure for sustainable water management
Educational purposes	Educational activities	Biodiversity conservation
Improve water infiltration	Implement sustainable guidelines	Infrastructure for sustainable water management
Groundwater recharge	Saving water	Infrastructure for sustainable water management
Recreational activities	Recreational activities	Green spaces and urban design

- ***Literature review***

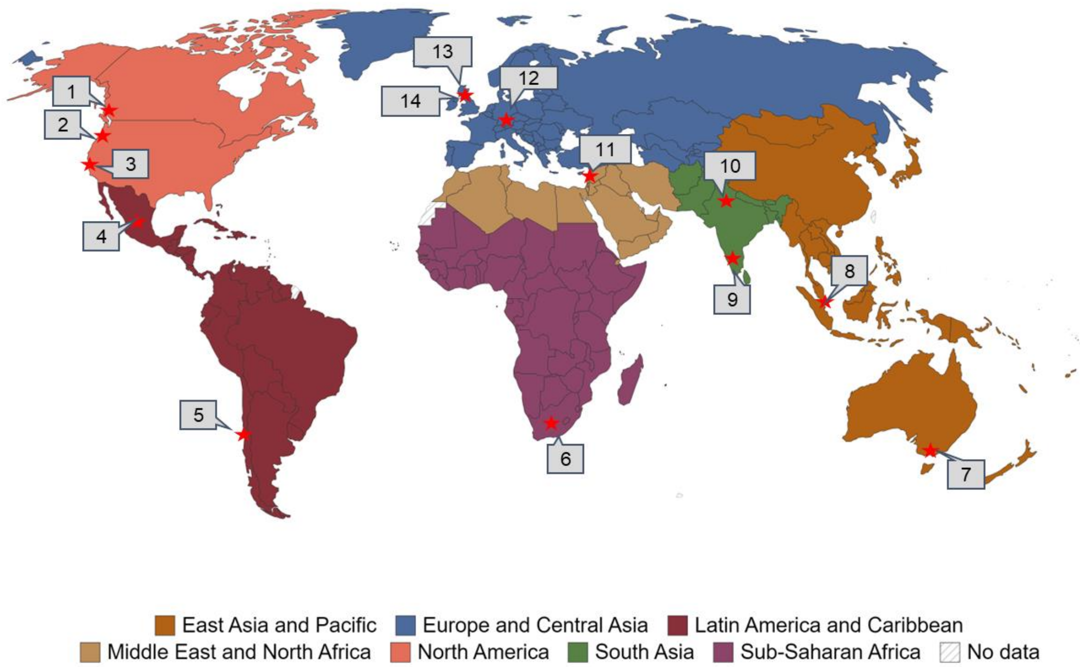
As there are many approaches to this subject, a review of different UGI management documents applied by universities is presented to identify recurring topics and actions present in strategies implemented around the world. The basic criteria for the inclusion of a tool into the review was:

- Relevance: The document must reign over some aspect of UGI management (planning, design, maintenance, monitoring, engagement, etc.) and must address ecosystem services in some way.
- Scope: The document must be applied by a university at institutional or campus level.
- Accessibility: The strategies must be publicly available in digital form, accessible from the web.
- Diversity: The review tries to include different world regions and strategies, covering multiple countries to get a broader understanding of the topic.

As can be seen on Figure 16, the final selected sample covers 14 universities from 11 countries, where at least one representative was found for each World Region, as categorized by The World Bank (TWB) (2023).

The instruments were screened and 56 different strategies for UGI management were identified. These were analyzed and 6 recurring topics were found: (1) climate change and natural disasters, (2) environmental management and conservation, (3) knowledge exchange, (4) landscape planning and design, (5) sustainable built environment, and (6) application of technologies for green spaces management. The summarized results can be found on Table 26.

Figure 16. Selected urban green infrastructure management documents subject to review



Source. (1) UBC, Canada, Green building action plan, (2) UW, United States, Urban Forest Management Plan, (3) UCLA, United States, UCLA Sustainability Plan, (4) UNAM, Mexico, Integrated Plan for Sustainability, 5 = PUC, Chile, Sustainability Report, (6) UCT, South Africa, UCT Environmental Sustainability Strategy, (7) UM, Australia, UM Sustainability Plan, (8) NUS, Singapore, Sustainability Strategic Plan, (9) IIMB, India, Sustainability Report, (10) AU, India, Sustainability Report, (11) AUB, Lebanon, Nature Conservation Strategic Vision, (12) TUM, Germany, Sustainable Futures Strategy, (13) UE, United Kingdom, Biodiversity Plan, (14) UG, United Kingdom, Biodiversity Strategy and Action Plan.

Table 26. Content analysis of reviewed documents

Codes		Categories		Themes	
Climate Change Adaptation	3	Climate change and natural disasters	6	Climate change and natural disasters	6
Natural disasters	3				
Ecological assessment	1	Ecological quality improvement	5	Environmental management and conservation	13
Ecological improvement	2				
Environmental Management	2				
Policy compliance	2	Policies and regulations	3		
Promote regulations	1				
Biodiversity Enhancement	3	Biodiversity conservation	5		
Biodiversity protection	1				
Native Vegetation Increase	1				
Engagement with Biodiversity	2	Engagement and education	5	Knowledge exchange	14
Environmental Education	1				
Communication	2				
Cultural activities	1	Knowledge exchange	6		
Knowledge sharing	2				
Positive social impact	3				
Research on campus	1	Research integration	3		
Research Urban Forestry	2				
Habitat restoration	1	Landscape planning and design	9	Landscape planning and design	9
Enhance connectivity	2				
Landscape for biodiversity	6				
Institutional sustainability management	8	Institutional sustainability management	8	Sustainable Built Environment	12
Sustainable buildings	2	Built environment integration	4		
Sustainable guidelines	2				
Technology for Green Spaces	2	Technology for Green Spaces	2	Technology for Green Spaces	2

Source. American University of Beirut (AUB) (2020, 2023); Ashoka University (AU) (2021a, 2021b); Indian Institute of Management Bangalore (IIMB) (2023); Mishra et al., n.d.; National University of Singapore (NUS), (2017); Pontificia Universidad Católica de Chile (PUC) (2019, 2020); Technical University of Munich (TUM) (2023); Universidad Nacional Autónoma de México (UNAM) (2022); University of British Columbia (UBC) (2018); University of California Los Angeles (UCLA) (2022a, 2022b); University of Cape Town (UCT) (2008, 2020); University of Edinburgh (UoE) (2022); University of Glasgow (UoG) (2022); University of Melbourne (UniMel) (2017, 2020); University of Washington (UW) (2022)

- ***Final proposal of strategies***

For the development of the final strategies, results from the last expert consultation were used as the main basis and refined using the recorded data of students needs and wants, supported by the information obtained from the previous non-systematic, non-exhaustive review of instruments being implemented by universities around the world, which allows us to overcome the reduced information and limitations and still create site-specific, science-based strategies, based on the opinions of both students and local experts. The final strategies are presented on Table 28, its baseline progress can be seen on Table 27. They were created based on the inducted themes, and developed further considering literature, experts, and students' opinions.

Table 27. Current progress of the strategies implementation

Status
21
11
3

Note. Status: green = relevant progress made, yellow = limited progress made, red = no progress made.

Table 28. Final proposed strategies

PUB General Objective: To integrally manage the flora and fauna found in the spaces and gardens of university campuses in a sustainable and respectful manner.							
Area/Priority	**Objectives**	**Strategic line**	**Indicator**	**Target**	**Recommended Frequency**	**Recommended actions**	**Status**
1. Biodiversity conservation and habitat connectiviy	1.1. Increase the proportion of UES provided by native species individuals	1.1.1. Use of high performing native species based on UES provision data	Proportion of priority UES provision from native species individuals	Increase the proportion of UES provided by native species individuals over time	Ongoing monitoring	Promote tree replacement initiatives prioritizing high performing native species	
						Install wildflower gardens of native species	
						Keep a constantly updated list of high performing native species based on emerging data	
	1.2. Increase UGI biodiversity	1.2.1. Enhance UGI effectiveness as a shelter for biodiversity	Diversity indexes (Shannon-Wiener, Simpson, Richness, etc)	Increase the diversity of species within UGI over time	Ongoing monitoring	Install artificial habitats like bug hotels, bird houses or bat houses to provide shelter	
						Adopt a reduced mowing regime in suitable areas	
						Consider plant selection carefully to ensure continuity of food sources throughout the year	
	1.3. Promote connectivity approaches for wildlife	1.3.1. Enhancement of wildlife movement and corridor connectivity	Increase in connectivity index measurements	Maintain or increase connectivity index measurements over time	Ongoing monitoring	Install wildlife green corridors with native vegetation, accompanied by a dedicated monitoring program to track wildlife presence and	

PUB General Objective: To integrally manage the flora and fauna found in the spaces and gardens of university campuses in a sustainable and respectful manner.							
Area/Priority	**Objectives**	**Strategic line**	**Indicator**	**Target**	**Recommended Frequency**	**Recommended actions**	**Status**
						movement within the UGI.	
2. Soil quality maintenance and improvement	2.1. Maintain or increase UGI soil quality	2.1.1. Implement sustainable soil management practices	Soil organnic matter percentage	Maintain or increase soil organic matter over time	Annual	Implement composting programs	
						Prioritize the use of natural fertilizers like compost, organic waste and garden waste	
						Maintain permanent cover of soil through mulching or vegetation to maintain moisture and prevent erosion	
3. Sustainable water management	3.1. Improve water consumption efficiency in irrigation	3.1.1. Implement water-efficienct infrastructure and practices	Percentage reduction in freshwater consumption for irrigation	Reduced freshwater consumption for irrigation over time	Ongoing monitoring	Install infrastructure for rainwater harvesting	
						Install smart technologies to monitor water consumption for irrigation purposes	
						Install efficient irrigation systems	
	3.2. Reduce water runoff	3.2.1. Increase permeable surfaces	Percentage reduction in water runoff volume	Reduced water runoff volume over time	Ongoing monitoring	Install rain gardens or bioswales on appropriate areas	

PUB General Objective: To integrally manage the flora and fauna found in the spaces and gardens of university campuses in a sustainable and respectful manner.							
Area/Priority	**Objectives**	**Strategic line**	**Indicator**	**Target**	**Recommended Frequency**	**Recommended actions**	**Status**
						to capture and infiltrate water	
						Establish permeable pavement zones on appropriate areas to allow water infiltration	
		3.2.2. Promote groundwater recharge	Percentage increase in water infiltration	Increased water infiltration volume over time	Annual	Install infiltration wells an appropriate area to recharge groundwater	
4. UGI coverage and UES provision	4.1. Expand UGI coverage and enhance UES provision	4.1.1. Install new spatial and technologial units of UGI	Percentage increase in UGI coverage compared to baseline	Increase UGI coverage compared to baseline	Annual	Habilitate unused spaces as spatial UGI (parks, gardens, etc)	
						Invest in UGI technological units (green roofs, green walls, etc)	
		4.1.2. Establish "experimental areas" to conduct pilot projects	Number and effectiveness of pilot projects	Increase in number and effectiveness of pilot projects over time	Annual	Establish zones as "experimental areas" to conduct pilot projects and test different UGI design approaches and their UES provision	

PUB General Objective: To integrally manage the flora and fauna found in the spaces and gardens of university campuses in a sustainable and respectful manner.							
Area/Priority	**Objectives**	**Strategic line**	**Indicator**	**Target**	**Recommended Frequency**	**Recommended actions**	**Status**
		4.1.3. Rehabilitate existing UGI	Rate of UES provision by rehabilitated UGI compared to baseline	Increased rate of UES provision by rehabilitated UGI compared to baseline	Annual	Establish a project to rehabilitate existing UGI and enhance its UES provision, developed over an assessment and identification of ecological needs and priority UES demand.	
5. Cultural and educational use	5.1. Increase the provision of cultural UES obtained from UGI	5.1.1. Increase the use of UGI for research and education programs	Number of students participating in UGI related educational programs	Increase number of students participating in UGI related educational programs over time	Ongoing monitoring	Install a botanical garden, accompanied by a specific program for research and education purposes	
						Promote in-campus urban gardening initiatives	
						Integrate UGI related projects, research and activities into the University's curricular activities	
						Develop educational workshops and programs focused on UGI-related topics (biodiversity, urban gardening, natural heritage, etc.)	

PUB General Objective: To integrally manage the flora and fauna found in the spaces and gardens of university campuses in a sustainable and respectful manner.							
Area/Priority	**Objectives**	**Strategic line**	**Indicator**	**Target**	**Recommended Frequency**	**Recommended actions**	**Status**
						Promote participation in citizen science projects inside the campus (iNaturalist)	
		5.1.2. Increase the use of UGI for recreational activities	Percentage of user satisfaction	Increase the percentage of user satisfaction over time	Ongoing monitoring	Provide designated spaces and amenities within or around UGI for recreational activities (benches, stands, pavillions, trails, fitness stations, etc)	
						Promote cultural, sport, recreational and leisure activities inside and around existing UGI that allows to appreciate these spaces and their benefits (yoga, picnic sessions, outdoor performances, fitness classes, art exhibitions, sports, outdoor film screenings, cultural events, etc.)	

PUB General Objective: To integrally manage the flora and fauna found in the spaces and gardens of university campuses in a sustainable and respectful manner.							
Area/Priority	**Objectives**	**Strategic line**	**Indicator**	**Target**	**Recommended Frequency**	**Recommended actions**	**Status**
6. Permanent monitoring	6.1. Increase the knowledge of UES provision inside the system	6.1.1. Implement continuous biophysical monitoring of UES provision	Number of UES monitored and its quantity	Increase the number of UES monitored and increase their provision	Ongoing monitoring	Establish a comprehensive monitoring and evaluation protocol to collect data on UES provision, that is subject to regular updating and reviews to incorporate emerging knowledge and techniques.	
	6.2. Increase the knowledge of UES demand inside the system	6.2.1. Implement continuous user surveys to monitor UES demand	Number of surveys recieved and UES demand incidence	Increase the number of surveys and reduce UES demand	Ongoing monitoring	Establish a comprehensive monitoring and evaluation protocol to collect data on UES demand through surveys or interactive platforms, that is subject to regular updating and reviews to incorporate emerging knowledge and techniques.	

PUB General Objective: To integrally manage the flora and fauna found in the spaces and gardens of university campuses in a sustainable and respectful manner.							
Area/Priority	**Objectives**	**Strategic line**	**Indicator**	**Target**	**Recommended Frequency**	**Recommended actions**	**Status**
7. Program evaluation and communication	7.1. Achievement of the "Strategy for adaptive management of UGI for the UASLP" objectives	7.1.1. Continuosly monitor and evaluate the effectiveness of this protocol adapting methods, indicators and targets based on an iterative learning process	Target achievement rate	Maintain a consistent high rate of achievement of predefined targets and objectives	Annual	Establish a comprehensive monitoring and evaluation protocol to assess the effectiveness of UGI interventions, that is subject to regular updating and reviews to incorporate emerging knowlede and techniques.	
	7.2. Guarantee the adaptive nature of the strategy	7.2.1. Maintain an updated database of UES and UGI	Number of UES with updated information	Increase the number of UES with updated information over time	Every three years	Maintain a consistent digital database of all data gathered.	
		7.2.2. Implement a periodic review of the strategy and modify it as needed based on current data	Number of reviews done	Do at least one review	Every three years	Generate a report encompassing the results of the review for communication and transparency	
		7.2.3. Include main stakeholders into the review of the strategy	Number of relevant stakeholders involved	Increase the number of relevant stakeholders involved over time	Every three years	Invite student representatives, administrative and maintenance personal, experts, etc. to an open review excercise	

PUB General Objective: To integrally manage the flora and fauna found in the spaces and gardens of university campuses in a sustainable and respectful manner.							
Area/Priority	**Objectives**	**Strategic line**	**Indicator**	**Target**	**Recommended Frequency**	**Recommended actions**	**Status**
	7.3. Communicate the results to the community	7.3.1. Implement a comprehensive communication protocol to inform the results to the community	Number of persons reached	Increase the number of persons reached	Ongoing monitoring	Establish a communications plan to constantly share UGI and UES related updates, achievements, and research findings through various channels such as websites, social media, or printed material	
						Operate an open-access, free, digital platform to publish UGI and UES gathered information, enhancing accessibility and public use of the data	

Note. Status: green = relevant progress made, yellow = limited progress made, red = no progress made.

6. DISCUSSION

6.1. On the protocol design

For the development of the instrument, the first choice to make was to select an appropriate design. Between the three basic approaches, qualitative, quantitative, or mixed methods, the election of the latter was done based on the recommendation made by Creswell (2009).

Since this is a phenomenon considered as complex, nonlinear, and dynamic, neither quantitative nor qualitative methods are sufficient in themselves to capture the trends and details of the situation (Creswell et al., 2004) so, qualitative methods can assess the context first, helping to develop the tool, while quantitative methods come later in the study, with a reduced scope based on previous results.

This rationale concurs with the use of mixed methods for development purposes, which involve the sequential use of qualitative and quantitative methods, where the first method is used to help inform the development of the second. The rationale behind it is to increase the validity of the devised tool and obtained results, by capitalizing on the inherent strengths of each approach (Greene et al., 1989).

This also coincides with the “instrument design model”, where implementation begins with qualitative data collection and analysis and moves to quantitative instrument testing. Integration happens at data analysis stage when qualitative data is analyzed and used to develop an instrument for data collection (Creswell et al., 2004).

The resulting protocol adheres to many of the criteria described as characteristics that decision makers consider key in selecting analytical UES tools (Bagstad et al., 2013). These are: quantified outputs, independent application, adequate documentation, scalability, generalizability, incorporation of non-monetary perspectives and affordability. However, time tool fails on some key aspects like level of development, uncertainty estimates and short time requirements. The first of these will be overcome by itself once the protocol begins running and data gathering starts to flow. The second aspect was not devised into the original design, but the recommendation should be expressed to be included in following iterations. Finally, because of the nature of the protocol, the tool can never be short timed. This is of great importance because most decision makers reported time and cost requirements are the most important requirements in tool adoption, stating a strong preference for low-cost screening tools. Transposing this view over the UASLP context is concerning, as decision makers can have the same opinions, disregarding the implementation of this protocol, which can explain the low participation rate of experts, which leads us to comment the pilot.

6.2. ON THE PROTOCOL VALIDATION

6.2.1. THE BASELINE

- ***ON EXISTING DATABASES***

Multiple challenges were faced with the acquisition of data. Starting with the low quality of existing databases which was often incomplete or outdated. This restricted the elements that could be analyzed and in turn, created a non-representative baseline for the study.

Multiple authors and institutions highlight the importance of a strong baseline in the development or implementation of an evaluation tool for decision-making (Dobbs et al., 2011; International Union for Conservation of Nature and Natural Resources (IUCN), 2020; Kim & Coseo, 2018; The Economics of Ecosystems and Biodiversity (TEEB), 2012; World Health Organization (WHO), 2017).

The implication of a weak baseline stemming from poor databases is that we lack the information against which to assess real impacts, so decision-making becomes impaired (Christiansen et al., 2022). This generates an impact on the credibility of the whole project, as adequate data collection is one of the primary elements to keep methodological rigor (Harrison et al., 2020). The importance of an adequate data collection and management needs to be highlighted for the protocol to be implemented successfully over the next years.

- ***ON PARTICIPATORY MAPPING***

Another data related challenge was the difficulty to establish the sampling effort found during the participatory mapping process. Due to time and resources restrictions, it was decided to carry out an estimation based on total population, but spatial based data is affected by different concerns than population-based data (Carrie et al., 2022).

Although it is still under debate, a common recommendation when dealing with participatory mapping polygons is to sample above 25 participants, assuming each one maps 4 – 5 polygons per ecosystem service, which translates to an average of 100 – 125 polygons per mapped attribute. The data gathered for this research was above the recommended number of participants, although the number of polygons per mapped attribute was way below the methodological requirement of 100, ranging from 20 to 66. This carries implications on the sample representativeness, impacting once again on the credibility of results obtained. For future iterations, a larger sample must be procured either through a stronger effort of convincement or a larger amount of time accepting surveys, although response rates for internet based PPGIS averages around 13% (Brown & Kyttä, 2014), which could be a problem in future assessments.

Regarding this, there is a high level of importance in having the support from local authorities, since people may not have the interest or motivation to participate, but structural incentives like enhancing bad communication structures and bureaucratic procedures could improve participation rates (Fors et al., 2021b).

The PPGIS exercise on this project was carried as a normal uses value mapping, presented as a single participation process of consultation, however, different examples in which this very same tool can be harnessed to engage users at higher levels of participation like active collaboration if users can vote for suggested changes, partnerships for the development of new trails, or empowerment when allowing for knowledge sharing of foraging sites have been documented (Fors et al., 2021b). This concurs with the opinions of other researchers, who sees PPGIS as a potential foundation for iterative public participation, throughout the complete management cycle of UGI (Brown & Kyttä, 2014).

- ***ON EXPERT CONSULTATION***

The expert consultation low participation rate was something expected, as loosing panelists is recognized as one of this method's main disadvantages. However, it is of little concern as the method does not call for a statistically representative sample, differing in this regard to other common surveys (Shariff, 2015). However, this presents its own set of problems, as the selection of experts introduces an inescapable bias into the results. There is a need to ensure sufficient commitment from participants, appropriate levels of expertise and a diverse range of responses, to ensure high quality responses from the selected panel of experts. The solution this research project devised for this was to develop a transparent expert selection process with clear criteria (Devaney & Henchion, 2018). However, a practice that should be removed on future iterations is snowball sampling, since it has been documented that friends, colleagues, or other contacts might share similar views with regards to several aspects, leading to a group of similar thinking individual, which in turn exponentiate cognitive biases related to framing and anchoring, desirability, bandwagon effect and belief perseverance.

Although cognitive biases are inevitable, a measure that was implemented on this research to counter this was to ask participants for an argument or justification of their answers, forcing them to enter a reasoning process. However, there are some features that should be used to counteract common biases on Delphi surveys, namely: high group heterogeneity, inclusion of individuals with strong opposing views, avoid snowball sampling, introduce role-playing to elicit different perspectives, warning about possible biases, participants with high expertise and cognitive abilities, ensure a high level of involvement, and design a questionnaire that ensures that each question is unrelated to the previous one (Winkler & Moser, 2016). These recommendations should be considered for future iterations of this protocol.

6.2.2. THE STRATEGIES

- ***ON FORESIGHTING***

Although there are many methods used in foresighting, including interviews, literature review, modelling, brainstorming, SWOT, back casting, simulation gaming, scenario building, among others, Delphi was the method of choice for developing the strategies due to its suitability when knowledge about a phenomenon is incomplete, and when the objective is to enhance the understanding of problems, opportunities, and solutions (Phdungsilp, 2011).

This method is considered as balanced when analyzed through "the foresight diamond", which means that it gives an almost equal weight to creativity or imaginative thinking, expertise or knowledge in a particular area, interaction to challenge and articulate different perspectives, and evidence, that recognizes the importance of reliable supporting documentation (Popper, 2008).

This, coupled with the fact that it has been identified as very useful in defining ways to achieve or avert future situations (Renzi & Freitas, 2015), a concept very similar to strategic management, reaffirms the selection of this technique as a starter for the development of the strategies.

- ***ON ADAPTIVE MANAGEMENT***

UGI is a complex system, and its successful management is not only about assigning suitable resources, but also about understanding the complexity of the system itself. Typically, UGI management activities are carried out routinely without a clear direction, neglecting the fact that this infrastructure can play a significant role in improving people's quality of life and offer the multiple benefits.

Successful management of public green spaces requires setting a direction through a strategic management plan (Aly & Dimitrijevic, 2022). This document set the link between daily operations and its context, allowing it to be responsive and flexible to its user's demands by receiving continuous feedback on the operation of the system, which may reveal a missing quality or a lost opportunity for interventions. This backs up the implementation of an adaptive strategy for the management of the UGI inside the UASLP campuses, based on ecosystem services provision.

The strategy, developed by following the pilot run of the protocol, intends to be an adaptive approach for enhancing UES provision in the ZUP campus. The key elements of adaptive management have been ingrained into it via an emphasis on constantly gathering knowledge of the system through a systematic and rigorous monitoring and evaluation (M&E) instrument; a proposed “experimental area” that has the purpose of testing new interventions at a small-scale, fostering innovation, creativity, and experimentation with different UGI configuration or management practices; and periodical stakeholder collaboration to discuss new ideas. Together these three elements provide constant supply of data about the system that will fuel the iterative learning cycles of the adaptive management plan. Coupled with continuous assessment and annual reports as the technical loop, and a periodical total revision of the plan every few years as the institutional loop, the adaptability and flexibility of the strategy are also assured, allowing modifications as necessary, informed by the emerging knowledge of the system (Hsu et al., 2020b; Razzaghi Asl & Pearsall, 2022a).

Now, to implement the strategy effectively, specific timelines for each loop are crucial. The technical loop involves continuous M&E with annual reports, aligned with the institutional working cycles to facilitate the generation, analysis, and publication of data, conforming to common sustainability frameworks. The institutional loop, however, demands careful consideration. Strategies like the one proposed should be proactive, influencing decision-making with scientific evidence. Therefore, the suggested approach is to align the institutional loop with major planning cycles inside the university. At the UASLP, the current Plan Institucional de Desarrollo (Institutional Development Plan, PIDE) is scheduled to reform in the 2024-2030 cycle, so the current project should aim to generate data to influence this plan. The subsequent institutional cycle should be scheduled for 2029, influencing the following PIDE, and maintaining its influential approach.

However, some insights about the future of this plan have been envisioned during the pilot run, and it’s looking more like a difficult start.

6.2.3. THE CHALLENGES

- ***THE BIG PICTURE: GOVERNANCE***

During the test of the pilot run some problems, previously identified as common for adaptive management strategies implementation on unsuitable governance systems emerged (Green et al., 2016b; Hsu et al., 2020b).

The lack of horizontal and vertical coordination resulted in overly complicated communications; the pluralization, lack of clarity in responsibilities and deficient internal coordination resulted in deficient databases and confusion over the status of information and data; and low stakeholder engagement and lack of interest resulted in difficulty to manage the increased number of stakeholders and a generally low response rate.

However, its necessary to understand that adaptive governance is not playing alone here. An interplay between hierarchical governance, scientific-technical governance, adaptive governance, and governing strategic behavior are working together, over different structures, at the same time. So, it is of importance to consider all of them, even when operating under the rules of one (Primmer et al., 2015).

For the scope of this research, hierarchical governance includes the legal context governing UGI and the UASLP institutional framework; scientific-technical governance refers to AA and all its programs in its current state; governing strategic behavior is represented by the interests of the many actors at play, and although at first glance adaptive governance seems absent from the institution, if considering the conception that this type of governance is a response to the constant shortcomings of centralized top-down approaches to governance (Frohlich et al., 2018), it could be expected that a heavily top-down hierarchical system like the UASLP’s institutional context developed some adaptive elements as coping mechanisms.

I argue that the development of a program of urban gardening with a strong focus on experimentation and student engagement (Unihuerto) is a clear example of that. Alongside their green roof initiative (Unitecho), an edible fungi production program (Fungicasita), the implementation of bug hotels on certain areas, the development of biodiversity databases, and the installation of a food forest initiative, indicates that there are some key actors pushing for adaptability, flexibility, experimentation, and innovation inside the institution. All characteristics of adaptive governance, that could push for the successful implementation of this adaptive management strategy for the urban green infrastructure of the UASLP.

- ***THE SMALL DETAILS: LANDSCAPE DESIGN***

Considering that the strategies developed are set at a university planning level, the scope is not supposed to reach the specific configuration of the proposed UGI, however it is imperative to acknowledge that the final implementation at project level, will fall in the realms of a different but related discipline: landscape design.

According to recent research, vegetation can be strategically planted and managed to optimize the provision of desired ecosystem services using demographic and urban landscape knowledge (Bodnaruk et al., 2017). Different locations and configurations offer different impacts on ecosystem services supply (Zhao et al., 2020). This is because the balance of UES is strongly related to the person's experience, use, and value of the infrastructure, but also in individual UGI characteristics and contextual factors (Cimburova & Berghauser Pont, 2021; Drillet et al., 2020).

Considering one example inside the UASLP ZUP campus, the Engineering Faculty cafeteria, was marked by people as an area where they like to socialize, making it a spot where comfortable and aesthetic spaces need to be installed. However, the specific way this could be reached must be subject to another technical analysis, where the details of different solutions, spatial configurations or even plant species, furniture color or construction materials must be analyzed. This technical analysis must be carried out by specialists on ecological landscape design, who must consider the different tradeoffs that come into play when working on such a detailed scale. This, however, falls outside of the scope of the present study.

7. Conclusions

7.1. Review of results

This research successfully achieved its general objective, by designing an urban green infrastructure (UGI) management strategy based on urban ecosystem services (UES) for the Universidad Autónoma de San Luis Potosí (Autonomous University of San Luis Potosí, UASLP).

For this, the relevant UES provision and demand provided by the UGI of the UASLP Zona Universitaria Poniente (Western Zone, ZUP) campus were defined and evaluated, and specific high-impact strategies to enhance the provision and satisfy the demand of UES from the students inside the institution were proposed.

The outcome goes beyond an applicable protocol to generate an adaptive management strategy. By conducting this study in the global south, at small local scale, with a vision towards the future, considering the communication of results, the inclusion of ecosystem disservices, the use of a systems perspective, and employing explicitly participatory and spatial methods, this research contributes significantly to expand the knowledge of an under-researched area.

Furthermore, the findings offer valuable insights, particularly on the importance of an appropriate governance structure for the successful implementation of the UGI management strategy, but also highlight various technical challenges related to data gathering, effective data visualization, communication of results, and the intricacies of the physical implementation at urban design level.

The obtained results on UES at small-scale UGI should be of great utility for urban planners and designers working in similar social-ecological contexts, to make science-based and informed decisions towards the sustainable development of cities, and to effectively adapt urban systems as resilient communities against climate change, that are functional to help preserve local biodiversity.

7.2. LIMITATIONS OF THE STUDY

For the tool development phase, the election of a certain purpose and design, although based on the stated objectives, could have been a different one, and its mostly related to the author's own views.

For the pilot phase, low participation by students and experts, incomplete databases, and a literature review that was non-exhaustive created biases that must not be overlooked.

Finally, strategy development had to be done different than planned due to scarcity of time and resources, which creates a different outcome than the one that could have been obtained if the protocol ran as originally planned. The final strategies were constructed by the author with the help of a non-exhaustive and non-systematic literature review, which alters the final proposal to the author's own opinions, capacities, and knowledge.

7.3. RECOMMENDATIONS AND FUTURE RESEARCH

During the implementation of the project, the overlooked steps must be carried out for the institutional cycle, for the experts to gather enough knowledge of the system and develop better suited strategies for the site.

Future researchers should consider participation rate to obtain a representative sample of the student's body. The expert selection and engagement strategies need to be revised to reduce the biases and increase participation. The possibilities of escalation at city level should be explored.

To allow a successful implementation over a long term, there needs to be integration with the strategic development plans at university level, to landscape design at implementation level, to financial bodies at economic level, and to other horizontal programs inside Agenda Ambiental (Environmental Agenda, AA), to align the water, energy, waste, biodiversity and the whole sustainability strategy under a single goal.

8. REFERENCES

Adam, A. M. (2020). Sample Size Determination in Survey Research. *Journal of Scientific Research and Reports*, 90–97. https://doi.org/10.9734/jsrr/2020/v26i530263

Adams, K. M., Hester, P. T., Bradley, J. M., Meyers, T. J., & Keating, C. B. (2014). Systems theory as the foundation for understanding systems. *Systems Engineering*, *17*(1), 112–123. https://doi.org/10.1002/sys.21255

Alberti, M. (2005). The effects of urban patterns on ecosystem function. *International Regional Science Review*, *28*(2), 168–192. https://doi.org/10.1177/0160017605275160

Aly, D., & Dimitrijevic, B. (2022). Systems approach to the sustainable management of urban public parks. *Urban Forestry and Urban Greening*, *68*. https://doi.org/10.1016/j.ufug.2022.127482

Aly, D., Hassan, D. K., Mohamed Kamel, S., & Hamhaber, J. (2018). Human Needs as an Approach to Designed Landscapes. *Journal of Natural Resources and Development*, *8*, 15–26. https://doi.org/10.5027/jnrd.v8i0.03

American University of Beirut. (2023). *AUB - Nature Conservation Center strategic vision*.

American University of Beirut (AUB). (2020). *Sustainability Report 2019-2020*.

Ashoka University. (2021a). *Annual SDG report 2021*.

Ashoka University. (2021b). *Environment Sustainability Report 2021*.

Bagstad, K. J., Semmens, D. J., Waage, S., & Winthrop, R. (2013). A comparative assessment of decision-support tools for ecosystem services quantification and valuation. In *Ecosystem Services* (Vol. 5, pp. 27–39). Elsevier B.V. https://doi.org/10.1016/j.ecoser.2013.07.004

Birgé, H. E., Allen, C. R., Garmestani, A. S., & Pope, K. L. (2016). Adaptive management for ecosystem services. *Journal of Environmental Management*, *183*, 343–352. https://doi.org/10.1016/j.jenvman.2016.07.054

Bodnaruk, E. W., Kroll, C. N., Yang, Y., Hirabayashi, S., Nowak, D. J., & Endreny, T. A. (2017). Where to plant urban trees? A spatially explicit methodology to explore ecosystem service tradeoffs. *Landscape and Urban Planning*, *157*, 457–467. https://doi.org/10.1016/j.landurbplan.2016.08.016

Bolund, P., & Hunhammar, S. (1999). Ecosystem services in urban areas. In *Ecological Economics* (Vol. 29).

Bowd, R., Quinn, N. W., & Kotze, D. C. (2015). Toward an analytical framework for understanding complex socialecological systems when conducting environmental impact assessments in South Africa. *Ecology and Society*, *20*(1). https://doi.org/10.5751/ES-07057-200141

Breen, A., Giannotti, E., Flores Molina, M., & Vásquez, A. (2020). From “Government to Governance”? A Systematic Literature Review of Research for Urban Green Infrastructure Management in Latin America. In *Frontiers in Sustainable Cities* (Vol. 2). Frontiers Media S.A. https://doi.org/10.3389/frsc.2020.572360

Brown, G., & Kyttä, M. (2014). Key issues and research priorities for public participation GIS (PPGIS): A synthesis based on empirical research. In *Applied Geography* (Vol. 46, pp. 122–136). Elsevier Ltd. https://doi.org/10.1016/j.apgeog.2013.11.004

Brzoska, P., & Spaǵe, A. (2020). From city-to site-dimension: Assessing the urban ecosystem services of different types of green infrastructure. In *Land* (Vol. 9, Issue 5). MDPI AG. https://doi.org/10.3390/LAND9050150

Buendía-Oliva, M., García-Torres, L. D., & Ramos-Palacios, C. R. (2021). *Bases para un plan de manejo del arbolado dentro del Programa Universitario de Biodiversidad en el campus Zona Poniente de la UASLP.*

Burkhard, B., & Maes, J. (2017). *Mapping Ecosystem Services* (B. Burkhard & J. Maes, Eds.). Pensoft Publishers.

Carrie, R. H., Stringer, L. C., Van Hue, L. T., Quang, N. H., Van Tan, D., Hackney, C. R., Nga, P. T. T., & Quinn, C. H. (2022). Social differences in spatial perspectives about local benefits from rehabilitated mangroves: insights from Vietnam. *Ecosystems and People*, *18*(1), 378–396. https://doi.org/10.1080/26395916.2022.2083237

Castellar, J. A. C., Popartan, L. A., Pueyo-Ros, J., Atanasova, N., Langergraber, G., Säumel, I., Corominas, L., Comas, J., & Acuña, V. (2021). Nature-based solutions in the urban context: terminology, classification and scoring for urban challenges and ecosystem services. *Science of the Total Environment*, *779*. https://doi.org/10.1016/j.scitotenv.2021.146237

Chapin, S. F., Matson, P. A., & Vitousek, P. M. (2012). Principles of terrestrial ecosystem ecology. In *Principles of Terrestrial Ecosystem Ecology*. Springer New York. https://doi.org/10.1007/978-1-4419-9504-9

Christiansen, S., Bräger, S., & Jaeckel, A. (2022). Evaluating the quality of environmental baselines for deep seabed mining. *Frontiers in Marine Science*, *9*. https://doi.org/10.3389/fmars.2022.898711

Cimburova, Z., & Berghauser Pont, M. (2021). Location matters. A systematic review of spatial contextual factors mediating ecosystem services of urban trees. In *Ecosystem Services* (Vol. 50). Elsevier B.V. https://doi.org/10.1016/j.ecoser.2021.101296

Costanza, R., de Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., Farber, S., & Grasso, M. (2017). Twenty years of ecosystem services: How far have we come and how far do we still need to go? In *Ecosystem Services* (Vol. 28, pp. 1–16). Elsevier B.V. https://doi.org/10.1016/j.ecoser.2017.09.008

Costanza, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., & Naeem, S. (1997). The Value of the World's Ecosystem Services and Natural Capital. *Nature*, *387*, 253–260.

Creswell, J. W. (2009). *Research design: Qualitative, Quantitative and Mixed Methods Approaches* (3rd ed.). SAGE Publications.

Creswell, J. W., Fetters, M. D., & Ivankova, N. V. (2004). Designing a mixed methods study in primary care. *Annals of Family Medicine*, *2*(1), 7–12. https://doi.org/10.1370/afm.104

Croci, E., Lucchitta, B., & Penati, T. (2021). Valuing ecosystem services at the urban level: A critical review. In *Sustainability (Switzerland)* (Vol. 13, Issue 3, pp. 1–16). MDPI. https://doi.org/10.3390/su13031129

Cumming, G. (2014). Theoretical frameworks for the analysis of social-ecological systems. In S. Sakai & C. Umetsu (Eds.), *Social-Ecological Systems in Transition*. Springer. http://www.springer.com/series/10124

Deutsche Gesellschaft für Internationale Zusammenarbeit, G. (2019). *Integración de los servicios ecosistémicos en la planificación y gestión urbana*.

Devaney, L., & Henchion, M. (2018). Who is a Delphi 'expert'? Reflections on a bioeconomy expert selection procedure from Ireland. *Futures*, *99*, 45–55. https://doi.org/10.1016/j.futures.2018.03.017

Devisscher, T., Ordóñez-Barona, C., Dobbs, C., Dias Baptista, M., Navarro, N. M., Orozco Aguilar, L. A., Cercas Perez, J. F., Rojas Mancebo, Y., & Escobedo, F. J. (2022). Urban forest management and governance in Latin America and the Caribbean: A baseline study of stakeholder views. *Urban Forestry and Urban*

Greening, *67*. https://doi.org/10.1016/j.ufug.2021.127441

Diario Oficial de la Federación (DOF). (1998). *Ley General del Equilibrio Ecológico y la Protección al Medio Ambiente*.

Ley General de Cambio Climático, (2012).

Diario Oficial de la Federación (DOF). (2016). *Ley General de Asentamientos Humanos, Ordenamiento Territorial y Desarrollo Urbano*.

Plan Nacional de Desarrollo 2019 - 2024, (2019).

Programa Nacional de Ordenamiento Territorial y Desarrollo Urbano 2021 - 2024, (2021).

NOM-001-SEDATU-2021, Espacios públicos en los asentamientos humanos, (2022).

Dobbs, C., Escobedo, F. J., & Zipperer, W. C. (2011). A framework for developing urban forest ecosystem services and goods indicators. *Landscape and Urban Planning*, *99*(3–4), 196–206. https://doi.org/10.1016/j.landurbplan.2010.11.004

Dodder, R., & Dare, R. (2000). *Complex Adaptive Systems and Complexity Theory: Inter-related Knowledge Domains* (Vol. 83).

Drillet, Z., Fung, T. K., Leong, R. A. T., Sachidhanandam, U., Edwards, P., & Richards, D. (2020). Urban vegetation types are not perceived equally in providing ecosystem services and disservices. *Sustainability (Switzerland)*, *12*(5). https://doi.org/10.3390/su12052076

Elia, G., Margherita, A., & Secundo, G. (2020). Project management canvas: a systems thinking framework to address project complexity. *International Journal of Managing Projects in Business*, *14*(4), 809–835. https://doi.org/10.1108/IJMPB-04-2020-0128

Elliott, H., Eon, C., & Breadsell, J. K. (2020). Improving city vitality through urban heat reduction with green infrastructure and design solutions: A systematic literature review. In *Buildings* (Vol. 10, Issue 12, pp. 1–30). MDPI AG. https://doi.org/10.3390/buildings10120219

Endlicher, W., Langner, M., Hesse, M., Mieg, H. A., Kowarik, I., Hostert, P., Kulke, E., Nützmann, G., Schulz, M., van der Meer, E., Wessolek, G., & Wiegand, C. (2007). Urban Ecology - Definitions and Concepts. In *Shrinking Cities: Effects on Urban Ecology and Challenges for Urban Development.* (pp. 1–15).

Erlingsson, C., & Brysiewicz, P. (2017). A hands-on guide to doing content analysis. In *African Journal of Emergency Medicine* (Vol. 7, Issue 3, pp. 93–99).

African Federation for Emergency Medicine. https://doi.org/10.1016/j.afjem.2017.08.001

Fors, H., Hagemann, F. A., Sang, Å. O., & Randrup, T. B. (2021a). Striving for Inclusion—A Systematic Review of Long-Term Participation in Strategic Management of Urban Green Spaces. In *Frontiers in Sustainable Cities* (Vol. 3). Frontiers Media S.A. https://doi.org/10.3389/frsc.2021.572423

Fors, H., Hagemann, F. A., Sang, Å. O., & Randrup, T. B. (2021b). Striving for Inclusion—A Systematic Review of Long-Term Participation in Strategic Management of Urban Green Spaces. In *Frontiers in Sustainable Cities* (Vol. 3). Frontiers Media S.A. https://doi.org/10.3389/frsc.2021.572423

Frank, B. (2017). Urban Systems: A Socio-Ecological System Perspective. *Sociology International Journal*, *1*(1). https://doi.org/10.15406/sij.2017.01.00001

Frohlich, M. F., Jacobson, C., Fidelman, P., & Smith, T. F. (2018). The relationship between adaptive management of social-ecological systems and law: A systematic review. *Ecology and Society*, *23*(2). https://doi.org/10.5751/ES-10060-230223

Gare, A. (2000). Systems Theory and Complexity: Introduction. *Democracy & Nature*, *6*(3), 327–339. https://doi.org/10.1080/10855660020020221

Grădinaru, S. R., & Hersperger, A. M. (2019). Green infrastructure in strategic spatial plans: Evidence from European urban regions. *Urban Forestry and Urban Greening*, *40*, 17–28. https://doi.org/10.1016/j.ufug.2018.04.018

Green, O. O., Garmestani, A. S., Albro, S., Ban, N. C., Berland, A., Burkman, C. E., Gardiner, M. M., Gunderson, L., Hopton, M. E., Schoon, M. L., & Shuster, W. D. (2016a). Adaptive governance to promote ecosystem services in urban green spaces. *Urban Ecosystems*, *19*(1), 77–93. https://doi.org/10.1007/s11252-015-0476-2

Green, O. O., Garmestani, A. S., Albro, S., Ban, N. C., Berland, A., Burkman, C. E., Gardiner, M. M., Gunderson, L., Hopton, M. E., Schoon, M. L., & Shuster, W. D. (2016b). Adaptive governance to promote ecosystem services in urban green spaces. *Urban Ecosystems*, *19*(1), 77–93. https://doi.org/10.1007/s11252-015-0476-2

Greene, J. C., Caracelli, V. J., & Graham, W. F. (1989). Toward a Conceptual Framework for Mixed-Method Evaluation Designs. In *Source: Educational*

Evaluation and Policy Analysis (Vol. 11, Issue 3). http://www.jstor.orgURL:http://www.jstor.org/stable/1163620

Guillen-Cruz, G., Rodríguez-Sánchez, A. L., Fernández-Luqueño, F., & Flores-Rentería, D. (2021). Influence of vegetation type on the ecosystem services provided by urban green areas in an arid zone of northern Mexico. *Urban Forestry and Urban Greening*, *62*. https://doi.org/10.1016/j.ufug.2021.127135

Haase, D., Frantzeskaki, N., & Elmqvist, T. (2014). Ecosystem services in urban landscapes: Practical applications and governance implications. *Ambio*, *43*(4), 407–412. https://doi.org/10.1007/s13280-014-0503-1

Haase, D., Larondelle, N., Andersson, E., Artmann, M., Borgström, S., Breuste, J., Gomez-Baggethun, E., Gren, Å., Hamstead, Z., Hansen, R., Kabisch, N., Kremer, P., Langemeyer, J., Rall, E. L., McPhearson, T., Pauleit, S., Qureshi, S., Schwarz, N., Voigt, A., … Elmqvist, T. (2014). A quantitative review of urban ecosystem service assessments: Concepts, models, and implementation. In *Ambio* (Vol. 43, Issue 4, pp. 413–433). Kluwer Academic Publishers. https://doi.org/10.1007/s13280-014-0504-0

Haines-Young, R., & Potschin, M. (2010). The links between biodiversity, ecosystem services and human well-being. In David G. Raffaelli & Christopher L. J. (Eds.), *Ecosystem ecology: a new synthesis*. Cambridge University Press. www.cbd.int/ecosystem/principles.shtml

Harrison, R. L., Reilly, T. M., & Creswell, J. W. (2020). Methodological Rigor in Mixed Methods: An Application in Management Studies. *Journal of Mixed Methods Research*, *14*(4), 473–495. https://doi.org/10.1177/1558689819900585

Hirschhorn, F. (2019). Reflections on the application of the Delphi method: lessons from a case in public transport research. *International Journal of Social Research Methodology*, *22*(3), 309–322. https://doi.org/10.1080/13645579.2018.1543841

Hsu, D., Lim, T. C., & Meng, T. (2020a). Rocky steps towards adaptive management and adaptive governance in implementing green infrastructure at urban scale in Philadelphia. *Urban Forestry and Urban Greening*, *55*. https://doi.org/10.1016/j.ufug.2020.126791

Hsu, D., Lim, T. C., & Meng, T. (2020b). Rocky steps towards adaptive management and adaptive governance in implementing green infrastructure at urban scale in Philadelphia. *Urban Forestry and Urban Greening*, *55*. https://doi.org/10.1016/j.ufug.2020.126791

Huck, J. J., Whyatt, J. D., & Coulton, P. (2014). Spraycan: A PPGIS for capturing imprecise notions of place. *Applied Geography*, *55*, 229–237. https://doi.org/10.1016/j.apgeog.2014.09.007

ICLEI - Local Governments for Sustainability. (n.d.). *Nature Based Solutions for Sustainable Urban Development*.

Indian Institute of Management Bangalore (IIMB). (2023). *Green Campus*.

Instituto Nacional de Estadística y Geografía (INEGI). (2023). *INEGI Official Website*. Instituto Nacional de Estadística y Geografía (INEGI). https://www.inegi.org.mx/

International Union for Conservation of Nature and Natural Resources (IUCN). (2020). *IUCN Global Standard for Nature-based Solutions*. https://doi.org/10.2305/IUCN.CH.2020.09.en

Kim, G., & Coseo, P. (2018). Urban park systems to support sustainability: The role of urban park systems in hot arid urban climates. *Forests*, *9*(7). https://doi.org/10.3390/f9070439

le Tourneau, F. M., & Scott, C. A. (2020). Editorial overview: Resilience and complexity in social–ecological systems: theory, applications, and methods. In *Current Opinion in Environmental Sustainability* (Vol. 44, pp. A1–A3). Elsevier B.V. https://doi.org/10.1016/j.cosust.2020.10.010

Liu, Y., Bi, J., Lv, J., Ma, Z., & Wang, C. (2017). Spatial multi-scale relationships of ecosystem services: A case study using a geostatistical methodology. *Scientific Reports*, *7*(1). https://doi.org/10.1038/s41598-017-09863-1

Luederitz, C., Brink, E., Gralla, F., Hermelingmeier, V., Meyer, M., Niven, L., Panzer, L., Partelow, S., Rau, A. L., Sasaki, R., Abson, D. J., Lang, D. J., Wamsler, C., & von Wehrden, H. (2015). A review of urban ecosystem services: Six key challenges for future research. In *Ecosystem Services* (Vol. 14, pp. 98–112). Elsevier. https://doi.org/10.1016/j.ecoser.2015.05.001

Martínez-Guzmán, J., Algara-Siller, M., Hamhaber, J., & Ramos Palacios, C. (2021). *Proposal for a food security program: The urban agriculture guideline at the Autonomous University of San Luis Potosí* [Maestría]. Universidad Autónoma de San Luis Potosí and TH Köln.

Mason, S.-A., & Moore, S. A. (1998). Using the Sorensen Network to Assess the Potential Effects of Ecotourism on Two Australian Marine Environments. *Journal of Sustainable Tourism*.

Max-Neef, M. A., Elizalde, A., & Hopenhayn, M. (1998). *Desarrollo a escala humana : conceptos, aplicaciones y algunas reflexiones*. Icaria.

McPhearson, T., Andersson, E., Elmqvist, T., & Frantzeskaki, N. (2015). Resilience of and through urban ecosystem services. *Ecosystem Services*, *12*, 152–156. https://doi.org/10.1016/j.ecoser.2014.07.012

Millenium Ecosystem Assessment (MEA). (2005). *Ecosystems and Human Wellbeing: Synthesis.*

Mishra, B. K., Chauhan, V., & Malik pg, N. (n.d.). *Environment Sustainability Report 2021*.

Monteiro, R., Ferreira, J. C., & Antunes, P. (2020). Green infrastructure planning principles: An integrated literature review. *Land*, *9*(12), 1–19. https://doi.org/10.3390/land9120525

Montes-Betancourt, L. A., Aldama-Aguilera, C., & Algara-Siller, M. (2020). *Riqueza y diversidad de insectos polinizadores en tres parques de la ciudad de San Luis Potosí*.

National University of Singapore (NUS). (2017). *NUS Sustainability Strategic Plan*.

Nieto-Caraveo, L. M., & Medellín-Milán, P. (2004). *Hacia la construcción de una Agenda Ambiental de la Universidad Autónoma de San Luis Potosí, Reporte de la Comisión de Medio Ambiente*.

Obalum, S. E., Chibuike, G. U., Peth, S., & Ouyang, Y. (2017). Soil organic matter as sole indicator of soil degradation. *Environmental Monitoring and Assessment*, *189*(4). https://doi.org/10.1007/s10661-017-5881-y

Olsen, A. A., Wolcott, M. D., Haines, S. T., Janke, K. K., & McLaughlin, J. E. (2021). How to use the Delphi method to aid in decision making and build consensus in pharmacy education. In *Currents in Pharmacy Teaching and Learning* (Vol. 13, Issue 10, pp. 1376–1385). Elsevier Inc. https://doi.org/10.1016/j.cptl.2021.07.018

Pataki, D. E., Carreiro, M. M., Cherrier, J., Grulke, N. E., Jennings, V., Pincetl, S., Pouyat, R. V., Whitlow, T. H., & Zipperer, W. C. (2011). Coupling biogeochemical cycles in urban environments: Ecosystem services, green solutions, and misconceptions. *Frontiers in Ecology and the Environment*, *9*(1), 27–36. https://doi.org/10.1890/090220

Reglamento de construcciones del municipio de San Luis Potosí, (1995).

Reglamento de Parques y Jardínes Públicos del municipio libre de San Luis Potosí, S.L.P., (2002).

Ley de Cambio Climático para el estado de San Luis Potosí, (2015).

Plan Estatal de Desarrollo 2015 - 2021 de San Luis Potosí, (2016).

Reglamento de ecología para el municipio de San Luis Potosí, (2016).

Ley de protección y conservación de árboles urbanos del estado de San Luis Potosí, (2017).

Programa Estatal de Ordeamiento Territorial y Desarrollo Urbano de San Luis Potosí, (2020).

Ley Ambiental del estado de San Luis Potosí, (2021).

Programa Municipal de Ordenamiento Territorial y Desarrollo Urbano de San Luis Potosí, SLP 2050, (2021).

Petrosillo, I., Aretano, R., & Zurlini, G. (2018). Socioecological systems. In *Reference Module in Earth Systems and Environmental Sciences* (pp. 1–7). Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.09518-X

Phdungsilp, A. (2011). Futures studies' backcasting method used for strategic sustainable city planning. *Futures*, *43*(7), 707–714. https://doi.org/10.1016/j.futures.2011.05.012

Picos-Benítez, A., & Rodríguez-Robledo, J. (2010). *Estudio para la reducción del consumo de agua en la zona universitaria poniente de la UASLP mediante sustitución de muebles sanitarios, captación de agua de lluvia, cambio de jardinería y reutilización de agua tratada* [Maestria]. Universidad Autónoma de San Luis Potosí.

Poder legislativo. (1917). *Constitucion Política de los Estados Unidos Mexicanos*.

Pontificia Universidad Católica de Chile (PUC). (2019). *Reporte sustantabiliad 2018 - 2019*.

Pontificia Universidad Católica de Chile (PUC). (2020). *Reporte Sustentabilidad 2020*.

Popper, R. (2008). How are foresight methods selected? *Foresight*, *10*(6), 62–89. https://doi.org/10.1108/14636680810918586

Primmer, E., Jokinen, P., Blicharska, M., Barton, D. N., Bugter, R., & Potschin, M. (2015). Governance of Ecosystem Services: A framework for empirical analysis. *Ecosystem Services*, *16*, 158–166. https://doi.org/10.1016/j.ecoser.2015.05.002

Razzaghi Asl, S., & Pearsall, H. (2022a). How Do Different Modes of Governance Support Ecosystem Services/Disservices in Small-Scale Urban Green Infrastructure? A Systematic Review. In *Land* (Vol. 11, Issue 8). MDPI. https://doi.org/10.3390/land11081247

Razzaghi Asl, S., & Pearsall, H. (2022b). How Do Different Modes of Governance Support Ecosystem Services/Disservices in Small-Scale Urban Green Infrastructure? A Systematic Review. In *Land* (Vol. 11, Issue 8). MDPI. https://doi.org/10.3390/land11081247

Renzi, A. B., & Freitas, S. (2015). The Delphi Method for Future Scenarios Construction. *Procedia Manufacturing*, *3*, 5785–5791. https://doi.org/10.1016/j.promfg.2015.07.826

Robinson, K. F., Fuller, A. K., Hurst, J. E., Swift, B. L., Kirsch, A., Farquhar, J., Decker, D. J., & Siemer, W. F. (2016). Structured decision making as a framework for large-scale wildlife harvest management decisions. *Ecosphere*, *7*(12). https://doi.org/10.1002/ecs2.1613

Rocha, S. Maia., Zulian, Grazia., Maes, Joachim., Thijssen, Martijn., & European Commission. Joint Research Centre. (2015). *Mapping and assessment of urban ecosystems and their services.* Publications Office.

Scheiner, S. M., & Willig, M. R. (2008). A general theory of ecology. *Theoretical Ecology*, *1*(1), 21–28. https://doi.org/10.1007/s12080-007-0002-0

Programa de fomento a la planeación urbana, metropolitana y ordenamiento territorial 2019, (2019).

Servicio Meteorológico Nacional (SMN). (2023). *SMN Official Website*. Servicio Meteorológico Nacional (SMN). https://smn.conagua.gob.mx/es/

Shariff, N. (2015). Utilizing the Delphi Survey Approach a review. *J Nurs Care*, *4*(3), 246–251.

Stahle, A. (2018). *Developing Public Space and Land Values in Cities and Neighbourhoods*.

Szumacher, I. (2011). Functions of urban greenspace and ecosystem services. *Miscellanea Geographica*, *15*, 123–129. https://doi.org/10.2478/v10288-012-0008-3

Technical University of Munich (TUM). (2023). *TUM Sustainable Futures Strategy 2030*.

The Economics of Ecosystems and Biodiversity (TEEB). (2012). *The Economics of Ecosystems and Biodiversity in Local and Regional Policy and Management*.

The World Bank (TWB). (2023). *World Bank Country and Lending Groups*. The World Bank (TWB). https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

TWB. 2009. Making Monitoring and Evaluation Systems Work. A Capacity Development Toolkit. (n.d.).

Universiad Nacional Autónoma de México (UNAM). (2022). *Plan Integral para la Sustantabilidad desde la UNAM. 4.1. Ordenamiento teritorial y manejo sustentable de suelos, áreas verdes y reservas naturales*. https://cous.sdi.unam.mx/

Universidad Autónoma de San Luis Potosí (UASLP). (n.d.). *Portal de la Agenda Ambiental*. Universidad Autónoma de San Luis Potosí (UASLP). Retrieved 24 May 2022, from https://ambiental.uaslp.mx/

Universidad Autónoma de San Luis Potosí (UASLP). (2022). *Tercer informe Indicadores Institucionales*.

University of British Columbia (UBC). (2018). *UBC Green Building Action Plan*.

University of California Los Angeles (UCLA). (2022a). *UCLA Landscape Plan*.

University of California Los Angeles (UCLA). (2022b). *UCLA Sustainability Plan*.

University of Cape Town (UCT). (2008). *UCT Green Campus Action Plan 2009*.

University of Cape Town (UCT). (2020). *UCT Environmental Sustainability Strategy*.

University of Edinburgh (UoE). (2022). *Biodiversity Plan*. www.ed.ac.uk/sustainability

University of Glasgow (UoG). (2022). *Biodiversity Strategy and Action Plan 2022-2027*.

University of Melbourne (UniMel). (2020). *Sustaianbility Plan 2020*.

University of Washington (UW). (2022). *Urban Forest Management Plan - University of Washington*.

Universtiy of Melbourne (UniMel). (2017). *Biodiversity Management Plan*.

US Forest Service. (2019). *i-Tree Eco Field Guide*.

Vogt, J., & Cortez, C. (2020). Urban social-ecological systems. In *Encyclopedia of the World's Biomes* (Vols 5–5, pp. 35–47). Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.12458-3

Ward, C., de Oliviera, E., Wheeler, B., Depledge, M., & van den Bosch, M. (2016). *Urban green spaces and health*.

Wentworth, J. (2017). *Urban Green Infrastructure and Ecosystem Services*. www.parliament.uk/post

Williams, B. K., & Brown, E. D. (2016). Technical challenges in the application of adaptive management. *Biological Conservation*, *195*, 255–263. https://doi.org/10.1016/j.biocon.2016.01.012

Winkler, J., & Moser, R. (2016). Biases in future-oriented Delphi studies: A cognitive perspective. *Technological Forecasting and Social Change*, *105*, 63–76. https://doi.org/10.1016/j.techfore.2016.01.021

Wong, C. P., Jiang, B., Kinzig, A. P., & Ouyang, Z. (2018). Quantifying multiple ecosystem services for adaptive management of green infrastructure. *Ecosphere*, *9*(11). https://doi.org/10.1002/ecs2.2495

World Economic Forum (WEF), & Alexander von Humboldt Biological Resources Research Institute. (2022). *BiodiverCities by 2030: Transforming Cities' Relationship with Nature*.

World Health Organization (WHO). (2017). *Urban green spaces: A brief for action*.

Wu, J. (2014). Urban ecology and sustainability: The state-of-the-science and future directions. *Landscape and Urban Planning*, *125*, 209–221. https://doi.org/10.1016/j.landurbplan.2014.01.018

Wu, J. (2019). Linking landscape, land system and design approaches to achieve sustainability. *Journal of Land Use Science*, *14*(2), 173–189. https://doi.org/10.1080/1747423X.2019.1602677

Zhao, D., Lei, Q., Shi, Y., Wang, M., Chen, S., Shah, K., & Ji, W. (2020). Role of species and planting configuration on transpiration and microclimate for urban trees. *Forests*, *11*(8). https://doi.org/10.3390/f11080825

9. ANNEXES

Annex A – Methodological Framework tools

Annex B – Protocol for the Adaptive Management of the UASLP green infrastructure

9.1. ANNEX A – PILOT TEST TOOLS

I. *First expert consultation survey*

Table 1. Pre-selection of relevant UES and UED, and proposed indicators and methodologies for their assessment.

UES / UED		Indicator	Method
Supporting	Biodiversity	Flora diversity. Bird richness. Native species percentage.	Shannon-Wiener Index, Specific richness or Literature search for native species.
	Habitat connectivity	Structural connectivity index. Beta-diversity.	Calculation of structural connectivity index or Calculation of beta-diversity.
Regulating	Microclimate regulation	Temperature reduction in °C. Increase in relative humidity by percentage. Reduction of solar radiation in kw/m^2.	Direct measurement at variable distances from the UGI
	Noise reduction	Noise reduction in dB.	Direct measurement at variable distances from the UGI
	Air quality regulation	Change in atmospheric pollutants concentration in ppm	Dry deposition model (i-tree eco)
	Carbon sequestration	Biomass carbon sequestration.	Allometric equations (i-tree eco)
	Pollinators	Pollinators diversity. Pollinators richness.	Shannon-Wiener Index or Specific richness.
	Pests	Number of experiences	Participatory mapping (Spraycan web)

UES / UED		Indicator	Method
	Soil quality maintenance	Chage in soil organic matter content in percentage	Loss on ignition
	Waterflow regulation	Decreased runoff. Rain interception.	Runoff curve number or Rain interception model (i-tree eco).
Cultural	Aesthetic pleasure	Number of experiences.	Mapeo participativo (Spraycan web)
Cultural	Connection with nature	Number of experiences	Participatory mapping (Spraycan web)
Cultural	Stress reduction	Number of experiences	Participatory mapping (Spraycan web)
Cultural	Allergens	Allergen species presence	Based on Ogren Plant Allergy Scale list.
Cultural	Community creation.	Number of experiences	Participatory mapping (Spraycan web)
Cultural	Perception of insecurity	Number of experiences	Participatory mapping (Spraycan web)
Provisioning	Food production	Food production capacity in kg/m^2.	Annual comparison of food production in kg/m^2.
Provisioning	Water infiltration	Infiltration capacity in m/h.	Estimation based on soil texture.
Provisioning	Water consumption	Quantity of water used above irrigation sheet.	Calculation of irrigation sheet.

Ecosystem good or service   Ecosystem disservice

Table 2. First expert consultation survey.

Survey 1. Considering that the attached pre-selected list of urban ecosystem goods, services, and disservices, with their proposed indicators and methodologies is only a reference, and is not restrictive, please respond. On the "Relevance" column please mark with an (x) the 10 UES / UED that you consider as the most relevant for the green areas inside the western campus of the UASLP. On the following column, please provide a short justification for your decision, based on your expert knowledge. You can elaborate using any criteria you find important, like extension, duration, intensity, or others. On the last 2 columns please select one indicator and one method of monitoring for each element you marked as relevant. You can select them from the reference list, or write a completely new one, if you think it could be better for the context of the project. If you consider important to add a different UES / UED to those provided on the reference list, please write it on the last row. You are free to add as many new items to the list as you want, as long as you provide a reason, indicator and method for it, and keep the final count of 10 relevant UES / UED.						
UES / UED			Relevance	Justification	Proposed indicator	Proposed method
Supporting	1	Biodiversity				
	2	Habitat connectivity				
Regulating	3	Microclimate regulation				
	4	Noise reduction				
	5	Air quality regulation				
	6	Carbon sequestration				
	7	Pollinators				
	8	Pests				
	9	Soil quality maintenance				
	10	Waterflow regulation				

Cultural	11	Aesthetic pleasure				
	12	Connection with nature				
	13	Stress reduction				
	14	Allergens				
	15	Community creation				
	16	Perception of insecurity				
Provisioning	17	Food production				
	18	Water infiltration				
	19	Water consumption				
Other	20					

II. Second expert consultation survey

Table 3. Pre-selection of relevant urban green infrastructure units or interventions.

Urban Green Infrastructure		Description
1	Food garden	An urban garden developed to produce food, promoting local food production, community engagement, and sustainable agriculture practices.
2	Floral garden	A garden primarily focused on cultivating ornamental flowers and plants, enhancing aesthetics and providing habitat for pollinators.
3	Botanical garden	A curated collection of diverse plant species for educational, research, and conservation purposes.
4	Etnobotanical garden	A garden that features plants of cultural and traditional significance, highlighting their historical, medicinal, and cultural uses.
5	Hedges / Barriers	Rows of closely spaced shrubs or small trees intentionally planted to form a dense boundary or barrier, providing privacy, windbreaks, and visual delineation.
6	Lined trees	Trees planted in a straight line or pattern along streets, walkways, or paths, enhancing aesthetics, providing shade, and creating visual definition.
7	Green corridor	A linear stretch of green space connecting different areas within an urban landscape, promoting biodiversity, enhancing connectivity, and providing recreational opportunities.
8	Green wall	Vertical structures covered with vegetation, often installed on building exteriors, enhancing aesthetics, improving air quality, and providing thermal insulation.
9	Green facade	Vegetation integrated into building facades, contributing to energy efficiency, improving air quality, and creating a visually appealing environment.
10	Vertical garden	Plants grown vertically on structures such as planters or frames, maximizing green spaces and providing aesthetic benefits.
11	Vegetated pergola	A structure with climbing plants or vines growing over it, providing shade, creating a pleasant outdoor space.

Urban Green Infrastructure		Description
12	Green roof	Vegetated roofs installed on buildings, reducing stormwater runoff, mitigating the urban heat island effect, and providing habitat for wildlife.
13	Infiltration well	A subsurface structure designed to collect and infiltrate stormwater runoff into the ground, replenishing groundwater and reducing runoff.
14	Bioswale	Shallow vegetated channels or depressions designed to manage stormwater runoff, promoting infiltration and filtering pollutants.
15	Rain garden	A planted depression or basin that collects and filters stormwater runoff, allowing water to infiltrate into the ground and reducing water pollution.
16	Permeable pavement	Porous surfaces that allow rainwater to infiltrate into the ground, reducing stormwater runoff and replenishing groundwater.
17	Use of native species	Planting indigenous plant species adapted to the local ecosystem, supporting biodiversity, and requiring less maintenance and resources.
18	Shelter for biodiversity	Providing habitat features like nesting boxes, insect hotels, or bird feeders to support wildlife and enhance urban biodiversity.
19	Biodiversity monitoring	Regular assessment and recording of species diversity and population trends to inform conservation efforts. It could be done either by specialists or using citizen science.
20	Integrated pest management	A holistic approach to pest control that combines various strategies, minimizing chemical pesticides and promoting natural pest control methods.
21	Nature-based art installations	Artistic installations incorporating natural elements or themes, enhancing the aesthetic appeal of urban spaces and promoting environmental awareness.
22	Seasonal management	Adapting green infrastructure practices based on seasonal variations, such as adjusting irrigation, plant selection, and maintenance activities like pruning and fertilizing.
23	Composting	Recycling organic waste into nutrient-rich compost, reducing landfill waste, and enhancing soil quality.

Urban Green Infrastructure		Description
24	Soil improvement practices	Techniques like soil aeration, mulching, and organic amendments to enhance soil health, fertility, and water retention.
25	Erosion control	Implementing measures to prevent soil erosion, such as erosion control blankets, retaining walls, and strategic planting to stabilize slopes.
26	Rainwater harvesting	Installing infrastructure to collect and store stormwater for future use, reducing demand on freshwater sources.
27	Efficient irrigation systems	Water-efficient irrigation methods like drip irrigation, smart controllers, and moisture sensors to minimize water waste and promote plant health.

Table 4. Second expert consultation survey.

Survey 2. A. First, take a look at the summary of the previous expert consultation on the attached "reference information" document, and answer question 1. B. On the same "reference information" document, analyze the ecosystem services currently provided by the ZUP Campus green areas, and the pre-selected list of urban green infrastructure initiatives, and answer question 2. C. Finally, open the "ZUP Campus map" document, and allocate the provided dots, according to the answers you gave on the previous question.
Question 1. Looking at the summarized table, please provide at least 3 actions or interventions that you consider as highly relevant to implement, in order to manage the university's green spaces in a sustainable way.
1
2
3
Question 2. From the pre-selected list provided on the reference document, please identify the 5 Urban Green Infrastructure units or interventions that you consider are the most relevant for implementation on the ZUP Campus green areas management plan. Write them in order of importance on the following table and provide a short justification for each.

Selected UGI unit or intervention		Justification
1		
2		
3		
4		
5		
Question 3. Considering the interventions as you ranked them on question 2; open the "ZUP Campus map" document and allocate the 5 dots spatially on the areas where you would implement each selected intervention.		

ZUP CAMPUS MAP.

Look at the blue circles on the right side of the map. Each one represents the UGI unit or intervention that you selected on Question 2, the number inside it represents the rank you gave them. Please clic and drag them to the spatial location that you would like to see the solution implemented. The idea is to spatially localize your previous answers.

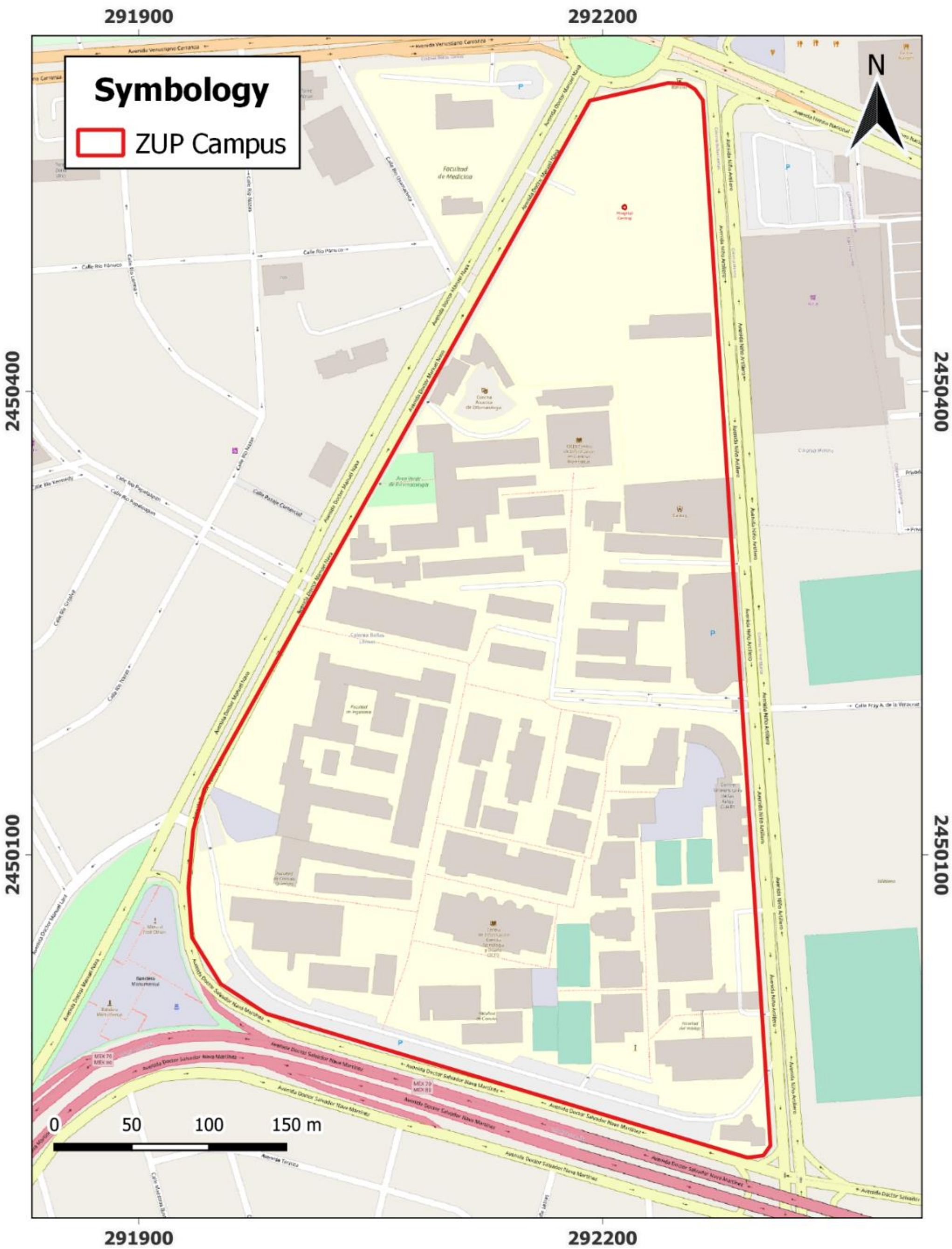


Figure 1. Reference document: ZUP Campus map

III. Participatory Mapping (PPGIS) survey

Table 5. Design of the participatory mapping survey (PPGIS).

INTRODUCTION This is a participatory mapping exercise of Urban Ecosystem Services within the Zona Poniente campus of the UASLP. Urban ecosystem services are the "benefits that people obtain from ecosystems and that are directly produced by ecological structures within urban areas". Under this logic, university green areas generate urban ecosystem services that all university students enjoy.
INSTRUCTIONS You will be presented with a series of interactive maps, on which you will be able to mark, with a "spray" type tool, the university green zones or areas that best answer the specific question. Remember to activate the tool by clicking on “activate spray tool” button, located on the upper section of the screen. If pressed again, the tool is deactivated. The “Delete” button eliminates the marked spots for the current question, and the “Restart” button brings you back to the original view. The website allows for the free navigation among questions, by clicking on “next question” and “previous question” buttons, located on the right section of the screen, which gives you freedom to edit your answers. Do not forget to zoom in to your area of interest before marking your answer. To facilitate the management of the information generated, please use the following scale when answering. 1 click - "The area I am marking answers the question **lightly**". 2 clicks - "The zone I am marking answers the question **moderately**". 3 clicks - "The zone I am marking responds to the question **intensely**".
DEMOGRAPHIC DATA ¿What is your role at the UASLP? *Student, professor, administrative, other* ¿What faculty or department are you a part of?
TRAINING Utilize this moment to familiarize yourself with the use of the spraycan tool. You can start by marking the location of your faculty or department inside the University

Western Campus. Remember to zoom in to an adequate level and that you can always delete your answer. When you are ready, please click on the “next question” button to start the survey. The information gathered on this specific question will not be used on the research.	
QUESTIONS	**UES / UED**
1. Considering the green areas located inside the UASLP Western Campus only. Does any green area on campus strike you as particularly aesthetically pleasing? What plant, animal, structure, or situation makes you feel this way?	Aesthetic pleasure
2. Considering the green areas located inside the UASLP Western Campus only. Is there any place on campus where you enjoy appreciating nature? What plant, animal, structure, or situation makes you feel this way?	Connection to nature
3. Considering the green areas located inside the UASLP Western Campus only. Is there a place on campus where you go to relax? What plant, animal, structure, or situation makes you feel this way?	Stress reduction
4. Considering the green areas located inside the UASLP Western Campus only. Is there a green area on campus where you prefer to socialize? What structure or situation makes you feel this way?	Community building
5. Considering the green areas located inside the UASLP Western Campus only. Does any place on campus feel unsafe to you?	Insecurity

Can you give a specific reason for this?	
6. Considering the green areas located inside the UASLP Western Campus only. Have you had negative encounters with animals inside the site? What animal was it?	Pests
7. Considering the whole campus. Do you know of any place on campus where you suffer from excessive heat?	Demand for microclimate regulation
8. Considering the whole campus. Do you know of any site on campus that suffers from flooding due to rainfall?	Demand for water flow regulation
9. Considering the whole campus. Do you know of any site on campus where outside noise reaches annoying levels?	Demand for noise regulation
10. Considering the whole campus ¿Is there a specific area where you think the installation of a new green infrastructure would be beneficial? If so, which infrastructure? (Some examples are: forested areas, floral garden, green roof, green walls, urban garden, xerophyte garden, simple pots, and so on) Which ecosystem service would you like to provide to that space?	
CONCLUSION: Will you be willing to participate in an interactive activity to support this research? If you do, please leave your name, e-mail and cellphone number for us to contact you.	

9.2. ANNEX B –PROTOCOL FOR THE ADAPTIVE MANAGEMENT OF THE UASLP GREEN INFRASTRUCTURE

PROTOCOL FOR THE ADAPTIVE MANAGEMENT OF THE UASLP GREEN INFRASTRUCTURE

TABLE OF CONTENTS

INTRODUCTION AND OVERVIEW.

Currently there is a great deal of interest on the importance of green spaces as support for a healthy life on urban areas. This is because the planet’s population is growing at an accelerated rate with a clear tendency towards urbanization. It is believed that by 2030, more than 60% of estimated population (4.9 of 8.1 billion) will live in cities, areas characterized by their huge and complex environmental footprints (Endlicher et al., 2007). Due to global climate change, ample regions of the world will have to face multiple common challenges in the coming years like demographic explosion, temperature rising, food insecurity, water scarcity and increased risk of droughts and floods (Kim & Coseo, 2018). Urban systems, composed by highly modified landscapes, are a key element to sustain the environment and their inhabitant’s wellbeing (Guillen-Cruz et al., 2021).

All ecosystems (including the highly urbanized) possess functions and provide services. The first ones refer to the properties or processes inherent to the system, while the second ones refer to the benefits that humans obtain directly or indirectly of said ecosystem functions (Costanza et al., 1997).

The publication of the Millenium Ecosystem Assessment in 2005 contributed to put the term of “ecosystem services” in the public eye, and related literature has grown exponentially ever since (Martínez-Guzmán et al., 2021). Afterwards it became consolidated in the international agenda in 2015, with the publication of the Sustainable Development Goals by the United Nations, by being included in the Objective 11. Sustainable communities and cities (Stahle, 2018).

At the Universidad Autónoma de San Luis Potosí (Autonomous University of San Luis Potosí, UASLP), the Agenda Ambiental (Environmental Agenda, AA) is an organization created with the explicit mission of articulating strategies to reach sustainability inside the university and society through the multidisciplinary integration of 4 pillars: education and research, institutional management, linkages and projects, and communication.

As part of its institutional management axis, the AA has implemented the Sistema de Gestión Ambiental (Environmental Management System, SGA), to improve the environmental performance of the UASLP in all its functions and transform it into a sustainable institution in conjunction with the community (Nieto-Caraveo & Medellín-Milán, 2004).

One of the many programs devised by the AA is the University Program for Biodiversity (PUB), whose general objective is "*to integrally manage the flora and fauna found in the spaces and gardens of university campuses in a sustainable and respectful manner"* (Universidad Autónoma de San Luis Potosí (UASLP), n.d.).

Considering that the UASLP has the interest and capacity for action by implementing these programs in all its campuses located in the whole state, and that as a whole they cover a vast number of social and ecological contexts, it has been decided to use its institutional capacity to design a strategy that can be applied in urban areas with different geographical extent, population size and climatic conditions.

Multiple relevant reports affirm that ecosystem services and biodiversity can be successfully managed through a cyclic and integrated management and planning style and recommends that it consists of a baseline of appropriate information, participatory consultation to determine objectives, implementation of actions, monitoring, assessment, and results reporting. This management methodology known as adaptive management is highly robust and responsive in the face of uncertainty. (Green et al., 2016; Hatfield-Dodds et al., 2007; Hsu et al., 2020; International Union for Conservation of Nature and Natural Resources (IUCN), 2020; McPhearson et al., 2015; Razzaghi Asl & Pearsall, 2022; The Economics of Ecosystems and Biodiversity (TEEB), 2012; Wentworth, 2017; World Economic Forum (WEF) & Alexander von Humboldt Biological Resources Research Institute, 2022)

This protocol integrates the concepts of systemic vision, participatory approaches, adaptive management, local idiosyncrasies, and inclusion of high impact actors in a logical sequence, adequate for its implementation on a small-scale, university campus context. (Table 1)

Table 1. Overview of the protocol.

Step		Overview
Specific objective 1	Define scope and objectives	Objectives will be taken from the institutional agenda. Geographic scope will be done through the categorization of urban green infrastructure by configuration and type. Main actors will be identified and classified by interest and influence. **Final product is the categorization of main components.** (Deutsche Gesellschaft für Internationale Zusammenarbeit, 2019).
	Identify and prioritize UES and UED	Based on e-Delphi methodology (Olsen et al., 2021) Selection of a group of experts through "type of actors" and "snowball" sampling, based on roles and experience. Data will be gathered and given to them based on a literature review. **Final product is a prioritized list of urban ecosystem services and disservices, their indicators and chosen methods of evaluation.**
Specific objective 2	Analyze the current state of the UES and UED	**Demand and provision** When possible, data gathering from literature review. When necessary, sampling or surveying using specific methodologies per ecosystem service or disservice. Indicators calculation. **Statistical analysis** (Liu et al., 2017) Correlation matrix comparing urban ecosystem services. Determination matrix comparing urban ecosystem services and urban green infrastructure. **Spatial analysis** (Burkhard & Maes, 2017) Elaboration of cartography for provision and demand of ecosystem services.
Specific objective 3	Generate a complex system	Identification of main components using a matrix based on key questions (Elia et al., 2020). Interrelations and goal of the system will be deducted. **Final product is a diagram of the complex system.**

Step		Overview
	Identify synergies and tradeoffs	Identification of spatial shortfalls on the provision and demand of ecosystem services. Creation of ecological production functions (EPF) through ordinary least square (OLS) regression. Calculation of marginal values through regression coeficients. **Final products are spatial shortfall maps and ecological production functions for each urban ecosystem service or disservice.** (Wong et al., 2018)
Specific objective 4	Develop an adaptive management strategy	Based on the structured decision-making methodology (Robinson et al., 2016). a) Problem statement. Taking the institutional objectives as basis. b) Definition of objectives and management strategies. Use of e-Delphi to determine fundamental objectives, subobjectives and management alternatives based on identified shortfalls. c) Consequences. Modelling of management alternatives using EPF. d) Optimal decision. using e-Delphi to assign different weights to the assessed alternatives and calculating the expected utility value for each one, selecting the optimal (Wong et al., 2018). e) Monitoring. Develop a set of indicators for monitoring based on the methodology of The World Bank (*TWB. 2009. Making Monitoring and Evaluation Systems Work. A Capacity Development Toolkit*, n.d.). f) Learning. Through the application of a double loop of learning. **Final product is an adaptive management strategy.**

1. Define objectives and scope.

The first step consists of defining objectives and scope and identifying the main actors on urban green infrastructure (UGI) management inside the area of study. This will be done through a literature revision and open interviews with workers and managers of the project.

The research objectives are already defined on the corresponding section of this document.

To define the geographic scope of the project, a digitalized and georeferenced plan of the UASLP western campus will be used, where the different UGI present will be identified. An on-site verification will be carried out afterwards.

The classification of Zhao et al. (2020) will be used to categorize the UGI, who determined differences in the provision of urban ecosystem services (UES) and urban ecosystem disservices (UED) based on their types and configurations.

The UGI themselves will be categorized using the hierarchical classification created by Castellar et al. (2021). This classification matrix is presented on Table 2.

Table 2. UGI categorization matrix.

				Configuration		
				Punctual	**Linear**	**Group**
Type	**Units**	**Spatial**	**Arboreal**	Individual tree	Lined trees Sidewalk trees	Urban forest Orchards
			Mixed vegetation	Small planter	Green corridor Hedges.	Park Urban garden Botanical garden
		Technological	**Vertical**	Vertical planter	Green wall Green facade	Vegetated pergola
			Horizontal	Infiltration basin	Bioswale	Green roof Rain garden Permeable pavement
	Interventions		**Soil**	Compost Soil improvement Systems for erosion control		
			Biodiversity	Biodiversity habitats and shelters Use of native vegetation.		
			River	Riverbank engineering Blue corridor Floodplain management Diverting elements.		

Source: Castellar et al. (2021); Zhao et al. (2020)

Table 3 presents the matrix required to identify and classify the different actors and stakeholders for the management of UGI inside the area of study. The matrix will be filled based on open interviews with administrative and maintenance personal inside the campus.

Table 3. Matrix for the identification and categorization of main actors

	Low interest	High interest
High influence	**Context creators** May become risk actors, must be monitored and managed	**Main actors** Must be actively involved in the process
Low influence	**Crowd** Irrelevant for the current project	**Subjects** Foster their partnerships with key stakeholders to empower them

Source: Deutsche Gesellschaft für Internationale Zusammenarbeit (2019)

2. IDENTIFY AND PRIORITIZE ECOSYSTEM SERVICES AND DISSERVICES.

The identification and prioritization of UES and UED allows to reduce the complexity of the evaluation and ensures relevant results applicable for decision making. The original methodology was modified in favor of an iterative method, in line with an adaptive strategy. The Delphi method from dell'Olio et al. (2018) is a formal, deep, and systemic methodology developed with the objective of reducing the diversity of opinions inside a group to converge in a common decision.

The criteria for selecting the experts were defined as: variety of roles, variety of academic disciplines and/or work positions, and prominence on the field. A summary is presented on Table 4

Table 4. Expert identification matrix

Role	Discipline / Position	Actor	Prominence
Academic	Ecology		
	Edaphology		
	Hydrology		
	Climatology		
	Urban planning		
	Sociology		
	Architecture		
Administrative	Agenda Ambiental		
	Directive		
	Rectory		
Operative	Urban garden		
	Waste management		
	Water management		
	Maintenance		

Source: Hirschhorn (2019)

The methodology will be adapted according to Olsen et al. (2021) by offering a list of possible answers based on a previous literature review, which reduces the necessary rounds, and using electronic tools for communication, considering that all the participants are part of the UASLP and have an institutional e-mail account and free internet access inside the installations. This decision is made to create a process that can be easier and more convenient for all the involved participants.

To expedite the discussion, a pre-selection of 19 UES and UED of interest was developed (presented on Table 5). Using this list as a basis, the first questionnaire (presented on Table 6) was designed with the objective of identifying priority ecosystem goods, services and disservices or adding or removing elements of the list. The expected result is a complete list of relevant UES and UED for the specific area of study.

This information will be compiled, reevaluated and the updated list, with the percentage of votes each item receives, will be forwarded as feedback to all participants.

Subsequently, the second survey (presented in Table 7) will be conducted to obtain a list of prioritized elements, for which a constant sum question will be asked.

Experts will distribute 100 points among the UES and UED in the updated list, the score indicating the importance of each element for the evaluation. According to Hirschhorn (2019), using a constant sum question makes it possible to analyze results using simple parametric statistics. Thus, the results will be compiled and analyzed as follows:

- Arithmetic mean of the score obtained for each variable.
- Standard deviation of the score obtained for each variable.
- Highest value obtained for each variable.
- Percentage of experts rating a variable as zero.
- Prioritization, considering the total score received.

Prioritization will be done considering the total sum of points, while the consensus or divergence among the experts will be measured through standard deviation, maximum value and the number of null scores attributed to each element.

Table 5. Pre-selection of relevant UES and UED, and proposed indicators and methodologies for their assessment.

UES / UED		Indicator	Method	Reference
Supporting	**Biodiversity** (Dobbs et al., 2011; Haase et al., 2014; Wentworth, 2017)	Flora diversity. Bird richness. Native species percentage.	Shannon-Wiener Index. Specific richness. Literature search for native species.	(Dobbs et al., 2011)
	Habitat connectivity (Haase et al., 2014)	Structural connectivity index. Beta-diversity.	Calculation of structural connectivity index. Calculation of beta-diversity.	(Tian et al., 2017) (Montes-Betancourt et al., 2020)
Regulating	**Microclimate regulation** (Bolund & Hunhammar, 1999; Brzoska & Spaġe, 2020; Dobbs et al., 2011; Pataki et al., 2011; Wentworth, 2017)	Temperature reduction in °C. Increase in relative humidity by percentage. Reduction of solar radiation in kw/m^2.	Direct measurement at variable distances from the UGI	(Maclean et al., 2021; Unwin, 1978; Zhao et al., 2020)
	Noise reduction (Bolund & Hunhammar, 1999; Dobbs et al., 2011; Wentworth, 2017)	Noise reduction in dB.	Direct measurement at variable distances from the UGI	(Department of Environment and Heritage Protection of Queensland, 2013; Izzaty Mohd Isa et al., 2018)

UES / UED		Indicator	Method	Reference
	Air quality regulation (Bolund & Hunhammar, 1999; Dobbs et al., 2011; Pataki et al., 2011; Wentworth, 2017)	Change in atmospheric pollutants concentration in ppm	Dry deposition model (i-tree eco)	(Hirabayashi et al., 2015)
	Carbon sequestration (Bolund & Hunhammar, 1999; Dobbs et al., 2011; Pataki et al., 2011; Wentworth, 2017)	Biomass carbon sequestration.	Allometric equations (i-tree eco)	(Nowak et al., 2008)
	Pollinators (Haase et al., 2014; Wentworth, 2017)	Pollinators diversity. Pollinators richness.	Shannon-Wiener Index. Specific richness.	(Montes-Betancourt et al., 2020)
	Pests (Haase et al., 2014; Wentworth, 2017)	Number of experiences	Participatory mapping (Spraycan web)	(Huck et al., 2014)
	Soil quality maintenance (Dobbs et al., 2011; Obalum et al., 2017)	Chage in soil organic matter content in percentage	Loss on ignition	(Pouyat et al., 2007; Roper et al., 2019)
	Waterflow regulation (Bolund & Hunhammar, 1999; Dobbs et al., 2011; Haase et al., 2014; Pataki et al., 2011; Wentworth, 2017)	Decreased runoff. Rain interception.	Runoff curve number. Rain interception model (i-tree eco).	(Domínguez Mora et al., 2008) (Hirabayashi, 2013)

UES / UED		Indicator	Method	Reference
Cultural	**Aesthetic pleasure** (Bolund & Hunhammar, 1999; Dobbs et al., 2011; Haase et al., 2014)	Number of experiences.	Mapeo participativo (Spraycan web)	(Huck et al., 2014)
	Connection with nature (Bolund & Hunhammar, 1999)	Number of experiences	Participatory mapping (Spraycan web)	(Huck et al., 2014)
	Stress reduction (Bolund & Hunhammar, 1999; Pataki et al., 2011)	Number of experiences	Participatory mapping (Spraycan web)	(Huck et al., 2014)
	Allergens (Dobbs et al., 2011; Pataki et al., 2011)	Allergen species presence	Based on Ogren Plant Allergy Scale list.	(Dobbs et al., 2011)
	Community creation. (Haase et al., 2014; Martínez-Guzmán et al., 2021)	Number of experiences	Participatory mapping (Spraycan web)	(Huck et al., 2014)
	Perception of insecurity (Pataki et al., 2011)	Number of experiences	Participatory mapping (Spraycan web)	(Huck et al., 2014)
Provisioning	**Food production** (Martínez-Guzmán et al., 2021; Wentworth, 2017)	Food production capacity in kg/m^2.	Annual comparison of food production in kg/m^2.	(Martínez-Guzmán et al., 2021)
	Water infiltration (Haase et al., 2014)	Infiltration capacity in m/h.	Estimation based on soil texture.	(Comisión Nacional del Agua (CNA), 2002)
	Water consumption	Quantity of water used	Calculation of irrigation sheet.	(Comisión Nacional del

UES / UED		Indicator	Method	Reference
	(Guillen-Cruz et al., 2021; Kim & Coseo, 2018; Pataki et al., 2011)	above irrigation sheet.		Agua (CNA), 2002)

Ecosystem good or service   Ecosystem disservice

Table 6. Survey for identification of UES and UED, their indicators and methods.

Survey 1.

Considering that the attached pre-selected list of urban ecosystem goods, services, and disservices, with their proposed indicators and methodologies is only a reference, and is not restrictive, please respond.

On the "Relevance" column please mark with an (x) the 10 UES / UED that you consider as the most relevant for the green areas inside the western campus of the UASLP.

On the following column, please provide a compelling reason for your decision, based on your expert knowledge.

On the last 2 columns please select one indicator and one method of monitoring for each element you marked as relevant. You can select them from the reference list, or write a completely new one, if you think it could be better for the context of the project.

If you consider important to add a different UES / UED to those provided on the reference list, please write it on the last row. You are free to add as many new items to the list as you want, as long as you provide a reason, indicator and method for it, and keep the final count of 10 relevant UES / UED.

UES / UED			Relevance	Provide a reason	Proposed indicator	Proposed method
Supporting	**1**	**Biodiversity**				
	2	**Habitat connectivity**				

Regulating	3	Microclimate regulation				
	4	Noise reduction				
	5	Air quality regulation				
	6	Carbon sequestration				
	7	Pollinators				
	8	Pests				
	9	Soil quality maintenance				
	10	Waterflow regulation				
Cultural	11	Aesthetic pleasure				
	12	Connection with nature				
	13	Stress reduction				
	14	Allergens				
	15	Community creation				
	16	Perception of insecurity				
Provisioning	17	Food production				
	18	Water infiltration				
	19	Water consumption				
Other	20					

Table 7. Survey for the prioritization of UES and UED, their indicators and methods

Survey 2.

The following list of ecosystem goods, services and disservices has been selected by the whole panel as the most relevant to analyze for the UASLP western campus.

Please distribute 100 points among the listed elements considering that the greater the number of points you give, the greater the relevance you consider the item to have.

You can allot any whole positive number to the items, including zero as long as the final sum is 100. Please try to avoid the use of decimals unless you consider it completely necessary.

Just like in the previous survey, on the following column, please provide a short reason for your decision, based on your expert knowledge. You can use any criteria you find important to decide, like extension, duration, intensity, or others.

UES / UED			Score	Provide a reason
Supporting	1	Biodiversity		
	2	Habitat connectivity		
Regulating	3	Microclimate regulation		
	4	Noise reduction		
	5	Air quality regulation		
	6	Carbon sequestration		
	7	Pollinators		
	8	Pests		
	9	Soil quality maintenance		
	10	Waterflow regulation		
Cultural	11	Aesthetic pleasure		
	12	Connection with nature		
	13	Stress reduction		

	14	Allergens		
	15	Community creation		
	16	Perception of insecurity		
Provisioning	17	Food production		
	18	Water infiltration		
	19	Water consumption		
Other	20			

3. Analyze the state of ecosystem services and disservices.

Once UES and UED elements have been prioritized and their indicators and evaluation methodologies have been chosen, the next step is their quantification and analysis.

To identify the status of the UES and UED present in the study area, their provision and demand must first be quantified, then the cause-effect relationships of the main trends, the factors driving their change, the main stakeholders, and the management decisions behind these drivers of change must be analyzed.

Table 5 includes the proposed assessment indicators and measurement methods for the supply, or provision of UES and UED, while demand consultation will be determined by low incidence areas when it can be measured biophysically or using participatory mapping by the "Map-me" web platform (Huck et al., 2014), when it is measured by perception.

3.1. Data collection for ecosystem services demand

The participatory mapping survey was designed to be sufficiently simple, with a brief introduction and easy-to-follow instructions. The basic structure is presented in Table 8. It is recommended to process the data obtained to weight each participant dataset equally.

Table 8. Design of the participatory mapping survey (PPGIS).

INTRODUCTION This is a participatory mapping exercise of Urban Ecosystem Services within the Zona Poniente campus of the UASLP. Urban ecosystem services are the "benefits that people obtain from ecosystems and that are directly produced by ecological structures within urban areas". Under this logic, university green areas generate urban ecosystem services that all university students enjoy.
INSTRUCTIONS You will be presented with a series of interactive maps, on which you will be able to mark, with a "spray" type tool, the university green zones or areas that best answer the specific question. Remember to activate the tool by clicking on "activate spray tool" button, located on the upper section of the screen. If pressed again, the tool is deactivated. The "Delete" button eliminates the marked spots for the current question, and the "Restart" button brings you back to the original view. The website allows for the free navigation among questions, by clicking on "next question" and "previous question" buttons, located on the right section of the screen, which gives you freedom to edit your answers. Do not forget to zoom in to your area of interest before marking your answer. To facilitate the management of the information generated, please use the following scale when answering. 1 click - "The area I am marking answers the question **lightly**". 2 clicks - "The zone I am marking answers the question **moderately**". 3 clicks - "The zone I am marking responds to the question **intensely**".
DEMOGRAPHIC DATA ¿What is your role at the UASLP? *Student, professor, administrative, other* ¿What faculty or department are you a part of?
TRAINING Utilize this moment to familiarize yourself with the use of the spraycan tool. You can start by marking the location of your faculty or department inside the University Western Campus. Remember to zoom in to an adequate level and that you can always delete your answer. When you are ready, please click on the "next

question" button to start the survey. The information gathered on this specific question will not be used on the research.	
QUESTIONS	**UES / UED**
1. Considering the green areas located inside the UASLP Western Campus only. Does any green area on campus strike you as particularly aesthetically pleasing? What plant, animal, structure, or situation makes you feel this way?	Aesthetic pleasure
2. Considering the green areas located inside the UASLP Western Campus only. Is there any place on campus where you enjoy appreciating nature? What plant, animal, structure, or situation makes you feel this way?	Connection to nature
3. Considering the green areas located inside the UASLP Western Campus only. Is there a place on campus where you go to relax? What plant, animal, structure, or situation makes you feel this way?	Stress reduction
4. Considering the green areas located inside the UASLP Western Campus only. Is there a green area on campus where you prefer to socialize? What structure or situation makes you feel this way?	Community building
5. Considering the green areas located inside the UASLP Western Campus only. Does any place on campus feel unsafe to you? Can you give a specific reason for this?	Insecurity

6. Considering the green areas located inside the UASLP Western Campus only. Have you had negative encounters with animals inside the site? What animal was it?	Pests
7. Considering the whole campus. Do you know of any place on campus where you suffer from excessive heat?	Demand for microclimate regulation
8. Considering the whole campus. Do you know of any site on campus that suffers from flooding due to rainfall?	Demand for water flow regulation
9. Considering the whole campus. Do you know of any site on campus where outside noise reaches annoying levels?	Demand for noise regulation
10. Considering the whole campus ¿Is there a specific area where you think the installation of a new green infrastructure would be beneficial? If so, which infrastructure? (Some examples are: forested areas, floral garden, green roof, green walls, urban garden, xerophyte garden, simple pots, and so on) Which ecosystem service would you like to provide to that space?	
CONCLUSION: Will you be willing to participate in an interactive activity to support this research? If you do, please leave your name, e-mail and cellphone number for us to contact you.	

3.2. DATA COLLECTION FOR ECOSYSTEM SERVICES PROVISION

The following is a breakdown of the proposed methods for collecting information and calculating indicators, grouped by type of UES and/or UED.

- ***SUPPORTING SERVICES***

Biodiversity

In terms of vegetation, and to obtain more concrete results, it is recommended that a total census of the flora individuals present within the area under study be carried out.

The software i-Tree Eco is proposed to be used for the assessment of a diverse range of UES and UED, so it is recommended to follow its Field guide, published by the US Forest Service (2019), the information collected should include as a minimum:

- species scientific name
- georeferenced location
- diameter at breast height (DBH)
- height of the individual
- crown width (X and Y axis)
- height to crown base
- percent crown missing
- crown health
- identifier of the specific green area (plot)
- photographic reference

For avifauna sampling in urban areas, the recommended methodology is the 5-minute point count (25 m radius), in 20 specific sites (10 in green areas and 10 in highly built-up areas) considering a timetable between 7:00 and 11:00 am (MacGregor-Fors et al., 2021).

If it is not possible to carry out direct sampling, or as a complement to this database, scientific information obtained in the area and published in scientific journals, theses, official databases, or the Naturalista portal (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), 2021), a citizen science project where trained and accredited personnel can approve the observations reported by users. Thus, those observations that have professional validation within the area under study will be added to the list.

Ecological parameters can be measured in a variety of ways. Specific richness (S) is the simplest way to do this, although it does not take species abundance into account, so it does not measure diversity (Supriatna, 2018).

S = number of different species in a specific list.

The Shannon-Wiener diversity index (H') does take species abundance into account, so it determines the diversity of a specific site (known as alpha diversity) (Supriatna, 2018).

$H' = \sum p_i \ln p_i$

Where p_i is the proportion of individuals belonging to a species in a specific inventory.

The percentage of native species will be obtained by a simple arithmetic calculation.

% sp = (n/N)*100

Where n refers to the number of individuals of the species of interest, and N refers to the total number of individuals.

Habitat connectivity

Connectivity will be assessed through structural connectivity, which refers to the biophysical connectivity existing in the landscape, without considering the ethological response of species. It can be measured through an evaluation of the configuration or proximity of the different landscape elements. The selected methodology is the structural connectivity index (CI_j) (Tian et al., 2017).

The ArcGis *Path Distance* module will be used to calculate the cumulative least cost distance to the nearest green areas. The resources needed to run the module are green area coverage, the elevation model, and a resistance map.

The green area coverage map is obtained through the NDVI, calculated with the following formula:

NDVI = (NIR-Red) / (NIR+Red)

Where NDVI is the normalized difference vegetation index, NIR is the near infrared spectral band and Red is the red spectral band.

The building density map is obtained is calculated with information from satellite images.

Bdi = ∑(BHij * BAij) / ALUi

Where BD is the density of buildings, BH is the height of buildings in meters, BA is the built-up area, and ALU is the area of the given land use, in m^2.

In the case of having biodiversity information from neighboring sites, in addition to that of the site under study, beta diversity can be used to determine connectivity. Beta diversity refers to the similarity between two neighboring communities, used to determine if there is species transfer between landscapes, and is commonly calculated using Sorensen's similarity index (β) (Baselga, 2010).

$$\beta = \frac{b + c}{2a + b + c}$$

Where a is the number of species common to both sites, b is the number of species occurring only at one site, and c is the number of species occurring only at the other site.

- ***REGULATING SERVICES***

Microclimate regulation

The microclimatic variables of temperature, solar radiation and relative humidity will be measured directly in the field, following the methodology of Zhao et al. (2020), who recommends taking the measurements at a height of 1.5 m from the ground, since this is the average height of human respiration, on sunny days, with little cloud cover and low wind speed. Measurements will be taken daily, from 8:00 a.m. to 6:00 p.m., with 2-hour intervals. Monitoring will be performed continuously for 10 minutes each time. Five sampling points will be established for each green area, one at the center of the green area and four additional ones, one at each edge of the green area (north, south, east and west). The average value of the 5 sampling points will be considered as the temperature, solar radiation, and relative humidity of the green area.

The effects of reduced temperature and solar radiation, as well as increased relative humidity, will be calculated by subtracting from the average value obtained the value measured at a control point, which should be an open field with a paved surface, without vegetation cover, located within the area under study.

To calculate the microclimate indicators, the methodology of Zhao et al. (2020):

$T - T_0$ = emperature reduction effect.

$RH - RH_0$ = h umidity increase effect.

$RS - RS_0$ = solar radiation reduction effect.

Where T_0, RH_0 and RS_0 are control measurements.

Noise regulation

Since noise measurements in this study are not for regulatory inspection purposes, it was decided to use the "Portable Rapid Assessment" methodology recommended by the Department of Environment and Heritage Protection of Queensland (2013).

To achieve an accurate measurement using this method, the sound level meter should be held with the arm fully extended to one side of the body, with the microphone pointed towards the sound source (in this case the street), to minimize the sound that may reflect from the body of the person taking the measurement, at a height of between 1.20 and 1.50 m from the floor level of the receiver, using the A scale.

When taking measurements outdoors, consideration should be given to moving at least 3.5 m away from any surfaces that reflect noise, such as concrete walls. In case of taking measurements in a doorway or window, the microphone should be placed in the center of the doorway or window.

In areas that present irregular noise, a long-term recording is recommended. In accordance with the methodology carried out by Izzaty Mohd Isa et al. (2018), measurements shall be performed during a period of peak traffic for a period of 1 hour, recording the maximum value of every 30 seconds elapsed, in decibels (dB).

Since vehicular traffic is restricted inside the campus, the sampling points will be selected based on the location of the university UGI near the external avenues and taking as reference a point on the side of the avenue and a point at the other end, which will serve to determine the noise reduction generated by the presence of the vegetation structure.

To calculate the noise reduction, a simple arithmetic equation should be performed, where:

$dB_1 – dB_2$ = noise reduction effect.

Where dB_1 refers to the average of the measurements obtained for a green area, on the side of the roads; while dB_2 refers to the average of the measurements obtained for the same green area, at the point opposite to the first measurement.

Air quality

The iTree software will be used to estimate dry deposition of air pollutants, which refers to the removal of pollutants during periods without precipitation. The software module calculates hourly dry deposition for criteria pollutants O3, SO2, NO2, CO and PM10 based on tree cover information, climate data and pollutant concentration (Hirabayashi et al., 2015).

Tree cover information should preferably be obtained from a total vegetation census of the area under study. The information collected should include species, georeferenced location and dasometric measurements (breast height diameter, individual height, and canopy cover).

Climatic information can be obtained directly from the climatological stations network of the National Water Commission (CONAGUA), from which information is required on average, maximum and minimum monthly temperature in °C; and total monthly and maximum precipitation in 24h in mm.

Air quality data can be obtained from the National Air Quality Information System (SINAICA), selecting the nearest available location to the site, with hourly measurements of criteria pollutants ($PM_{2.5}$, CO, O_3, SO_2 and NO_2) (Instituto Nacional de Ecología y Cambio Climático (INECC), 2022).

The hourly pollutant removal is obtained by calculating the average hourly pollutant flux (F) obtained by the following equation:

$F = V_d * C * 3600$

Where F is the pollutant flux (g m^2/h), V_d is the deposition velocity (m/s) and C is pollutant concentration (g/m^3).

The software performs the deposition rate calculations based on climatic information, as well as specific to the pollutant and tree species evaluated, taking information from an extensive database maintained by the USDA Forest Service.

Finally, the indicator of hourly air quality regulation by tree cover generated by dry deposition of atmospheric pollutants is calculated as:

$I = F / (F+M) * 100$

Where I is the percent air quality improvement per tree; F is the average hourly pollutant flux and M is the total mass of pollutants per tree cover.

Carbon sequestration

Annual biomass carbon storage and sequestration will be calculated using iTree software, developed in conjunction with the USDA Forest Service. The sequence of calculations, described by McPherson E et al. (1994) is presented below.

For carbon stock, the biomass of each tree is calculated using specific allometric equations compiled from literature; if no equation is available for a given species, the average of those within its genus is used; if no species of its genus is available, the average of the equations for conifers or angiosperms is used.

Tree cover information should preferably be obtained from a total vegetation census of the area under study. The information collected should include species, georeferenced location and dasometric measurements (diameter at breast height, individual height, and crown cover).

If the equation does not take this into account, the software determines the belowground biomass by multiplying the result by a factor of 0.26; the dry biomass is then calculated using species-specific conversion factors.

In the case of urban trees, the software considers that their root system has lower biomass by multiplying the results by a factor of 0.8.

For deciduous trees, leaf biomass is not considered since it is considered to be released to the environment on an annual basis.

Finally, the total dry weight of biomass is converted to total carbon stock by multiplying by a factor of 0.5.

For annual carbon sequestration, a standard growth of 0.83 cm per year is considered and adjusted with the following equation:

Standard growth = 0.83 cm/year * number of frost-free days / 153.

Pollinators

Weekly sampling will be carried out for 12 months, considering the vegetation that is in bloom. The traps used will be homemade traps for pollinating species, made with cut plastic bottles, and using a mixture of water, sugar, and yeast as bait (Montes-Betancourt et al., 2020).

If it is not possible to carry out the sampling directly, or as a complement to this database, scientific information obtained in the area and published in scientific journals, theses, official databases, or otherwise use the Naturalista website (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), 2021), a citizen science project where trained and accredited personnel can approve the observations reported by users. Thus, those observations that have professional validation within the area under study will be added to the list.

Pests

The responses from the participatory mapping will be analyzed by density obtained in each UGI, for this purpose, the sum of the number of responses for each UGI will be carried out, following the following formula.

Incidence of experiences in each UGI = $\sum n_{UGI}$

Where n_{UGI} is the number of experiences registered in each UGI.

Soil quality

Following the methodology of Pouyat et al. (2007), n those green areas that are large enough, a circular plot with a radius of 11.35 m (0.04 ha) will be defined, while smaller ones will be considered as a whole plot.

A composite soil sample will be taken from within these plots, from a depth of between 0 and 10 cm, taken with a 2 cm sampling auger. The composite sample will be generated by mixing between 10 and 15 cores, randomly selected following a simple random sampling pattern. In those green areas that are too small, a single sample will be taken in triplicate. These samples will be collected, labeled appropriately with date, plot and sampling number, and analyzed for organic matter.

Organic matter is considered a good indicator of overall soil quality (Obalum et al., 2017; USDA Natural Resources Conservation Service, 2015), and will be determined following the ignition mass loss methodology as described by Roper et al. (2019).

The soil samples obtained will be sent to an EMA certified laboratory to obtain the percentage of organic matter. In case outsourcing is not possible, the methodology to analyze it in laboratory is set out below, as described by Roper et al. (2019).

10 g of dry soil will be taken and placed in a 35 ml mortar previously tared to be dried in a convection oven at 105 °C and cooled in a sealed desiccator. Once cooled, the joint weight is recorded (Weight 1). This step will be repeated until a continuous mass is achieved. Subsequently a muffle will be preheated to 360 °C, and the soil will be

subjected to this temperature for 2 hours. After this time, it will be placed to cool in a sealed desiccator. Once cooled, the joint weight is recorded (Weight 2). The formula for calculating the percentage of organic matter is as follows:

% Organic Matter = ((Weight 1 - Weight 2) / Weight 1) * 100

Water flow regulation

To determine the amount of water runoff at a given site, it is necessary to model the transformation of rainfall into runoff. It was decided to follow the curve number method of the Soil Conservation Service, adapted by Domínguez Mora et al. (2008) for the Mexican territory, which considers the cartographic nomenclature of INEGI, calculated using the following formula.

Ce = Pe / P

Where Ce is the runoff coefficient, Pe is the effective precipitation, or the part of the precipitation that runs off, and P is the total precipitation recorded.

$$Pe = \frac{(P - \frac{508}{CN} + 5.08)^2}{(P + \frac{2032}{CN} - 20.32)}$$

Where CN is the curve number, determined from land use and soil types.

Precipitation information can be obtained directly from the network of climatological stations of the National Water Commission (CONAGUA), from which the information of maximum precipitation in 24h in mm is required.

To obtain CN, the use of GIS and vector layers of edaphology and land use and vegetation provided by INEGI is required. The value is obtained from tables, where the hydrological group of the soil is determined, and crossed with the predominant land use in the area.

The CN value must be obtained for all possible combinations of soil type and land use within the area to be evaluated, which must then be weighted by surface area following the following formula.

$$weighted\ CN = \sum \frac{CN * \%surface}{100}$$

Once the value of Ce is obtained, the amount of runoff expected at the site can be modeled through the formula:

Pe = Ce * P

In addition to determining the expected runoff at a site, there is a way to determine the water flow regulation capacity by the action of vegetation through the amount of rainfall interception, which reduces the amount of runoff in the area, since a certain amount of water is stored in the vegetation cover and in soil depressions, in addition to considering the infiltration in permeable surfaces under the trees.

It was decided to use the iTree software to carry out this calculation, obtained as the volume of precipitation interception per individual tree (Si), using the following formula (Hirabayashi, 2013).

$$Si = S * \frac{LAi}{\sum LA}$$

Where S equals the annual precipitation interception volume, LAi refers to the leaf area of the evaluated tree, and ∑LA is the summation of the leaf area of all trees.

- ***CULTURAL SERVICES***

Aesthetic pleasure

The responses from the participatory mapping will be analyzed by density obtained in each UGI, for this purpose, the sum of the number of responses for each UGI will be carried out, following the following formula.

Incidence of experiences in each UGI = $\sum n_{UGI}$

Where n_{UGI} is the number of experiences registered in each UGI.

Connection with nature

The responses from the participatory mapping will be analyzed by density obtained in each UGI, for this purpose, the sum of the number of responses for each UGI will be carried out, following the following formula.

Incidence of experiences in each UGI = $\sum n_{UGI}$

Where n_{UGI} is the number of experiences registered in each UGI.

Stress reduction

The responses from the participatory mapping will be analyzed by density obtained in each UGI, for this purpose, the sum of the number of responses for each UGI will be carried out, following the following formula.

Incidence of experiences in each UGI = $\sum n_{UGI}$

Where n_{UGI} is the number of experiences registered in each UGI.

Allergens

A total census of the individuals of allergenic flora present within the area under study be carried out, based on the Ogren Plant Allergy Scale list. The information collected should include species and georeferenced location (Dobbs et al., 2011).

The software i-Tree provides an Allergy Index score based on specific species allergic potential with a scale going from least allergic (1) to most allergic (10) potential. (Nowak & Ogren, 2021)

This specific allergic index is weighted by the species leaf area to calculate an Allergy Index.

$$AI_x = \sum_{i=0}^{n} (AP_i \; x \; LA_{ix})/LA_x$$

Where AI_x = allergy index in class x (city or land use), AP_i = allergy potential of species *i* (1 – 10), LA_{ix} = leaf area (m^2) of species *i* in class *x*, and LA_x = total leaf area (m^2) in class *x*.

The results are combined and presented into low, medium and high index classes where: Low = classes 1 – 3, Medium = classes 4 – 7, High = classes 8 – 10.

Creation of community

The responses from the participatory mapping will be analyzed by density obtained in each UGI, for this purpose, the sum of the number of responses for each UGI will be carried out, following the following formula.

Incidence of experiences in each UGI = $\sum n_{UGI}$

Where n_{UGI} is the number of experiences registered in each UGI.

Perception of insecurity

The responses from the participatory mapping will be analyzed by density obtained in each UGI, for this purpose, the sum of the number of responses for each UGI will be carried out, following the following formula.

Incidence of experiences in each UGI = $\sum n_{UGI}$

Where n_{UGI} is the number of experiences registered in each UGI.

- ***PROVISIONING SERVICES***

Food production

Information on food production should be requested from the AA, which collects it within the "Unihuerto" scheme, a university program that carries out urban agriculture activities on campus. It will be requested in kg and broken down by product.

The annual difference in production will be calculated by a simple arithmetic operation, to calculate the increase or decrease in annual production in kg.

(Annual production per year X) – (Annual production per year X-1)

Fresh water provision.

Infiltration is the process by which water passes through the surface and is distributed in the soil strata. This parameter can be obtained from in situ tests; however, it is more practical to estimate infiltration characteristics based on soil textural classes.

Following the methodology of Pouyat et al. (2007), in those green areas that are large enough, a circular plot with a radius of 11.35 m (0.04 ha) will be defined, while smaller ones will be considered as a whole plot.

A composite soil sample will be taken from within these plots, from a depth of between 0 and 10 cm, taken with a 2 cm sampling auger. The composite sample will be generated by mixing between 10 and 15 cores, randomly selected following a simple random sampling pattern. In those green areas that are too small, a single sample will be taken in triplicate. These samples will be collected, labeled appropriately with date, plot and sampling number, and analyzed for texture using a hydrometer (Pouyat et al., 2007).

Table 9 presents a reference published by the Comisión Nacional del Agua (CNA), (2002), which will be used to determine the basic water infiltration rate of each UGI within the area under study.

Table 9. Basic water infiltration rate by textural class.

Textural class	Basic water infiltration rate (cm/h)
Very coarse (Sand)	>10.0
Coarse (Sandy clay)	5.5 – 10.0

Textural class	Basic water infiltration rate (cm/h)
Moderately coarse (Sandy loam)	4.0 – 5.5
Medium (Loam)	2.0 - 4.0
Moderately fine (Clay loam, Clay sandy)	1.0 – 2.0
Fine (Clay, Silty clay)	0.5 – 1.0

Source: Comisión Nacional del Agua (CNA), (2002)

Water consumption

Excessive water consumption shall be determined as the amount of irrigation water used above the required irrigation sheet.

Irrigation sheet is defined as the amount of water required to replenish the moisture that is usable by vegetation in the root zone. In low frequency irrigation, optimum irrigation is applied when irrigation requirements equal this value (Comisión Nacional del Agua (CNA), 2002). It is determined with the formula:

$$Lr = \frac{(PScc - PSpmp) * Da * Pr}{100}$$

Where:

Lr = irrigation sheet (cm).

PScc = percentage of moisture at field capacity (%)

PSpmp = percentage of moisture at permanent wilting point (%)

Da = bulk density (gr/cm3)

Pr = rooting depth

Lr, PScc, PSpmp and Da parameters will be calculated for each UGI using the SPAW (soil - plant - atmosphere - water) software developed by the USDA Natural

Resources Conservation Service (NRCS) (2004). The software makes use of an extensive database developed by the USDA Hydrology Laboratory, where they have compiled data for a wide combination of soil textures, with validity in a range of textures from 5 to 60% clay and 5 to 95% sand, also considering variables such as organic matter, bulk density, and salinity. The Pr value will be considered in all cases as 0.40 m, considering the great variety of vegetation present, and that in urban areas it has been found that up to 80% of the roots develop between 0 and 0.40 m soil depth (Mohamadzade et al., 2021).

3.3. DATA ANALYSIS

The next step is the analysis of the data obtained. For this, it was decided to combine a spatial analysis with a classical regression analysis, because this is a suitable strategy to quantify and explain the multiple spatial relationships of ecosystem services (Liu et al., 2017).

- ***STATISTICAL ANALYSIS***

A correlation matrix will be generated to analyze the existing relationship between the different UES and UED analyzed, in addition, a determination coefficient matrix will be calculated to determine the existing relationship between the different UGI classifications with the supply and demand of UES and UED at the site.

The correlation matrix is obtained by solving the calculation of Pearson's correlation coefficient (r) between all combinations of UES and UED, using the following equation (Liu et al., 2017).

$$r = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sum(x-\bar{x})^2 \sum(y-\bar{y})^2}$$

Table 10. Correlation matrix

	A1	A2	A3	An
A1	R1	R2	R4	Rn
A2	R2	R3	R5	Rn
A3	R4	R5	R6	Rn
An	Rn	Rn	Rn	Rn

Where: A represents an ecosystem service or disservice, and R represents the correlation between the two.

This information is used to analyze the existing relationships between the various UES / UED. Through this process it is possible to visualize synergies (high values of positive correlation) and tradeoffs (high values of negative correlation).

Subsequently, the coefficient of determination (r2) calculated for the relationship between the different UGI classifications and the various UES and UED will be analyzed to determine the percentage of the service or disservice explained by the infrastructure.

Table 11. Determination matrix.

	X1	X2	X3	Xn
Y1	Z1	Z2	Z4	Zn
Y2	Z2	Z3	Z5	Zn
Y3	Z4	Z5	Z6	Zn
Yn	Zn	Zn	Zn	Zn

Where: X represents the demand or provision of an ecosystem service or damage, Y represents a specific UGI, and Z represents the correlation between the two.

- ***SPATIAL ANALYSIS***

The data will be analyzed spatially by generating maps. According to (Burkhard & Maes, 2017), the type of map to be generated will depend on the information obtained, but in general, the information expressed in Table 12 will be taken as a reference.

Table 12. Recommended maps for each type of spatial phenomena.

	Spatially discrete (phenomena occurring in distinct and separate locations)	**Spatially continuous** (phenomena occurring continuously throughout space)
Abrupt changes (measurable properties change abruptly in space)	Proportional symbol map	Coroplastic map
Smooth changes (measurable properties change smoothly in space)	Point density map or heat map	Isarithmic map Interpolation map

Source: Burkhard & Maes (2017)

This will make it possible to analyze the geospatial distribution of services, allowing the integration and prioritization of multiple environmental and social values for their appropriate management (Raymond et al., 2009). For the creation of these maps, we will take as a reference the methodologies presented by Bettinger et al. (2020).

The choropleth map is a type of map that presents ranges of quantitative characteristics of spatial features through color changes. Spatial areas of the same color represent similar conditions. To accomplish this, data must be classified into appropriate ranges of intervals, and then appropriate colors must be selected to represent those values.

Isarithmic maps use isolines (lines on a map representing points in space that have similar values) and areas representing similar values to illustrate similar conditions of a phenomenon across a continuous surface. To create them, an interpolation process needs to be used to model a realistic and continuous distribution of the surface. Interpolation is recommended only as a rough and general representation, and it needs to be stated that the surface is not continuous in the real world, and that the configuration of the built environment have a strong effect on ecosystem services spatial distribution.

A heat map is basically an isarithmic map that, instead of focusing on specific measured values, represents the density of occurrences of a given phenomenon.

Finally, the proportional symbol map requires the precise identification of a specific location, which will be designated a unique symbol, whose characteristics will vary with respect to an intensity scale.

4. Creating a complex system

At this point, a wide range of information will be available, from stakeholders, infrastructure, current supply, and demand of UEG; UES and UED, statistical relations, among others. The next step is to outline the complex system of current UGI management. To do so, the information gathered so far should be considered and use the systems thinking discussed above.

A system is composed of elements, interconnections, and a purpose. The purpose can only be deduced when studying the system, and the interconnections will become evident when analyzing the elements, so the initial step, and the only one that can be described is the identification of the elements (Meadows, 2008).

The construction of an integral complex system cannot be given by a specific framework, because due to the very nature of the system there are no predefined sequences or actions to follow that are applicable to all cases. Taking this into account, the categorization of components elaborated by Elia et al. (2020) for the development of complex systems for project management will be used as a guide. The format to be filled out to support the identification of the different components is presented in Table 13.

Table 13. Component identification matrix for the elaboration of the complex system.

Component	Key question	UGI Management
Beneficiaries	For whom does it exist?	
Outcomes	What objective does it serve?	
Stakeholders	Who is involved?	
Activities	What activities are executed?	
Time	How is it structured over time?	
Resources	What is required?	
Budget	How much does it cost?	
Benefit	What is the impact?	
Governance	How is it managed?	

Source: Elia et al. (2020)

5. SYNERGIES AND TRADE-OFFS ANALYSIS USING ECOLOGICAL PRODUCTION FUNCTIONS (EPF)

Following the methodology of Wong et al. (2018), regression models that link ecosystem characteristics and produced services, also known as ecological production functions (EPF), must be created.

EPFs are calculated through the ordinary least squares (OLS) regression method, which consists of minimizing the sum of squares of the model prediction error. The function obtained has structure of y = a + bx, where the coefficients a and b must be calculated as follows:

$$a = \frac{n\,(\sum xy) - (\sum x)(\sum y)}{n\,(\sum x^2) - (\sum x)^2}$$

$$b = \frac{(\sum y)(\sum x^2) - (\sum x)(\sum xy)}{n\,(\sum x^2) - (\sum x)^2}$$

Where n is the amount of data.

Once the regression coefficients have been calculated, they will be used to estimate the line of best fit and thus calculate the marginal values of the different UES and UED, to evaluate the synergies and tradeoffs in terms of the feasibility of reducing the deficits of ecosystem services (understanding deficits as the difference between supply and demand).

Marginal values refer to changes in ecosystem services relative to changes in units of ecosystem characteristics:

$$marginal\ value = \frac{\Delta\ \text{final ecosistem services}}{\Delta\ \text{ecosystem characteristics}}$$

These regression coefficients can also be used to analyze different future scenarios, and the possibility of being implemented. The synergies and tradeoffs will be summarized in a matrix as presented in Table 14.

Table 14. Summary of synergies and tradeoffs.

Shortfall	Management option	Synergy / tradeoff	Feasibility

Source: Wong et al. (2018)

6. THE MAKING OF AN ADAPTIVE MANAGEMENT STRATEGY.

Crevier & Parrott (2019) explain that the steps for creating an adaptive management strategy are as follows:

1. Initial assessment of the socio-ecological problem, and the development of a model that represents the managed system.

2. Use of the model to determine the management strategy or policy.

3. Implementation of management actions.

4. Evaluation of the impact of the management strategy on the system.

5. Increased knowledge about the management of the system by learning from the results of the applied management strategy.

To accomplish the first two of these steps, the methodology of Robinson et al. (2016) for structured decision making will be followed, as it is a participatory process, applicable to systems of different scale and complexity, which allows transparent decision making that can be subjected to evaluation, and mainly, it uses much of the information collected previously in this study.

The development of the strategy will be based on the synergies and disjunctions identified, which should be put into the local context, through the complex system elaborated previously, with the support of the spatial and statistical information generated, which will allow an adequate understanding of the complex relationships in the system, and the making of appropriate management decisions.

6.1. PROBLEM STATEMENT

Considering the institutional context, the problem that the management strategy intends to solve should be approached from the objectives of the PUB, understood as "*To manage integrally the flora and fauna found in the spaces and gardens of the university campuses in a sustainable and respectful manner* (Universidad Autónoma de San Luis Potosí (UASLP), n.d.).

6.2. OBJECTIVE DEFINITION

For this stage, the Delphi method will be applied again, using the same panel of experts that was selected previously, who will be consulted on the fundamental objectives and sub-objectives appropriate for the strategy. Survey 3 is presented in Table 15.

Table 15. Survey to determine the objectives of the adaptive management strategy.

Survey 3. Considering the following objectives extracted from the Biodiversity Program of the Agenda Ambiental. ***General objective*** *To manage integrally in all UASLP activities the flora and fauna found in the spaces and gardens of the university campuses in a sustainable and respectful manner.* ***Specific objectives*** • *Continue with the programs, projects and multidisciplinary and interdisciplinary efforts for the diagnosis and creation of knowledge regarding the species housed in the UASLP campuses with the commission of experts that considers health, safety, and environment.* • *Generate communication, education, and community participation strategies where the procedures for good management of gardens and non-human animals are made known and applied.* • *Consider the management of threatened and endangered species of fauna that are beneficial to the environment, pollination, air quality, as well as those that bring an imbalance to the ecosystem in which they are found or in human activities.* • *Consider flora species in gardens, planters, roofs, and patios that contain a landscape design, with endemic vegetation and agroecological care for pest control and pruning.* • *Replicate, scale up and implement the Unihuerto program in more places, as well as the creation of new programs to ensure food security, the creation and maintenance of green spaces and respect for animals.* • *Conduct forums, conferences and worktables for the integration and participation of all stakeholders, as well as training courses for gardening and maintenance personnel.* Please respond.	
Questions	**Answers**
In the following space, please define a set of fundamental objectives and sub-objectives that, in your opinion, will allow meeting the purpose of the Biodiversity Program, considering economic, social and ecological factors within a context of supply and demand of UES and UED.	

The summarized data of this survey will be analyzed and if there is no consensus (defined as 70% agreement), a summary will be provided to you for consideration and a new iteration of the survey will take place.

6.3. ALTERNATIVES

For this stage, the Delphi method will be applied again, using the same panel of experts that was selected previously, who will be consulted to propose management alternatives that address the deficits found in reference to the UES and UED within the study area. Survey 4 is presented in Table 16.

Table 16. Survey to propose management alternatives.

<table>
<tr><td colspan="2">Survey 4.
Considering the following information which is given to you:
• List and maps of identified shortfalls of UES within the UASLP western campus.
• Sorensen Network representation linking urban green infrastructure, ecosystem functions, ecosystem services, satisfactors of human needs and human well-being.
• Diagram of the complex social-ecological system for the urban green infrastructure management of the UASLP western campus.
• List of fundamental objectives and sub-objectives generated by this panel of experts.
Please respond.</td></tr>
<tr><td>Question</td><td>Answer</td></tr>
<tr><td>In the following space, propose management alternatives based on ecosystem services that will allow, in your opinion, to fulfill the fundamental objectives and subobjectives.</td><td></td></tr>
<tr><td colspan="2">The summarized data of this survey will be analyzed and if there is no consensus (defined as 70% agreement), a summary will be provided to you for consideration and a new iteration of the survey will take place.</td></tr>
</table>

6.4. CONSEQUENCES

Using the EPF built during the statistical analysis, the management alternatives selected by the panel of experts will be modeled, to evaluate their effect on the fulfillment of the different objectives set.

6.5. OPTIMAL DECISION

For this stage, it will be necessary to apply the Delphi method again, for which the same panel of experts that was previously selected will be used, who will be consulted to assign weights to the different strategies proposed. The experts must distribute 100 points between the fundamental objectives and sub-objectives considering the results obtained from the modeling of consequences for each of the proposed management strategies. Survey 5 will be carried out considering Table 17.

Table 17. Survey to determine the relevance of the different management alternatives proposed.

<table>
<tr><td colspan="2">Survey 5.
Considering the following information which is given to you:
• Maps of the modeled consequences for each of the proposed management strategies if applied within the UASLP western campus.
Please respond.</td></tr>
<tr><td>Questions</td><td>Answers</td></tr>
<tr><td>Distribute 100 points between the fundamental objectives and sub-objectives listed, considering the results obtained by the various applicable management alternatives.
The more points, the more relevance.</td><td></td></tr>
<tr><td>Additional comments.</td><td></td></tr>
</table>

The optimal management alternative decision will be obtained by calculating the expected utility value "E(U)" using the following formula.

$$E(U) = Wf1\,(Ws1 * Us1 + Ws2 * Us2 + \ldots) + Wf2\,(Ws3 * Us3 + Ws4 * Us4 + \ldots) + \ldots$$

Where:

E(U) = expected utility value.

Wf (1, 2, …) = weight given to a fundamental objective x.

Ws (1, 2, …) = weight given to a subgoal y.

Us (1, 2, …) = value obtained for some sub-objective through the consequence analysis (normalized, from 0 to 1)

The alternatives with the highest value of E(U) are considered the best options, since they represent those options that can reduce the greatest amount of deficit. These will be the measures that will be proposed for the adaptive management strategy.

6.6. MONITORING AND EVALUATION

Monitoring and evaluation (M&E) are needed to measure the achievement of objectives and are of special importance in the context of an adaptive management strategy meant to evolve in an iterative manner, constantly learning from the collected data.

For this, a monitoring and evaluation plan needs to be devised. This plan is directly linked to the proposed strategy because the indicators that are being assessed are directly derived from (and respond to) the objectives of the strategy.

A good indicator is measurable, practical, reliable, relevant, useful to manage, direct, sensitive, responsive, objective, and capable of being disaggregated. The following step-by-step guide is provided to select good quality indicators.

1. Identify what needs to be measured.
2. Develop a list of possible indicators (brainstorming, research, literature).
3. Assess each possible indicator.
4. Select the best indicators.
5. Draft the protocols.
6. Collect baseline data.
7. Refine indicators and protocols.

According to The World Bank (TWB) (2009), the development of an M&E Plan requires the construction of a Logical framework which links objectives, indicators, measurement information and data sources. Table 18 presents the matrix for the M&E Logical framework to be filled for this Protocol, once the strategies, indicators and methodologies are set by the experts.

Table 18. Monitoring and Evaluation framework

Strategic objective	Indicator	Baseline	Target	Frequency	Data source

Table 19 presents an example of the annual schedule that will be generated once the selected indicators and frequency of assessment are decided. An important point is to indicate responsibility for its fulfillment.

Table 19. Monitoring and Evaluation schedule

Indicator	Responsible	month											
		J	F	M	A	M	J	J	A	S	O	N	D

Communication products and channels are to be decided by the UASLP or AA, but the recommendation is to publish a yearly report containing the status for each ecosystem service indicator, accompanied by maps to show the spatial configuration of their provision.

It is necessary to train personal for the continuous M&E of this Protocol, so a Capacity Building schedule must be devised for the workers responsible to run this Plan.

Table 20. Capacity building schedule

	Training hours per month												Total hours
	J	F	M	A	M	J	J	A	S	O	N	D	
A. Relevant topic (fill row with ∑)													
1. Role or individual to be trained													
2. Role or individual to be trained													
3. Role or individual to be trained													
B. Relevant topic (fill row with ∑)													
1. Role or individual to be trained													
2. Role or individual to be trained													
3. Role or individual to be trained													

6.7. Double loop learning

Following the framework of adaptive management, a learning process based on two cycles should be proposed. The short cycle, or technical learning phase, will be based on monitoring the state of the UGI, as well as the supply and demands of the UES and UED within the area under study. The long cycle, or institutional learning phase, should focus on reassessing the entire strategy, going back to the deliberative phase, and including the objectives and methodologies used. Figure 1 represents the double loop learning scheme in a graphic manner.

The recommended timeframe is to carry a continuous monitoring with annual reports, for the technical learning phase, and to carry an institutional cycle every time a major institutional plan is about to be reformed. The current suggestion is to link it with the Plan Institucional de Desarrollo 2024-2030 (Institutional development plan, PIDE), so the following institutional cycle should come in 2029, in preparation for the next PIDE.

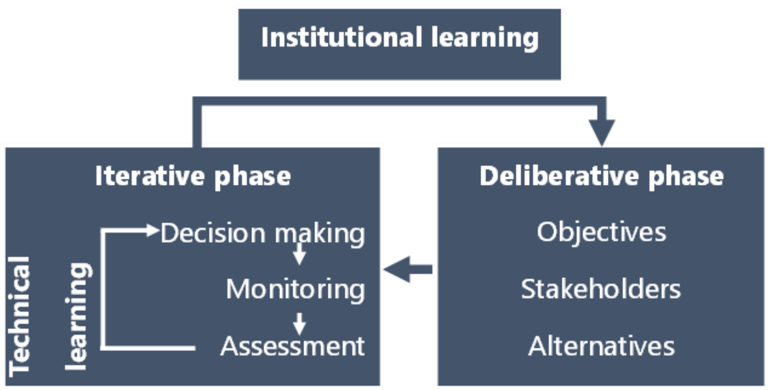


Figure 1. Double loop learning scheme

PROTOCOL REFERENCES

Allen, R., Pereira, L., Raes, D., & Smith, M. (1998). *Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56*.

Baselga, A. (2010). Partitioning the turnover and nestedness components of beta diversity. *Global Ecology and Biogeography*, *19*(1), 134–143. https://doi.org/10.1111/j.1466-8238.2009.00490.x

Bettinger, P., Merry, K., & Boston, K. (2020). *Mapping human and natural systems* (Elsevier Academic Press, Ed.). Joe Hayton.

Bolund, P., & Hunhammar, S. (1999). Ecosystem services in urban areas. In *Ecological Economics* (Vol. 29).

Brzoska, P., & Spaǵe, A. (2020). From city-to site-dimension: Assessing the urban ecosystem services of different types of green infrastructure. In *Land* (Vol. 9, Issue 5). MDPI AG. https://doi.org/10.3390/LAND9050150

Burkhard, B., & Maes, J. (2017). *Mapping Ecosystem Services* (B. Burkhard & J. Maes, Eds.). Pensoft Publishers.

Castellar, J. A. C., Popartan, L. A., Pueyo-Ros, J., Atanasova, N., Langergraber, G., Säumel, I., Corominas, L., Comas, J., & Acuña, V. (2021). Nature-based solutions in the urban context: terminology, classification and scoring for urban challenges and ecosystem services. *Science of the Total Environment*, *779*. https://doi.org/10.1016/j.scitotenv.2021.146237

Comisión Nacional del Agua (CNA). (2002). *Manual para la elaboración y revisión de proyectos ejecutivos de sistemas de riego parcelario*.

Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO). (2021). *Naturalista*. Comisión Nacional Para El Conocimiento y Uso de La Biodiversidad (CONABIO). http://www.naturalista.mx

Costanza, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., & Naeem, S. (1997). The Value of the World's Ecosystem Services and Natural Capital. *Nature*, *387*, 253–260.

Crevier, L. P., & Parrott, L. (2019). Synergy between adaptive management and participatory modelling: The two processes as interconnected spirals. *Ecological Informatics*, *53*. https://doi.org/10.1016/j.ecoinf.2019.100982

dell'Olio, L., Ibeas, A., Oña, J. de, & Oña, R. de. (2018). Public Participation Techniques and Choice of Variables. In *Public Transportation Quality of Service* (pp. 33–47). Elsevier. https://doi.org/10.1016/b978-0-08-102080-7.00003-3

Department of Environment and Heritage Protection of Queensland. (2013). *Noise Measurement Manual*.

Deutsche Gesellschaft für Internationale Zusammenarbeit, G. (2019). *Integración de los servicios ecosistémicos en la planificación y gestión urbana*.

Dobbs, C., Escobedo, F. J., & Zipperer, W. C. (2011). A framework for developing urban forest ecosystem services and goods indicators. *Landscape and Urban Planning*, *99*(3–4), 196–206. https://doi.org/10.1016/j.landurbplan.2010.11.004

Domínguez Mora, R., Esquivel Garduño, G., Méndez Antonio, B., Mendoza Reséndiz, A., Liliana Arganis Juárez, M., & Carrizosa Elizondo, E. (2008). *Manual del Modelo para pronóstico de escurrimiento*.

Elia, G., Margherita, A., & Secundo, G. (2020). Project management canvas: a systems thinking framework to address project complexity. *International Journal of Managing Projects in Business*, *14*(4), 809–835. https://doi.org/10.1108/IJMPB-04-2020-0128

Endlicher, W., Langner, M., Hesse, M., Mieg, H. A., Kowarik, I., Hostert, P., Kulke, E., Nützmann, G., Schulz, M., van der Meer, E., Wessolek, G., & Wiegand, C. (2007). Urban Ecology - Definitions and Concepts. In *Shrinking Cities: Effects on Urban Ecology and Challenges for Urban Development.* (pp. 1–15).

Green, O. O., Garmestani, A. S., Albro, S., Ban, N. C., Berland, A., Burkman, C. E., Gardiner, M. M., Gunderson, L., Hopton, M. E., Schoon, M. L., & Shuster, W. D. (2016). Adaptive governance to promote ecosystem services in urban green spaces. *Urban Ecosystems*, *19*(1), 77–93. https://doi.org/10.1007/s11252-015-0476-2

Guillen-Cruz, G., Rodríguez-Sánchez, A. L., Fernández-Luqueño, F., & Flores-Rentería, D. (2021). Influence of vegetation type on the ecosystem services provided by urban green areas in an arid zone of northern Mexico. *Urban Forestry and Urban Greening*, *62*. https://doi.org/10.1016/j.ufug.2021.127135

Haase, D., Larondelle, N., Andersson, E., Artmann, M., Borgström, S., Breuste, J., Gomez-Baggethun, E., Gren, Å., Hamstead, Z., Hansen, R., Kabisch, N., Kremer, P., Langemeyer, J., Rall, E. L., McPhearson, T., Pauleit, S., Qureshi, S., Schwarz, N., Voigt, A., … Elmqvist, T. (2014). A quantitative review of urban ecosystem service assessments: Concepts, models, and implementation. In *Ambio* (Vol. 43, Issue 4, pp. 413–433). Kluwer Academic Publishers. https://doi.org/10.1007/s13280-014-0504-0

Hatfield-Dodds, S., Nelson, R., & Cook, D. (2007). *Adaptive governance: An introduction, and implications for public policy*. http://ageconsearch.umn.edu

Hirabayashi, S. (2013). *i-Tree Eco Precipitation Interception Model Descriptions*.

Hirabayashi, S., Kroll, C. N., & Nowak, D. J. (2015). *i-Tree Eco Dry Deposition Model Descriptions*.

Hirschhorn, F. (2019). Reflections on the application of the Delphi method: lessons from a case in public transport research. *International Journal of Social Research Methodology*, *22*(3), 309–322. https://doi.org/10.1080/13645579.2018.1543841

Hsu, D., Lim, T. C., & Meng, T. (2020). Rocky steps towards adaptive management and adaptive governance in implementing green infrastructure at urban scale in Philadelphia. *Urban Forestry and Urban Greening*, *55*. https://doi.org/10.1016/j.ufug.2020.126791

Huck, J. J., Whyatt, J. D., & Coulton, P. (2014). Spraycan: A PPGIS for capturing imprecise notions of place. *Applied Geography*, *55*, 229–237. https://doi.org/10.1016/j.apgeog.2014.09.007

Instituto Nacional de Ecología y Cambio Climático (INECC). (2022). *Estación de monitoreo de calidad del aire: Industriales Potosinos Asociados (IPAC)*. Instituto Nacional de Ecología y Cambio Climático (INECC). https://sinaica.inecc.gob.mx/

International Union for Conservation of Nature and Natural Resources (IUCN). (2020). *IUCN Global Standard for Nature-based Solutions*. https://doi.org/10.2305/IUCN.CH.2020.09.en

Izzaty Mohd Isa, I., Zafflina Mohd Zaki, Z., & Kassim, J. (2018). Traffic noise pollution at residential area. In *International Journal of Engineering & Technology* (Vol. 7, Issue 3). www.sciencepubco.com/index.php/IJET

Kim, G., & Coseo, P. (2018). Urban park systems to support sustainability: The role of urban park systems in hot arid urban climates. *Forests*, *9*(7). https://doi.org/10.3390/f9070439

Liu, Y., Bi, J., Lv, J., Ma, Z., & Wang, C. (2017). Spatial multi-scale relationships of ecosystem services: A case study using a geostatistical methodology. *Scientific Reports*, *7*(1).

https://doi.org/10.1038/s41598-017-09863-1

MacGregor-Fors, I., Escobar-Ibáñez, J. F., Schondube, J. E., Zuria, I., Ortega-Álvarez, R., Sosa-López, J. R., Ruvalcaba-Ortega, I., Almazán-Núñez, R. C., Arellano-Delgado, M., Arriaga-Weiss, S. L., Calvo, A., Chapa-Vargas, L., Silvestre Lara, P. X., García-Chávez, J. H., Hinojosa, O., Koller-González, J. M., Lara, C., de Aquino, S. L., López-Santillán, D., … Vega-Rivera, J. H. (2021). The urban contrast: A nationwide assessment of avian diversity in Mexican cities. *Science of the Total Environment*, *753*. https://doi.org/10.1016/j.scitotenv.2020.141915

Maclean, I. M. D., Duffy, J. P., Haesen, S., Govaert, S., de Frenne, P., Vanneste, T., Lenoir, J., Lembrechts, J. J., Rhodes, M. W., & van Meerbeek, K. (2021). On the measurement of microclimate. *Methods in Ecology and Evolution*, *12*(8), 1397–1410. https://doi.org/10.1111/2041-210X.13627

Martínez-Guzmán, J., Algara-Siller, M., Hamhaber, J., & Ramos Palacios, C. (2021). *Proposal for a food security program: The urban agriculture guideline at the Autonomous University of San Luis Potosí* [Maestría]. Universidad Autónoma de San Luis Potosí and TH Köln.

McPhearson, T., Andersson, E., Elmqvist, T., & Frantzeskaki, N. (2015). Resilience of and through urban ecosystem services. *Ecosystem Services*, *12*, 152–156. https://doi.org/10.1016/j.ecoser.2014.07.012

McPherson E, Nowak D, & Rowntree R. (1994). *Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project*.

Meadows, D. (2008). *Thinking in Systems* (Sustainability Institute, Ed.).

Mohamadzade, F., Gheysari, M., & Kiani, M. (2021). Root adaptation of urban trees to a more precise irrigation system: Mature olive as a case study. *Urban Forestry and Urban Greening*, *60*. https://doi.org/10.1016/j.ufug.2021.127053

Montes-Betancourt, L. A., Aldama-Aguilera, C., & Algara-Siller, M. (2020). *Riqueza y diversidad de insectos polinizadores en tres parques de la ciudad de San Luis Potosí*.

Nieto-Caraveo, L. M., & Medellín-Milán, P. (2004). *Hacia la construcción de una Agenda Ambiental de la Universidad Autónoma de San Luis Potosí, Reporte de la Comisión de Medio Ambiente*.

Nowak, D. J., Crane, D. E., Stevens, J. C., Hoehn, R. E., Walton, J. T., & Bond, J. (2008). A Ground-Based Method of Assessing Urban Forest Structure and Ecosystem Services. *Arboriculture and Urban Forestry*, *34*(6).

Nowak, D. J., & Ogren, T. L. (2021). Variations in urban forest allergy potential among cities and land uses. *Urban Forestry and Urban Greening*, *63*. https://doi.org/10.1016/j.ufug.2021.127224

Obalum, S. E., Chibuike, G. U., Peth, S., & Ouyang, Y. (2017). Soil organic matter as sole indicator of soil degradation. *Environmental Monitoring and Assessment*, *189*(4). https://doi.org/10.1007/s10661-017-5881-y

Olsen, A. A., Wolcott, M. D., Haines, S. T., Janke, K. K., & McLaughlin, J. E. (2021). How to use the Delphi method to aid in decision making and build consensus in pharmacy education. In *Currents in Pharmacy Teaching and Learning* (Vol. 13, Issue 10, pp. 1376–1385). Elsevier Inc. https://doi.org/10.1016/j.cptl.2021.07.018

Pataki, D. E., Carreiro, M. M., Cherrier, J., Grulke, N. E., Jennings, V., Pincetl, S., Pouyat, R. V., Whitlow, T. H., & Zipperer, W. C. (2011). Coupling biogeochemical cycles in urban environments: Ecosystem services, green solutions, and misconceptions. *Frontiers in Ecology and the*

Environment, *9*(1), 27–36. https://doi.org/10.1890/090220

Pouyat, R. v., Yesilonis, I. D., Russell-Anelli, J., & Neerchal, N. K. (2007). Soil Chemical and Physical Properties That Differentiate Urban Land-Use and Cover Types. *Soil Science Society of America Journal*, *71*(3), 1010–1019. https://doi.org/10.2136/sssaj2006.0164

Raymond, C. M., Bryan, B. A., MacDonald, D. H., Cast, A., Strathearn, S., Grandgirard, A., & Kalivas, T. (2009). Mapping community values for natural capital and ecosystem services. *Ecological Economics*, *68*(5), 1301–1315. https://doi.org/10.1016/j.ecolecon.2008.12.006

Razzaghi Asl, S., & Pearsall, H. (2022). How Do Different Modes of Governance Support Ecosystem Services/Disservices in Small-Scale Urban Green Infrastructure? A Systematic Review. In *Land* (Vol. 11, Issue 8). MDPI. https://doi.org/10.3390/land11081247

Robinson, K. F., Fuller, A. K., Hurst, J. E., Swift, B. L., Kirsch, A., Farquhar, J., Decker, D. J., & Siemer, W. F. (2016). Structured decision making as a framework for large-scale wildlife harvest management decisions. *Ecosphere*, *7*(12). https://doi.org/10.1002/ecs2.1613

Roper, W. R., Robarge, W. P., Osmond, D. L., & Heitman, J. L. (2019). Comparing Four Methods of Measuring Soil Organic Matter in North Carolina Soils. *Soil Science Society of America Journal*, *83*(2), 466–474. https://doi.org/10.2136/sssaj2018.03.0105

Stahle, A. (2018). *Developing Public Space and Land Values in Cities and Neighbourhoods*.

Supriatna, J. (2018). Biodiversity Indexes: Value and Evaluation Purposes. *E3S Web of Conferences*, *48*. https://doi.org/10.1051/e3sconf/20184801001

The Economics of Ecosystems and Biodiversity (TEEB). (2012). *The Economics of Ecosystems and Biodiversity in Local and Regional Policy and Management*.

Tian, Y., Liu, Y., Jim, C. Y., & Song, H. (2017). Assessing structural connectivity of urban green spaces in metropolitan Hong Kong. *Sustainability (Switzerland)*, *9*(9). https://doi.org/10.3390/su9091653

TWB. 2009. Making Monitoring and Evaluation Systems Work. A Capacity Development Toolkit. (n.d.).

Universidad Autónoma de San Luis Potosí (UASLP). (n.d.). *Portal de la Agenda Ambiental*. Universidad Autónoma de San Luis Potosí (UASLP). Retrieved 24 May 2022, from https://ambiental.uaslp.mx/

Unwin, D. M. (1978). Simple techniques for microclimate measurement. *Journal of Biological Education*, *12*(3), 179–189. https://doi.org/10.1080/00219266.1978.9654195

US Forest Service. (2019). *i-Tree Eco Field Guide*.

USDA Natural Resources Conservation Service. (2015). *Soil Quality Indicators*. http://go.usa.gov/zUAH

USDA Natural Resources Conservation Service (NRCS). (2004, June 16). *SPAW Reference Manual*. USDA NRCS. https://hrsl.ba.ars.usda.gov/SPAW/SPAW%20Reference%20Manual/Index.htm

Villasís-Keever, R., Medellín Milán, P., & Bassols Ricárdez, M. (2011). *Indicadores de sustentabilidad urbana El caso de la zona metropolitana de San Luis Potosí* [Doctorado]. Universidad Autónoma de San Luis Potosí and TH Köln.

Wentworth, J. (2017). *Urban Green Infrastructure and Ecosystem Services*. www.parliament.uk/post

Wong, C. P., Jiang, B., Kinzig, A. P., & Ouyang, Z. (2018). Quantifying multiple ecosystem services for adaptive management of green infrastructure.

Ecosphere, *9*(11). https://doi.org/10.1002/ecs2.2495

World Economic Forum (WEF), & Alexander von Humboldt Biological Resources Research Institute. (2022). *BiodiverCities by 2030: Transforming Cities' Relationship with Nature*.

Zhao, D., Lei, Q., Shi, Y., Wang, M., Chen, S., Shah, K., & Ji, W. (2020). Role of species and planting configuration on transpiration and microclimate for urban trees. *Forests*, *11*(8). https://doi.org/10.3390/f11080825