ArborMetropolis

Regional afforestation as a backbone for ecosystem-based adaptation in the metropolitan area of Monterrey

Isa van der Bijl

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Isa Elizabeth Anna van der Bijl
4819578
MSc Architecture, Urbanism and Building Sciences
Track: Landscape Architecture

Delft University of Technology
Faculty of Architecture and the Built Environment
Department of Urbanism

Urban Ecology
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First mentor: Dr.ir. N.M.J.D. (Nico) Tillie
Second mentor: Dr. D.A. (Diego) Sepulveda Carmona

Thank you, Nico, for your enthusiasm about urban ecology and for sharing your understanding and respect for nature. For all your sketches and dynamic meetings. For introducing me to the project in Monterrey. For sharing your knowledge and your guidance during this intensive year.

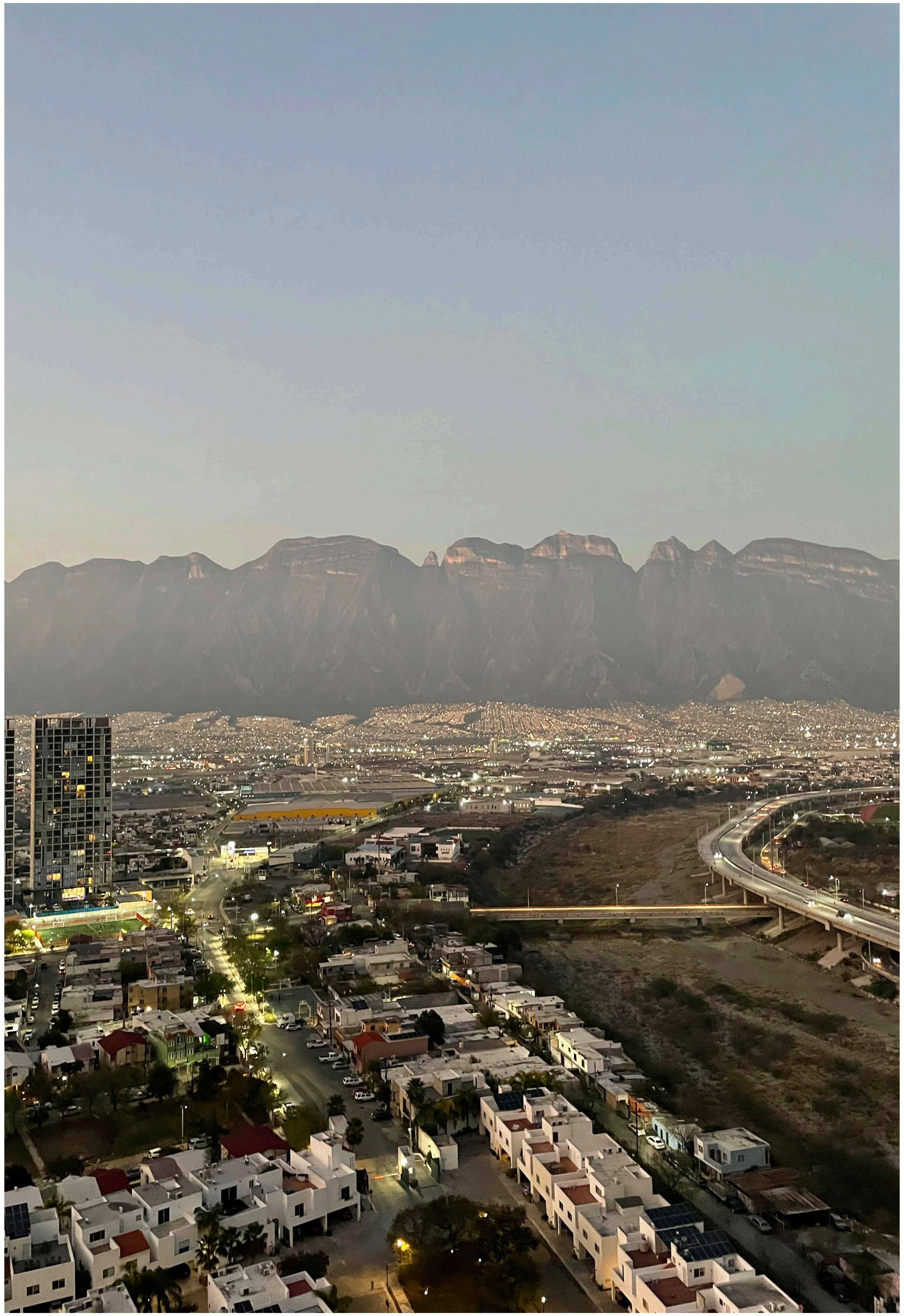
Thank you, Diego, for your support, and your commitment towards my project. For your responsibility to the urbanism discipline, your sensibility towards the Mexican culture, and for accompanying me in this process.

Thank you to all the experts and students I collaborated with during my site visit in Monterrey, Mexico. In particular, Rob Roggema, for hosting us on site, and Oswaldo Zurita Zaragoza, for guiding me in selecting native tree species for my project.

To my friends and family, thank you for being an inexhaustible source of encouragement and support. For your curiosity to understand what landscape architecture entails. For giving me the motivation to make this world a better place. Thank you for making this possible.

Enjoy reading my ArborMetropolis report!

Contents



Own photograph.

1. Introduction

Abstract

In response to the need for robust and extensive green infrastructure in Monterrey, Mexico, this thesis will explore the potentialities of upscaling urban forestry and regional afforestation as a solution. The metropolitan area of Monterrey, and it's urban landscape morphology, is facing severe environmental pressures shaped by a conflict between powerful natural forces, such as extreme weather events and deforestation, and turbulent human activities, such as urban expansion and poor management of natural areas. This results in an inaccessible, fragmented natural landscape. This thesis will define forest types suitable for arid climates, assess which ecosystems services an afforestation plan will deliver, and design strategies for sustainable, long-term green-blue infrastructures. The project's results contribute to enhancing ecosystem services, defragmenting the natural landscape, and harmonizing the relationship between people and nature. The research also identifies the key challenges and barriers to expanding Monterrey's green network, by creating a value map, and proposing design interventions for overcoming them. These findings will emphasize the potential of regional afforestation in arid urban landscapes and underscore the significance of ecosystem-based adaptation. Finally, this thesis proposes an evolutionary framework to find the potential capacities to connect Monterrey's landscape patches with the natural protected areas.

Keywords:
Monterrey Metropolitan Area, Regional afforestation, Urban forestry, Ecosystem-based adaptation, Urban ecology, Arid urban landscapes, Ecological fragmentation

Own photograph.

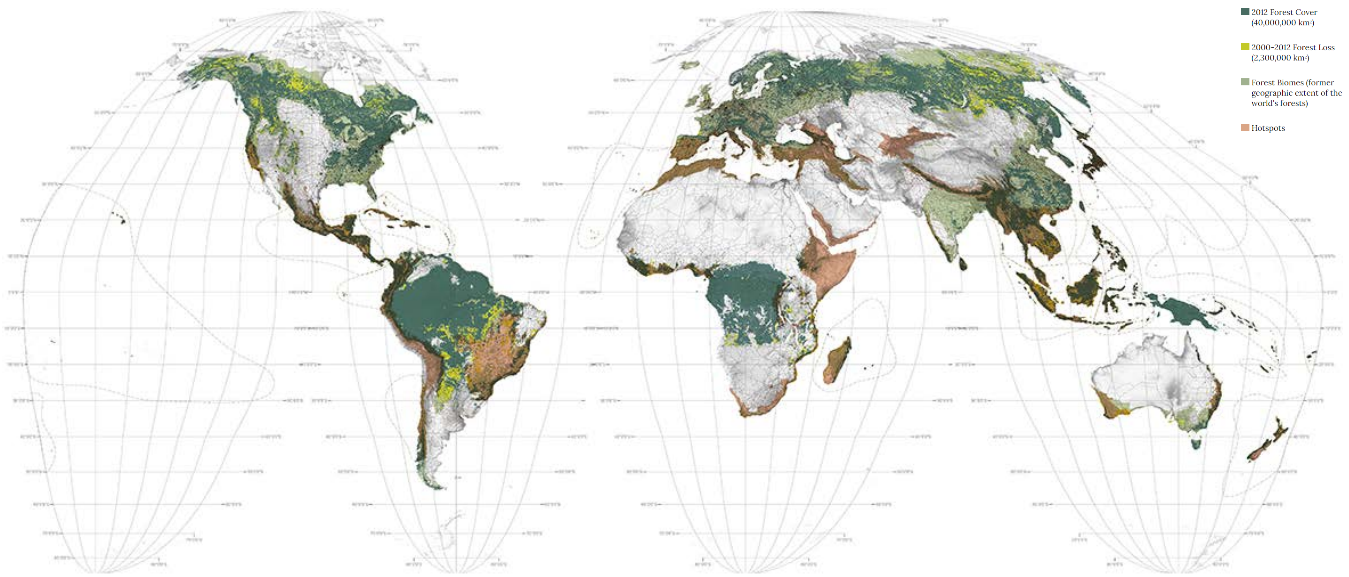
Motivation

My motivation begins with the importance of worldwide ecology and biodiversity. Globally we deforest around 10 million hectares of forest every year (Ritchie & Roser, 2023). Since 1990, Mexico has lost 49.000 km^2 of forest (FAO, 2021). Deforestation contributes to a loss of biodiversity and woodlands, which has a big influence on Mexico's natural landscape.

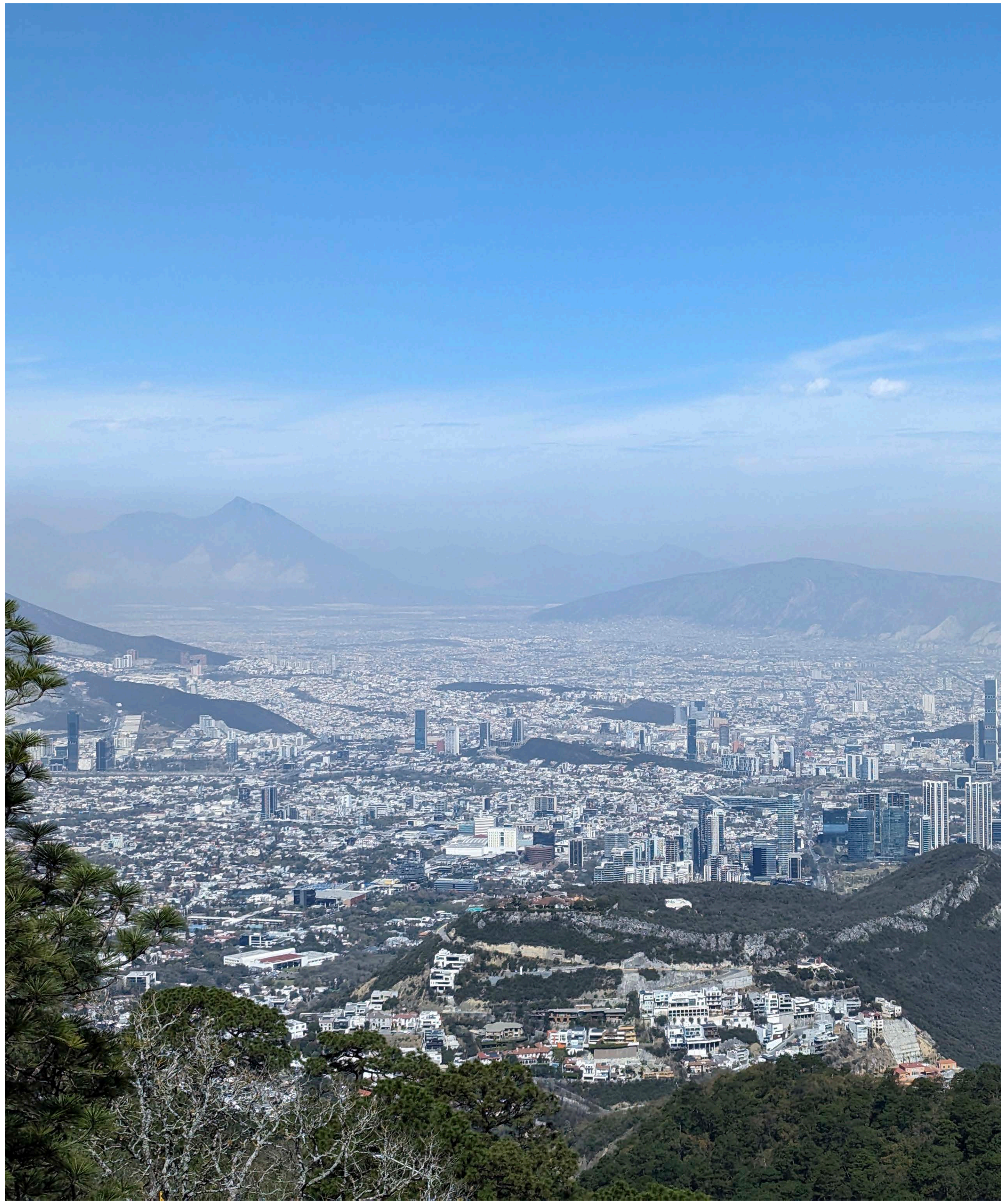
The city of Monterrey faces severe ecological risks if it continues to use its landscape as it does now. Every decade, a hurricane destroys all existing infrastructure, there are more and more wildfires, and they continue building fast-paced, non-resilient neighbourhoods. There is a huge potential to create a more natural approach to managing the metropolitan region.

This thesis aims to show that it is possible to manage a city of 5.5 million people ecologically with regional afforestation as a basis.

Worldwide deforestation



Weller, R. J. (2017). *World Maps - Deforestation*. Retrieved April 24, 2024, from http://atlas-for-the-end-of-the-world.com/world_maps/world_maps_deforestation.html



Own photograph.

Social context

"The Monterrey Metropolitan Area (MMA) (image 1) has experienced rapid and intense development, particularly since the signing of the North American Free Trade agreement in the early 90s" (Carpio et al., 2021). This growth is represented by agglomeration economies, where economic production systems benefit from co-location (Carpio et al., 2021).

The MMA consists of 12 municipalities. Its population has doubled since 1990, from 2,691,000 to 5,117,000 people in 2023. Correlated to this, the Tons of CO_2 have also doubled (image 2). The expansion's boundaries were limited by the mountains, natural protected areas, and municipal borders. Therefore, the expension is marked as a linear strip development.

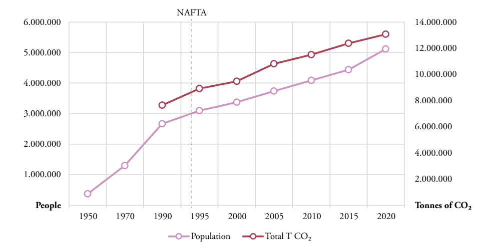
This rapid development caused an average trip duration of 1.3 hours and even 2.0 hours in peripheral urban areas (Carpio et al., 2021).

In conclusion, the demand for the metropolitan region is growing. There are immense developed hillsides (image 3), and the current urban expansion is taking up more space in a northern direction.

[1] Monterrey Metropolitan Area

Huertas, et al. © 2020. This work is openly licensed via CC BY 4.0. *Detailed map on location of MMA.* ResearchGate. Retrieved April 26, 2024, adapted from https://www.researchgate.net/figure/Detailed-map-on-the-location-of-a-Monterreys-Metropolitan-Area-MMA-and-b-the_fig2_342634789

[2] Relation between population growth and Tons of CO_2



Carpio, A., Ponce-Lopez, R., & Lozano-García, D. F. (2021). Urban form, land use, and cover change and their impact on carbon emissions in the Monterrey Metropolitan area, Mexico. *Urban Climate*, 39, 100947. https://doi.org/10.1016/j.uclim.2021.100947

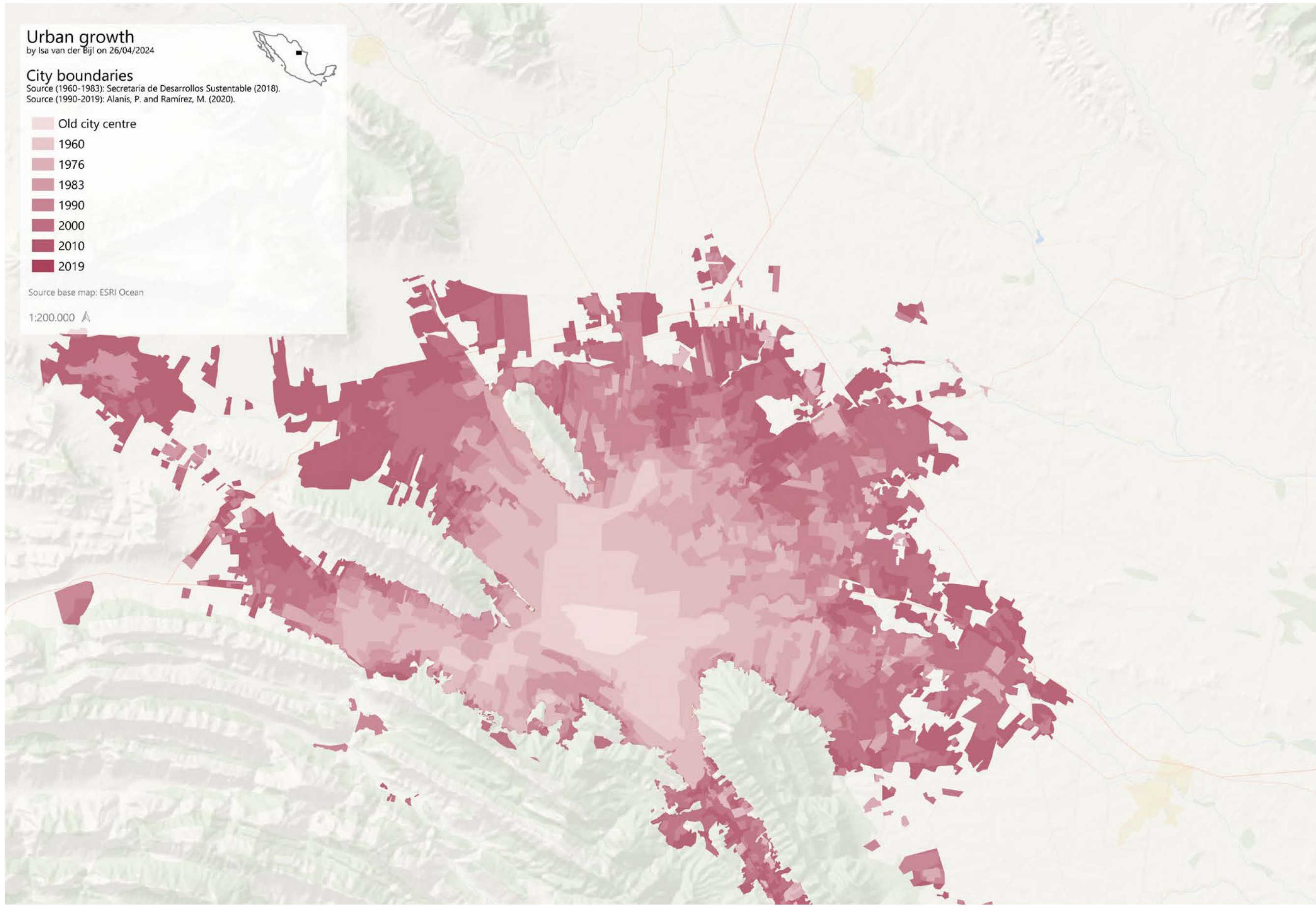
[3] Developed hillsides in Monterrey

Lozano Valdes, D. (2016). *Developed hillsides loom over the city of Monterrey*. The Nature Conservancy. https://www.nature.org/en-us/what-we-do/our-insights/perspectives/growing-greener-in-mexico-city-of-the-mountains/

The juxtaposition of the urban sprawl and the natural protected areas

Heim, A. (2011, September 8). *Cerro de la Silla*. TNW. https://thenextweb.com/news/why-monterrey-mexico-needed-a-startup-weekend

Demographic growth



Landscape biography

Monterrey was founded in 1596 by Diego de Montemayor, along with twelve other companions and their families (Garza, 2020). Its development was shaped by its location in a valley surrounded by the Sierra Madre Oriental mountains. Before industrialisation, it was a small settlement with a dense urban fabric of adobe houses and stone buildings.

During the Mexican-American War in 1846, Monterrey was the site of a key battle between U.S. forces under General Zachary Taylor and Mexican troops (Bluhm, 2017). The city's landscape, including Independence Hill (image 3) and the Bishop's Palace (image 2), played a pivotal role in the battle's outcome.

After the war, Monterrey grew into a significant industrial and economic centre. The Monterrey Institute of Technology and Higher Education, founded in 1943, became a driver of the city's development (Cooper, 2022).

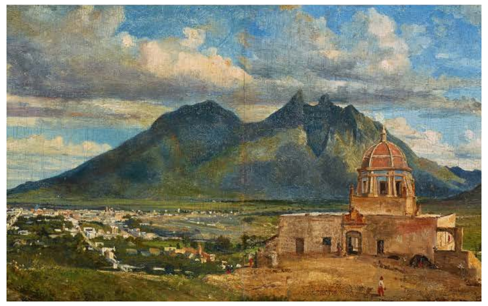
Today, Monterrey is a growing metropolis that still has marks of its storied past. Independence Hill remains a prominent feature, and the Bishop's Palace is now a museum that connects visitors to the city's history.

From its origins to its current status, Monterrey's landscape has witnessed centuries of change, war, and growth that have shaped its identity.

[1] Cerro de la Silla

Pinterest. (n.d.). *Monterrey*. https://ar.pinterest.com/pin/272678952424540234/

[2] Bishop's Palace near Monterrey

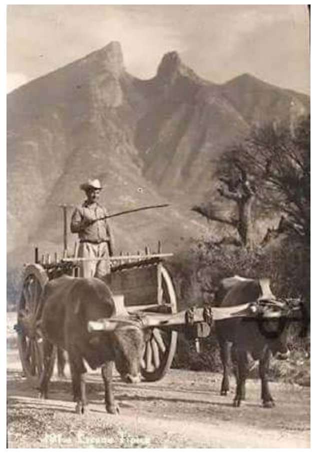


Chapman, C. (1856). *View of Bishop's Palace near Monterrey*. [1865 oil on paper mounted on canvas 22 x 81 cm. (Sotheby's)] Leoncillo Sabino. Retrieved from https://eliasjorge4.blogspot.com/2015/02/conrad-wise-chapman-un-artista-soldado.html

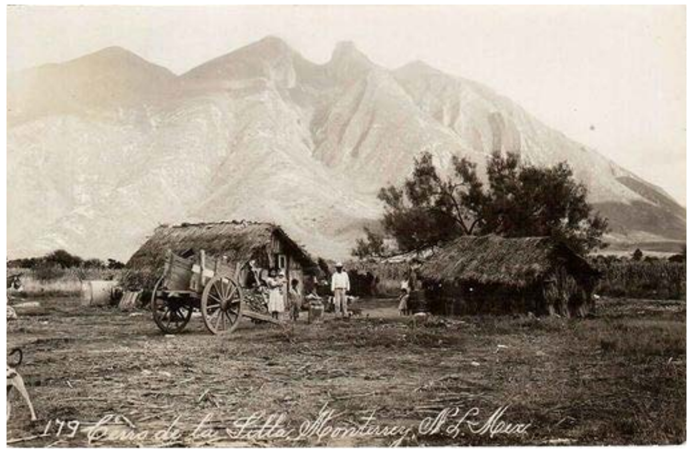
[3] Monterrey from independence hill

Swinton, F. (1847). *Monterey, From Independence Hill, in the rear of the Bishop's Palace*. Wikimedia Commons. Retrieved from https://upload.wikimedia.org/wikipedia/commons/b/bf/Frederick_Swinton_-_Monterey%2C_From_Independence_Hill%2C_in_the_rear_of_the_Bishop%27s_Palace._As_it_appeared_on_23rd_Septemb. . ._-_Google_Art_Project.jpg

Impressions from Monterrey before industrialization



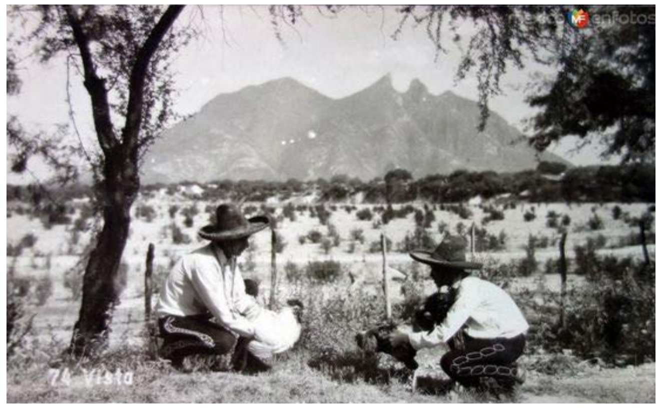
Pinterest. (n.d.-b). *Monterrey* [pinterest post]. Retrieved April 26, 2024 from https://ar.pinterest.com/pin/272678952424540234/



Pinterest. (n.d.-a). *Cerro de la Silla* [pinterest post]. Retrieved April 26, 2024 from https://i.pinimg.com/564x/12/31/ef/1231ef-cd807976af242312066730f0df.jpg

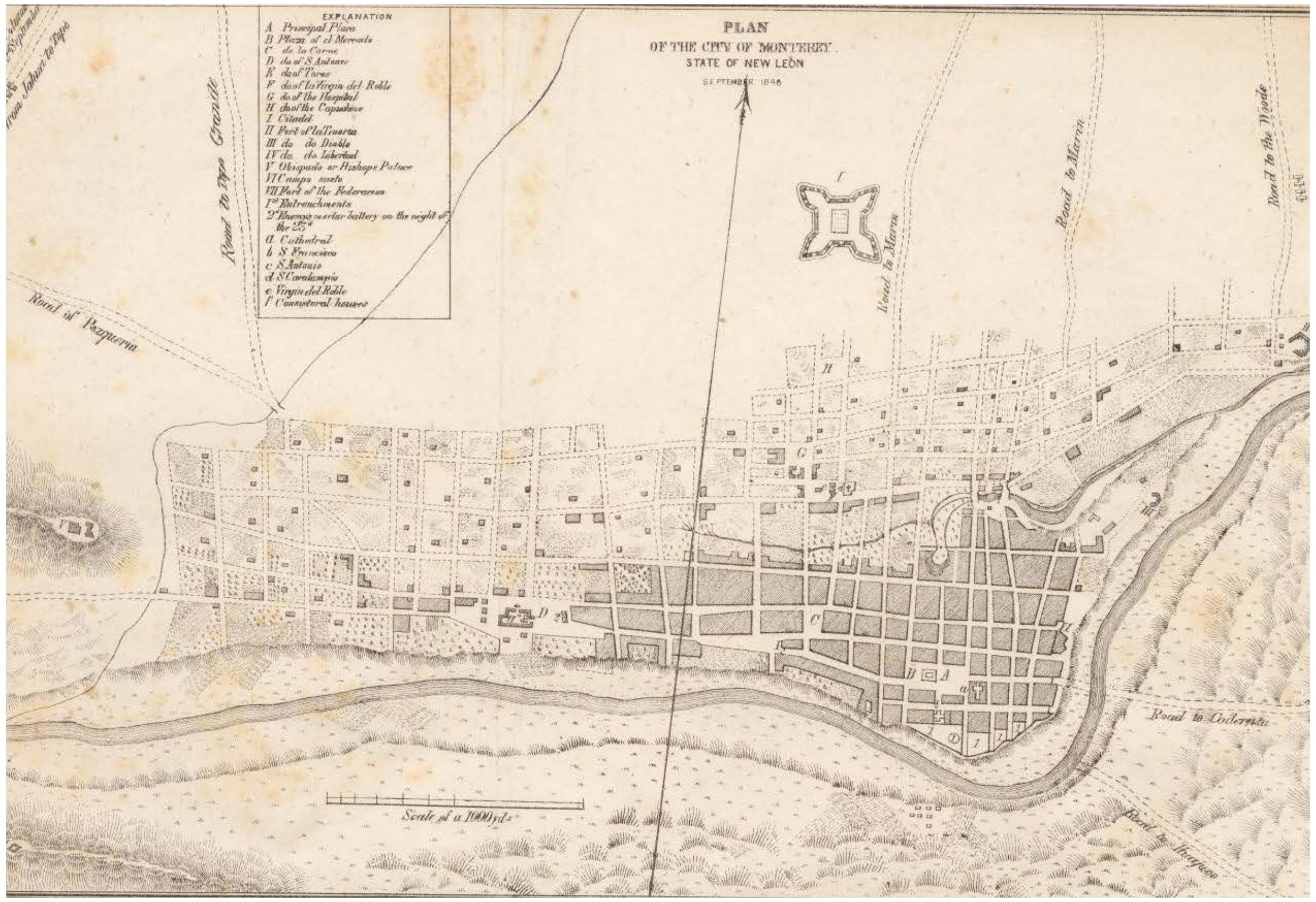
Mantecon Siller, E. (n.d.). *El canastero* [pinterest post]. Retrieved April 26, 2024 from https://i.pinimg.com/564x/86/ef/34/86e-f342ac052c94adee54ed790c579c3.jpg

MexicoEnFotos. (n.d.-a). *Tipos Mexicanos adolecente yuntero* [pinterest post]. Retrieved April 26, 2024 from https://i.pinimg.com/564x/95/dc/ad/95dcad87d56a600b618ccad6202862f8.jpg



MexicoEnFotos. (n.d.-b). *Vista tipica* [pinterest post]. Retrieved April 26, 2024 from https://i.pinimg.com/564x/81/57/6a/81576a877a2c-84420c96e6d0d9c2ccd9.jpg

City map of Monterrey 1847 during Mexican War



Ackerman, L. (1847). Plan of the city of Monterey State of New Leon. Texas History. https://texashistory.unt.edu/ark:/67531/metapth187658/#who

Geomorphology of Monterrey

Monterrey, the capital city of the state of Nuevo León in north-eastern Mexico, is known as the "King of Mountains" due to its mountainous landscape. The iconic Cerro de la Silla, or "Saddle Hill", is a symbol of the city (image 2) and a source of great pride for its residents together with the other mountain landscapes (De La Mora-de La Mora, 2015). The people of Monterrey have a deep connection to their mountains, which are an integral part of the city's identity and culture.

To protect this natural landscape, local authorities have established natural protected areas, aiming to conserve biodiversity and to prevent the destruction of the mountains. These conservation efforts have helped preserve the environment and provide opportunities for residents and visitors to engage with nature. This is achieved mainly through extensive hiking trails suitable for all experience levels, as well as activities like wildlife observation and other recreational opportunities (image 3). By safeguarding the mountains, Monterrey has reinforced its identity as the "King of Mountains" (De La Mora-de La Mora, 2015).

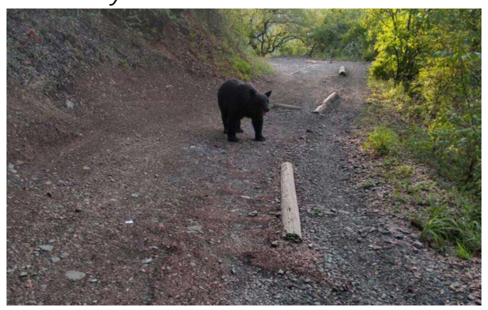
[1] Area Natural Protegida Sierra de las Mitras

Materia prima, Loana, E., & Sisniega. (n.d.). *Las Mitras*. Atlas Materia Prima. https://atlasmateriaprima.net/Las-Mitras

[2] Monumento Natural Cerro de la Silla

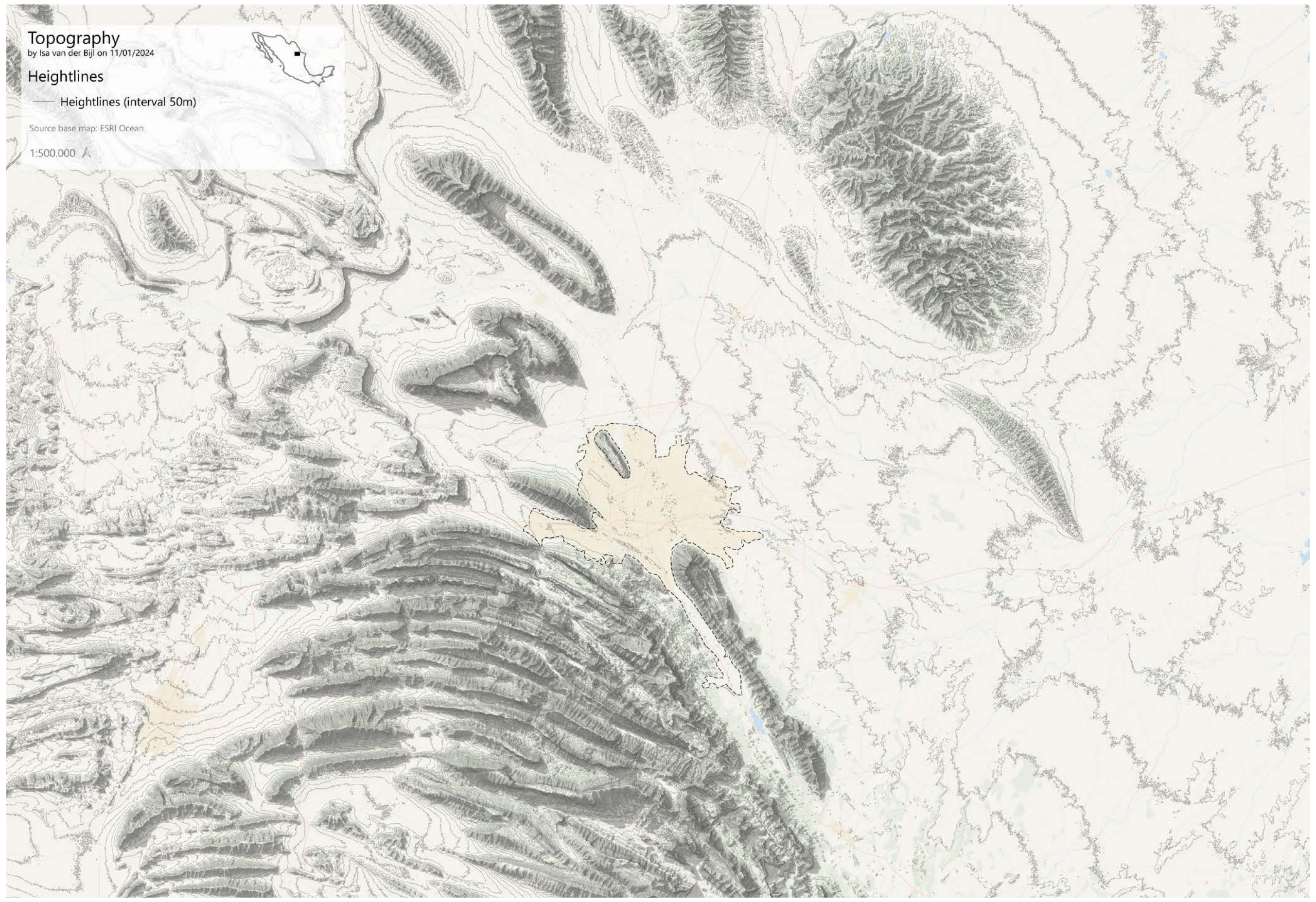
Trejo, Y. & Special. (2022, August 1). *Cerro de la Silla*. Diario AS. https://mexico.as.com/actualidad/cerro-de-la-silla-por-que-se-llama-asi-donde-se-localiza-y-curiosidades-n/

[3] Parque National Cumbres de Monterrey

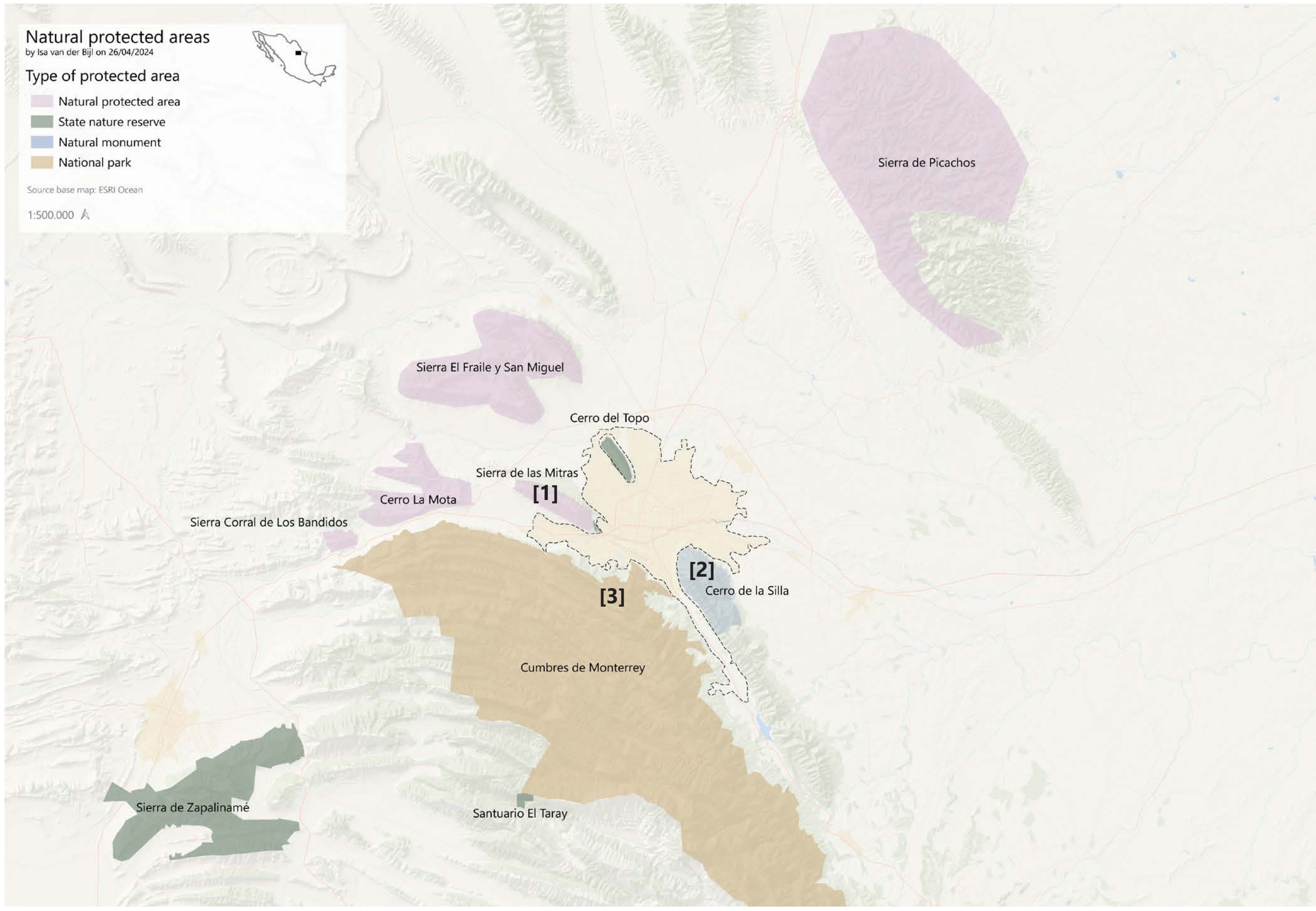


Escapadas por México Desconocido. (2022, December 12). *Parque Ecológico Chipinque*. Escapadas. https://escapadas.mexicodesconocido.com.mx/atractivos/parque-ecologico-chipinque-el-bosque-sobre-la-ciudad/

Topography map



Natural protected area types



Landscapes of Monterrey

In the region of Monterrey there is a cohabitation of three primary forest ecological zones. All three have a subtropical climate domain meaning the average temperature is over 10°C for eight months or more per year and the climate region is warm temperate dry (FAO, 2010). However, each ecological zone has different characteristics.

[1] Subtropical desert
Arid and all months dry.

[2] Subtropical steppe
Semi-arid with more evaporation than precipitation.

[3] Subtropical mountain system
Approximately a higher altitude than 800 to 1000 m.

These ecological zones consist of various types of vegetation, ranging from the stereotypical oak-pine forests of the Sierra Madre Oriental region to desert-like vegetation such as green desert spoon, dense thickets, mesquites, and thorn scrub that characterize Monterrey's landscape.

[1] Subtropical desert

Wikiloc. (n.d.-a). *Aguja Superior, Carricitos, Mina, Nuevo León*. Wikiloc: Trails of the World. https://www.wikiloc.com/trails/hiking/mexico/nuevo-leon/carricitos

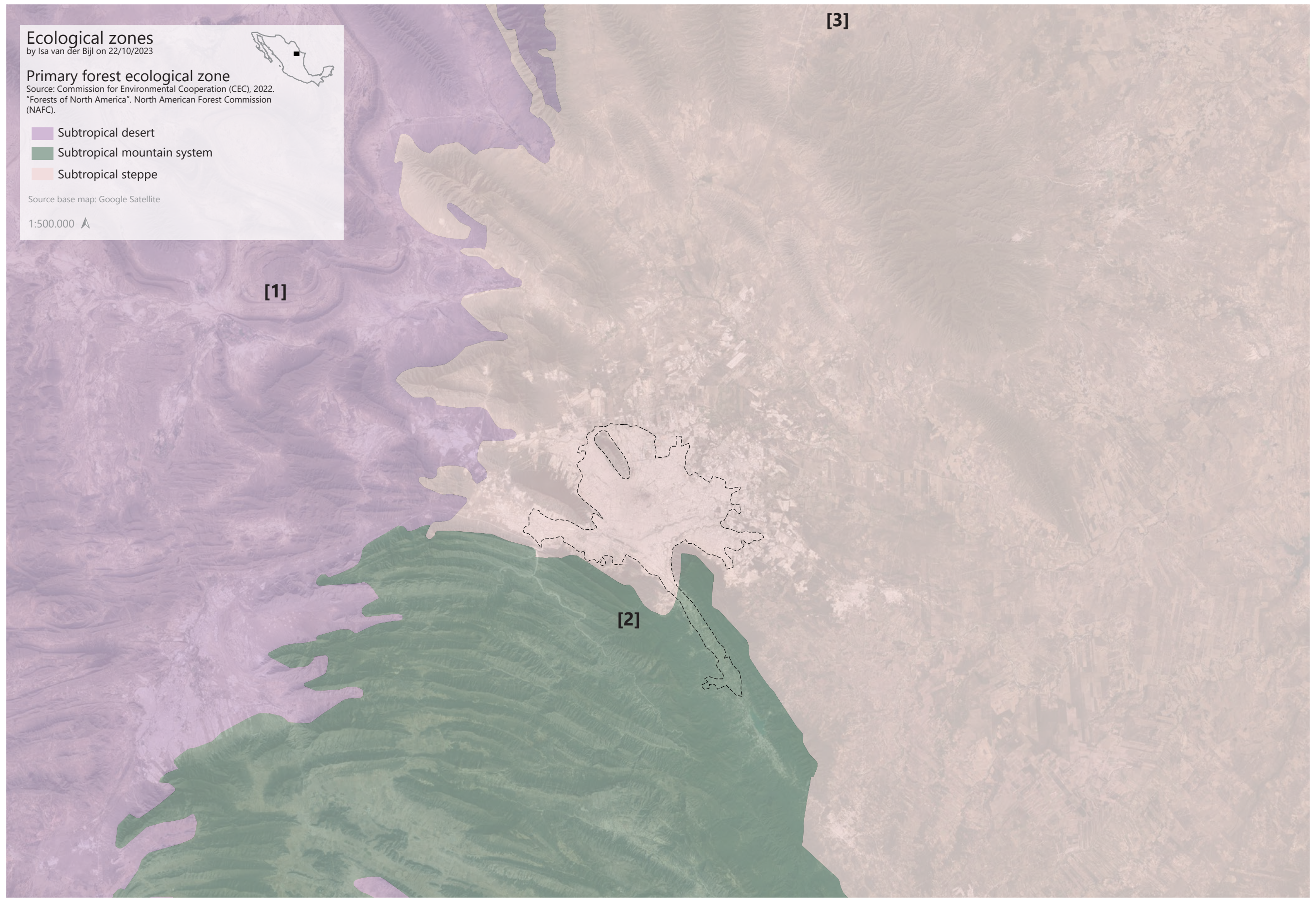
[2] Subtropical mountain system

Serafini, G. (2008, April 20). *Hiking to El Pinal*. https://www.flickr.com/photos/gserafini/2427214184/

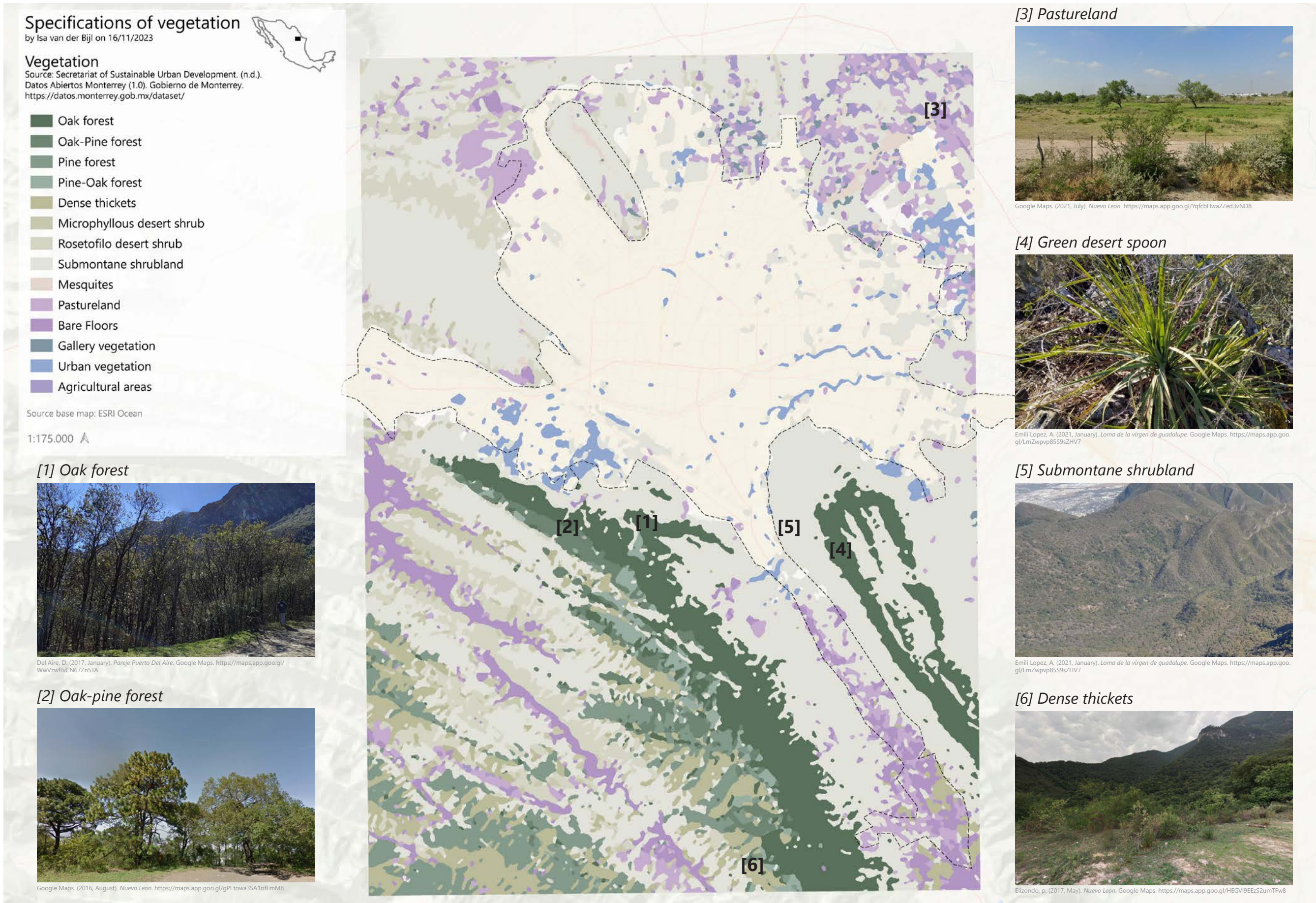
[3] Subtropical steppe

Wikiloc. (n.d.-c). *El cóleo bordo rio*. Wikiloc: Trails of the World. https://www.wikiloc.com/hiking-trails/rio-salado-san-blas-120522533/photo-77227027

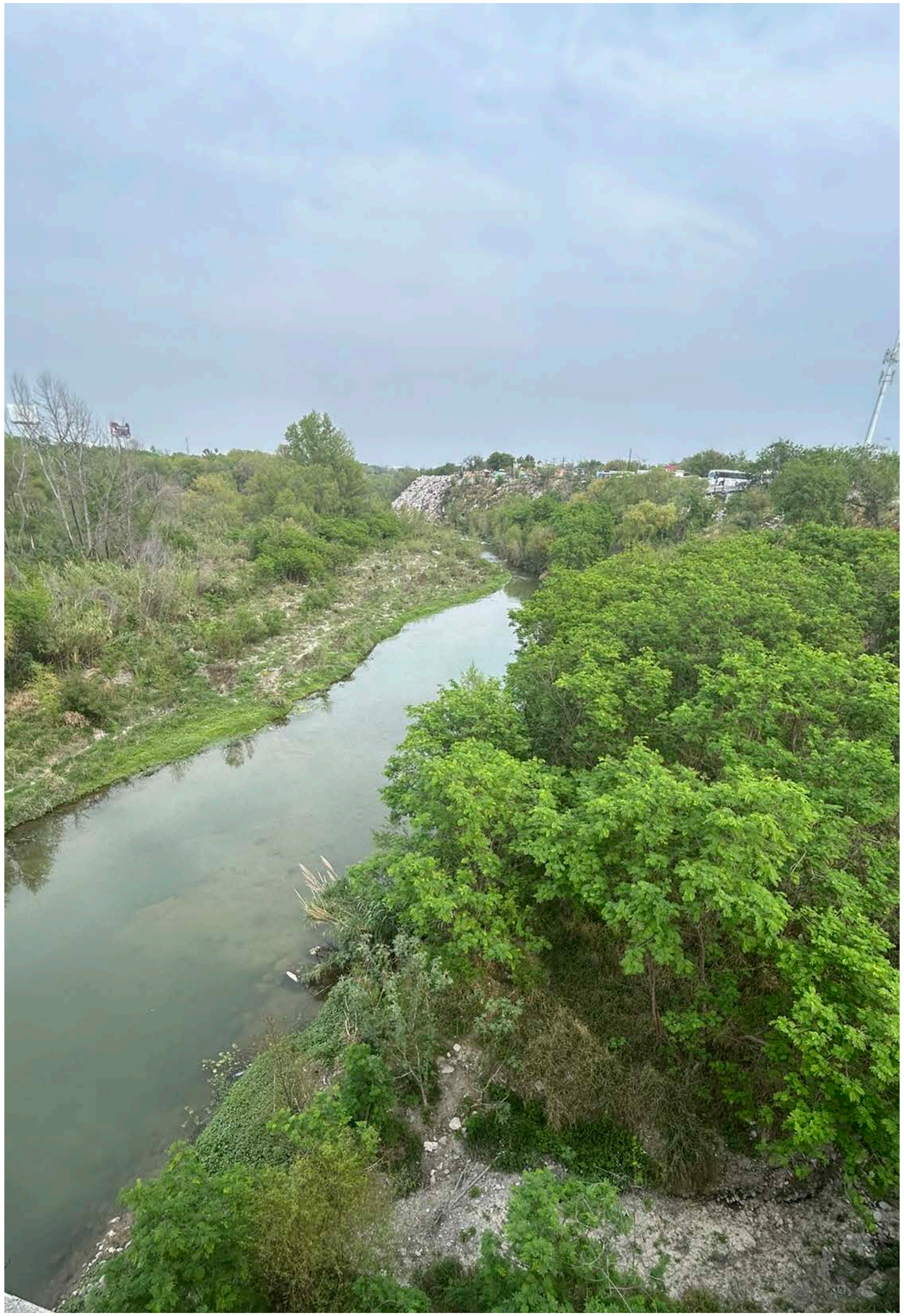
Three types of primary forest ecological zones



Vegetation types



This dataset is limited to the municipal borders of Monterrey, therefore it is a rectangle.



Own photograph.

2. Problematisation

Human influence

"Alterations in climatic patterns have been evident in the Mexican northeast, in recent times. In the past, the dry season and hurricanes were the most feared element. Nowadays, the irregularity of the rains, high temperatures and short winters represent manifestations of change. Explanations for this are evident everywhere, including: deforestation, overexploitation of water resources, demographic increase and environmental contamination." (Museo del Noreste, n.d.)

As this quote implies, the alterations in the climatic pattern in the Mexican north-east are caused by a high human influence on the landscape. Humans have been taking possession of the land, there is a high level of land use change, and this struggle is still present. This high human influence is visible in the city centre, but also in the peripheral and rural areas. This shows the need for a regional design strategy.

As Mexico's third-largest metropolitan area and a major industrial hub, the city's rapid growth and car dependency (image 3) have taken a heavy toll on the environment and public health. Air quality in Monterrey frequently reaches unhealthy levels (image 1), with high concentrations of pollutants like PM2.5, PM10, ozone, and nitrogen dioxide (IQAiR, n.d.).

Contamination extends beyond the air to Monterrey's streets and water supply. Illegal dumping and inadequate waste management cause many neighbourhoods, and even Río Santa Catarina (image 2), with trash and debris (Córdova & Ramos, 2019). Furthermore, industrial activities, especially from the cement, steel, glass, and petrochemical industries, are major contributors to the city's air pollution.

This toxic combination of industrial and vehicular pollution has serious health consequences. Air pollution causes an estimated 1,252 premature deaths yearly in the metropolitan area (Córdova & Ramos, 2019). In order to solve any of these problems, there is a need for an integrative holistic design approach on the metropolitan scale.

[1] Severe air quality issues

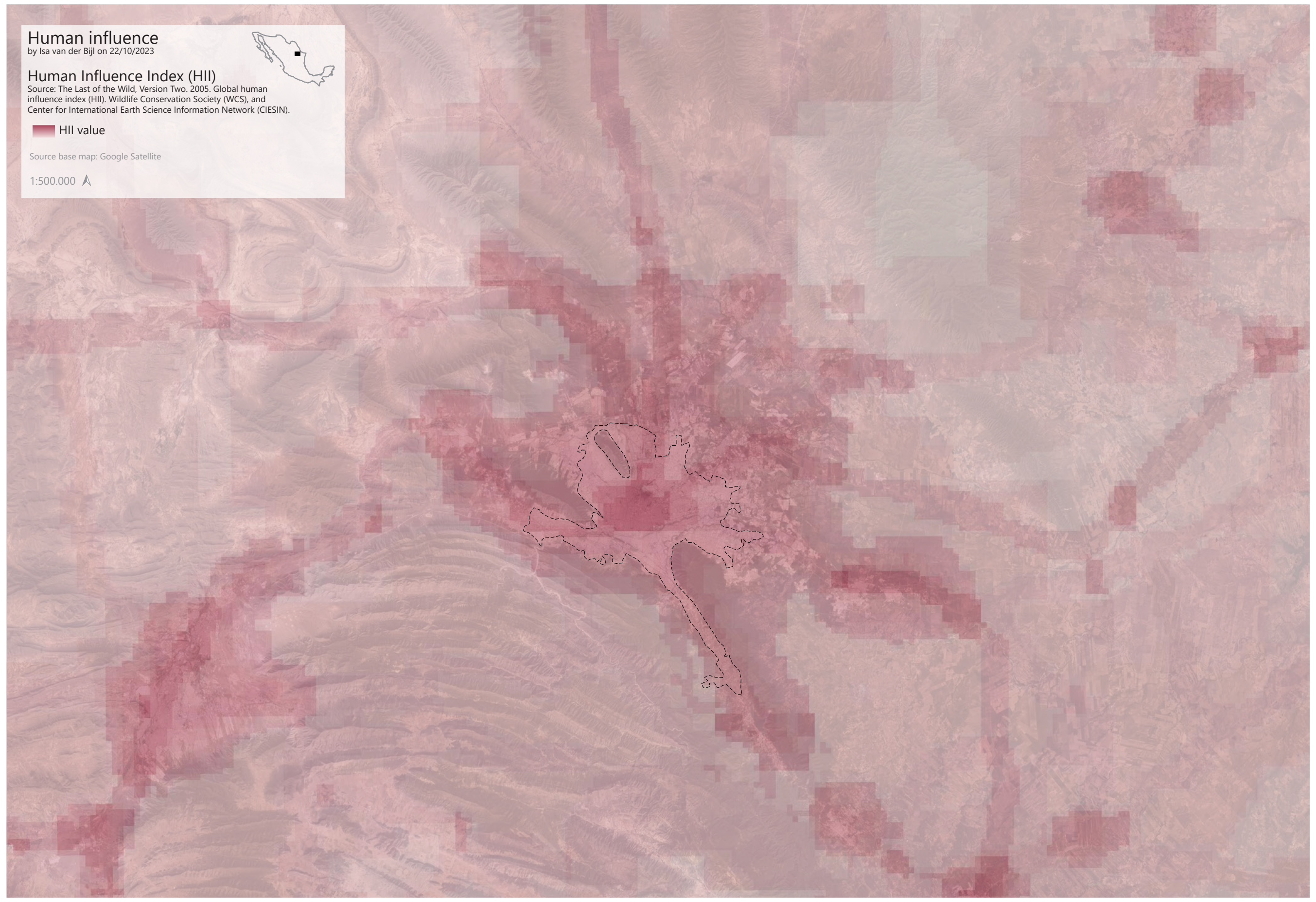
Copeland, C. (2019, November 30). *Air quality alert issued in Nuevo León for second time this week. Mexico News Daily*. Retrieved October 28, 2023, from https://mexiconewsdaily.com/news/air-quality-alert-in-nuevo-leon-for-second-time/

[2] Pollution

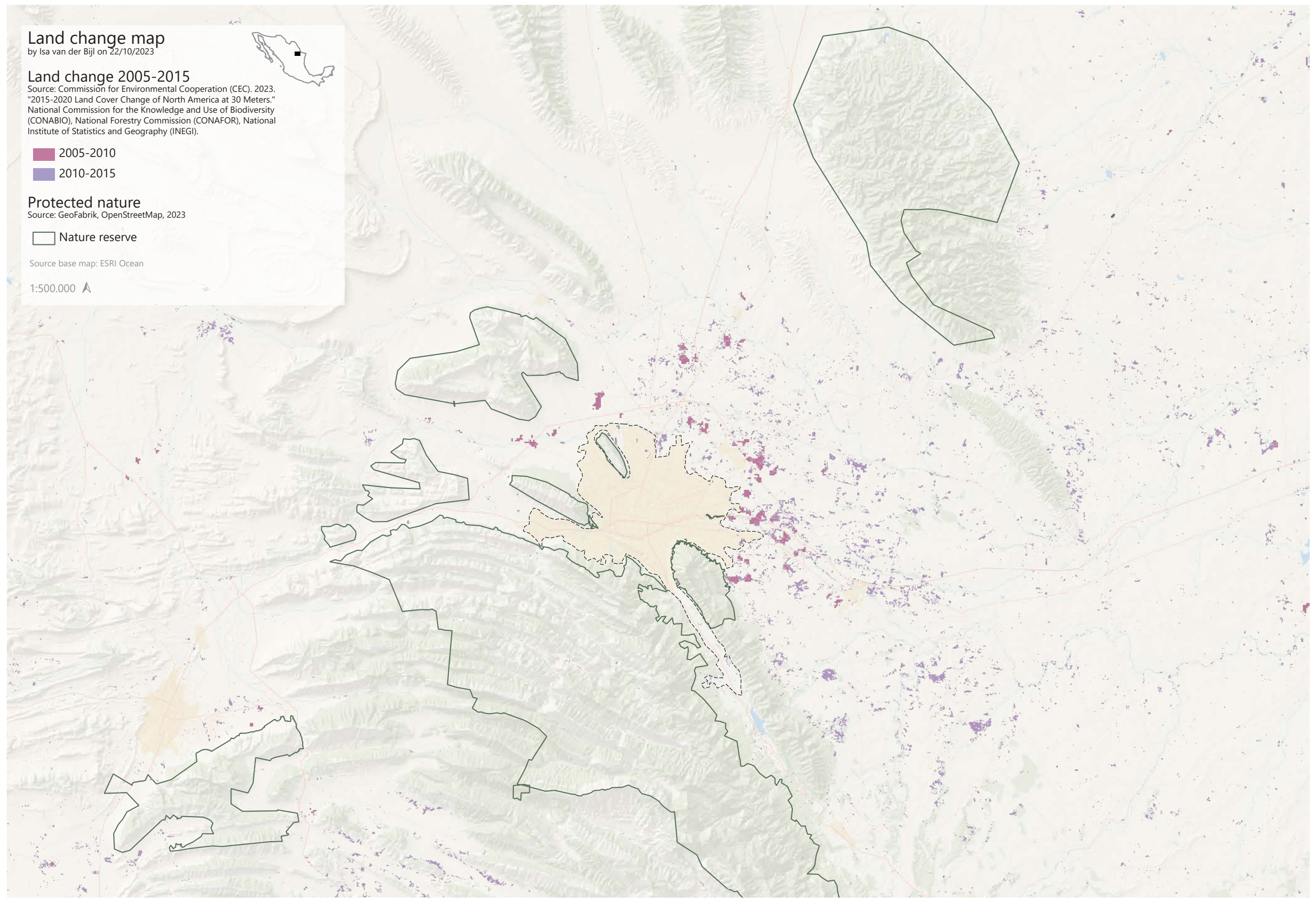
[3] Car dependency

Reddit. (2021). *Monterrey, NL, MX*. Image from Carlows93. Retrieved from https://www.reddit.com/r/UrbanHell/comments/mqsvyn/monterrey_nl_mx/

Human influence on terrestrial ecosystems



Land use change



Deforestation

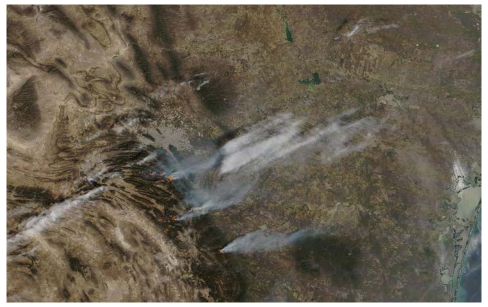
Throughout history, forests have been essential for human settlements, providing wood for various purposes like cooking, building structures, and keeping warm. Around 1.2 billion people depend on forests for their livelihood, and 840 million collect firewood daily (Dugan et al., 2014). Over the last 10,000 years, the world has lost one-third of its forests, an area twice the size of the United States (Ritchie & Roser, 2023). Between 1990 and 2015, the world's forest area decreased from 4,128 million hectares to 3,999 million hectares (Bartz et al., 2015).

Deforestation refers to the complete clearing and permanent conversion of forested land into another land use, such as farms, mining sites, or cities (Ritchie & Roser, 2023). In contrast, forest degradation, often caused by forestry production and wildfires, is a temporary disturbance from which the forest can regrow if left alone (Ritchie & Roser, 2023). Deforestation primarily results from logging, land clearance for agriculture, infrastructure, and urban sprawl (Weller, 2017).

Deforestation in Monterrey has been attributed to various factors, including urbanization, industrialization, and poor forest management practices (LAC Geo, 2024). Illegal logging for firewood and charcoal, as well as land clearing for agriculture and grazing, have contributed to the loss of forest cover (Lai, 2022). Between 1990 and 2015, Nuevo León experienced some of the highest deforestation rates in Mexico. In 2021, Nuevo León battled its worst wildfire season in over a decade (image 1), with the National Park Cumbres de Monterrey being one of the most affected areas (Lai, 2022). The wildfires (image 2) were fuelled by drought conditions, high temperatures, and strong winds. Climate change has significantly increased the frequency and intensity of these fires (Lai, 2022).

The consequences of deforestation and wildfires extend beyond the immediate loss of forest cover (image 3). Deforestation has led to soil erosion, loss of biodiversity, reduced water absorption, and increased runoff, creating ideal conditions for more severe flooding during heavy rainfall events (LAC Geo, 2024). The degradation of the National Park Cumbres de Monterrey has also threatened the city's water security, as the forests play a crucial role in capturing and filtering water (Lai, 2022).

[1] Wildfires burning in Nuevo León on March 27, 2021



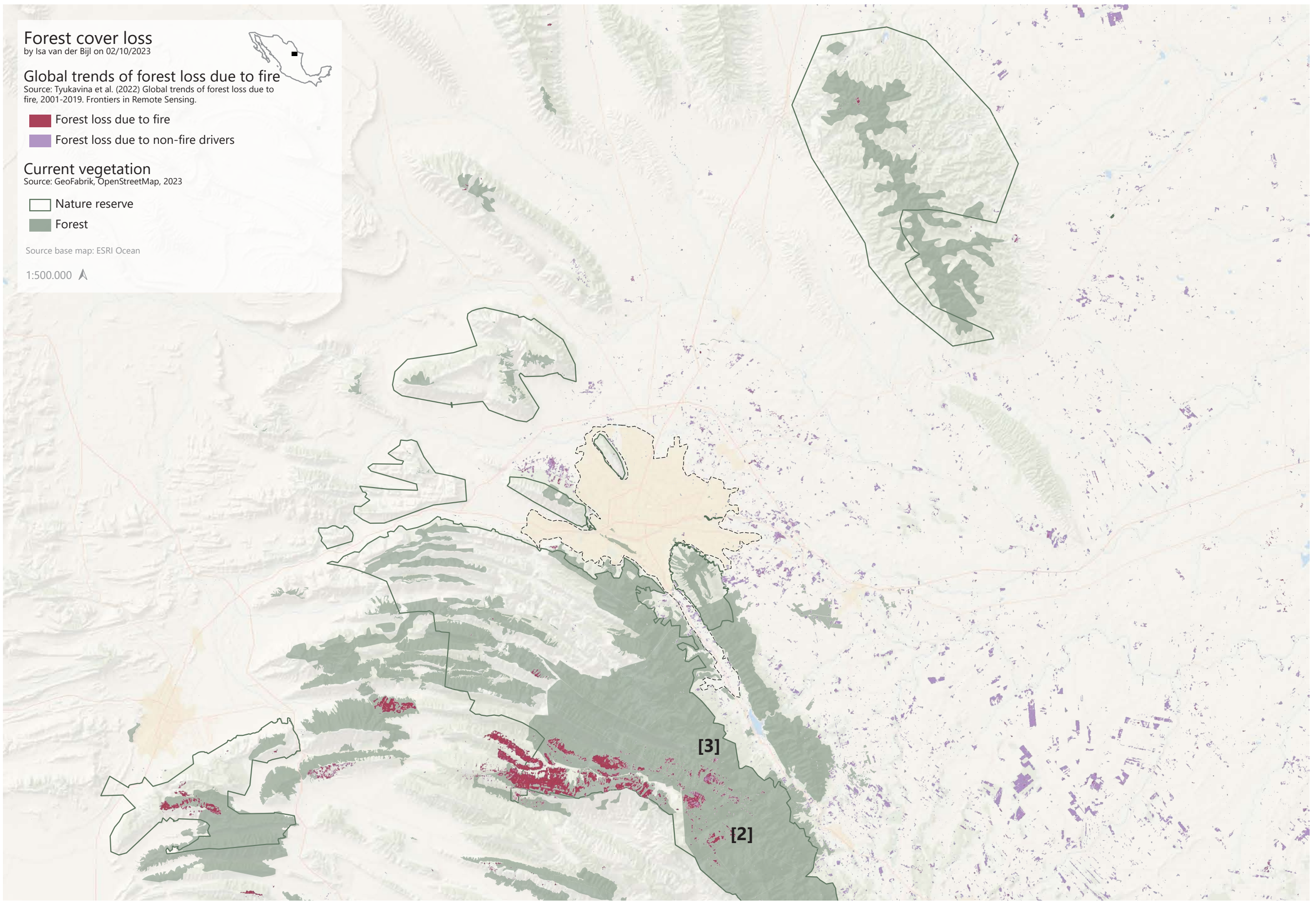
NASA. (2021, March 27). *Fires and Thermal Anomalies*. NASA Worldview. https://worldview.earthdata.nasa.gov/

[2] Wildfires in Sierra de Santiago

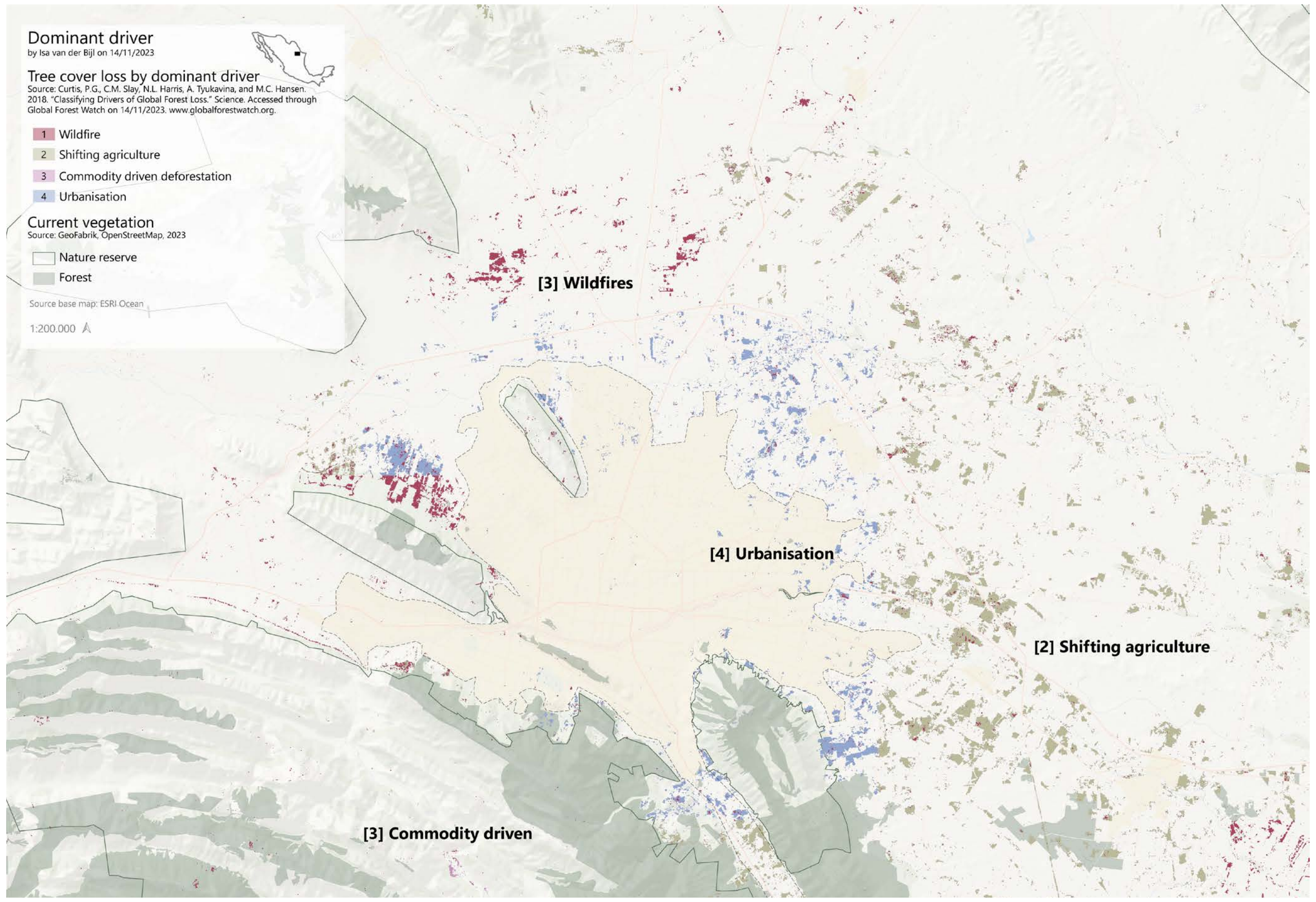
Protección Civil Nuevo León. (2022). *El incendio en la Sierra de Santiago*. Infobae. https://www.infobae.com/en/2022/04/19/nuevo-leon-forest-fire-in-the-sierra-de-santiago-was-100-controlled/

[3] Result of wildfires close to La Ciénega de González

Forest cover loss



Dominant driver of cover loss

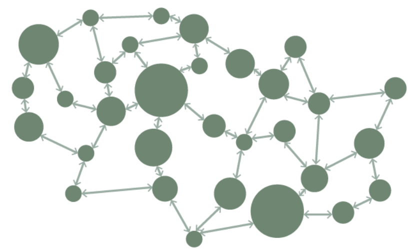


Fragmented landscape

Habitat fragmentation and connectivity are key concepts in landscape ecology that describe the spatial arrangement of vegetation. Fragmentation refers to how vegetation communities are broken apart into smaller, isolated patches within a landscape (image 2), often happening simultaneously with habitat loss (Smith, 2013). In contrast, connectivity describes a condition where habitat patches are linked across a landscape, promoting species movement and ecological processes (image 1) (Smith, 2013).

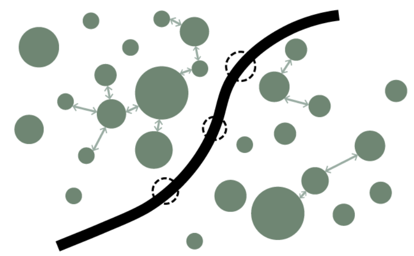
Recubenis Sanchis (2020) analysed the recognition of the Open Space Matrix and its potential for transformation, finding that the higher the land occupation level, the lower the degree of possible land transformation. This implies that the potential for intervention is lower in dense urban areas. Monterrey faces a similar challenge with its highly fragmented landscape, where urban expansion has disrupted the continuity of natural habitats.

[1] Landscape with high patch connectivity



Redrawn after Smith, C. (2013, April 15). *Landscape patterns* [Slide show; PDF]. https://www.albertap-cf.org/rsu_docs/landscape-patterns-presentation-02-may13.pdf

[2] Landscape fragmented by road



Redrawn after Smith, C. (2013, April 15). *Landscape patterns* [Slide show; PDF]. https://www.albertap-cf.org/rsu_docs/landscape-patterns-presentation-02-may13.pdf

Potential for transformation in Monterrey

Adapted from Recubenis Sanchis, I. (2020). *Restoring Systemic Proximities: Towards the re-territorialization of the Dutch Rivierenland*. TU Delft. Retrieved from http://resolver.tudelft.nl/uuid:2d79ab24-9ac8-4b1f-8bca-ed4eeb999e71

Fragmented landscape

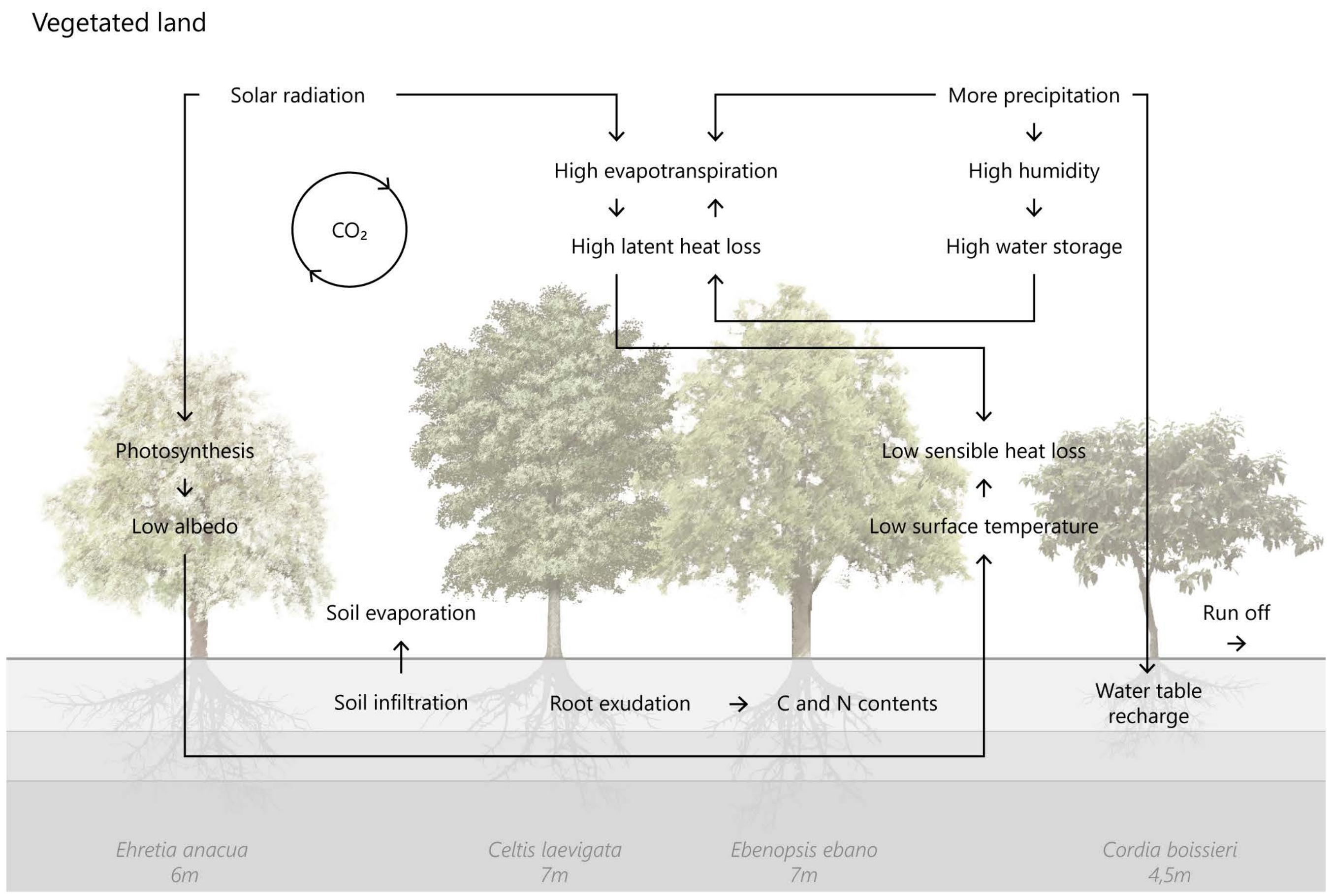
Disrupted cycles

Due to deforestation, there has been, among other things, a loss of vegetation in the metropolitan area of Monterrey. This has disrupted the local ecological cycles, led to soil degradation, and reduced biodiversity.

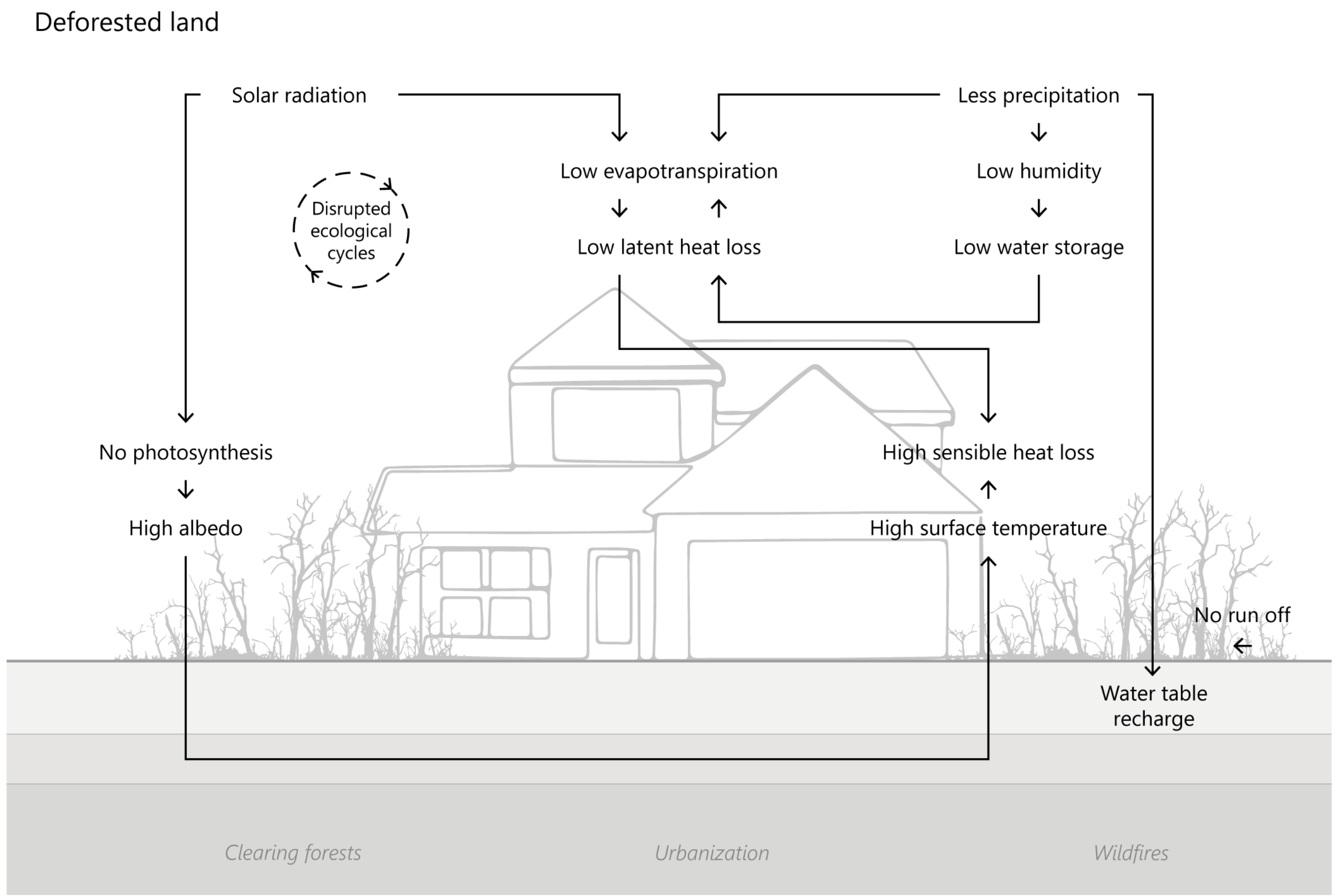
This is illustrated in the "Deforestation - Deforested land" section, showing the disruption of ecological cycles caused by the removal of vegetation, clearing forests, urbanisation and wildfires. This leads to consequences such as low evapotranspiration, low humidity, high surface temperature, and reduced water storage. In contrast, the "Natural cycles - Vegetated land" section shows the natural processes that occur in the presence of vegetation, including photosynthesis, high evapotranspiration, high humidity, low surface temperature, and efficient water storage facilitated by soil infiltration and root exudation.

The evident contrast between these two sections highlights the significant impact of deforestation on the local ecosystem and its ability to maintain a balanced and sustainable environment. Restoring and protecting the remaining forests in Monterrey, together with afforestation, is crucial for preserving the area's biodiversity, water resources, and environmental health.

Natural cycles



Deforestation



Own photograph.

3. Methodology

Project framing

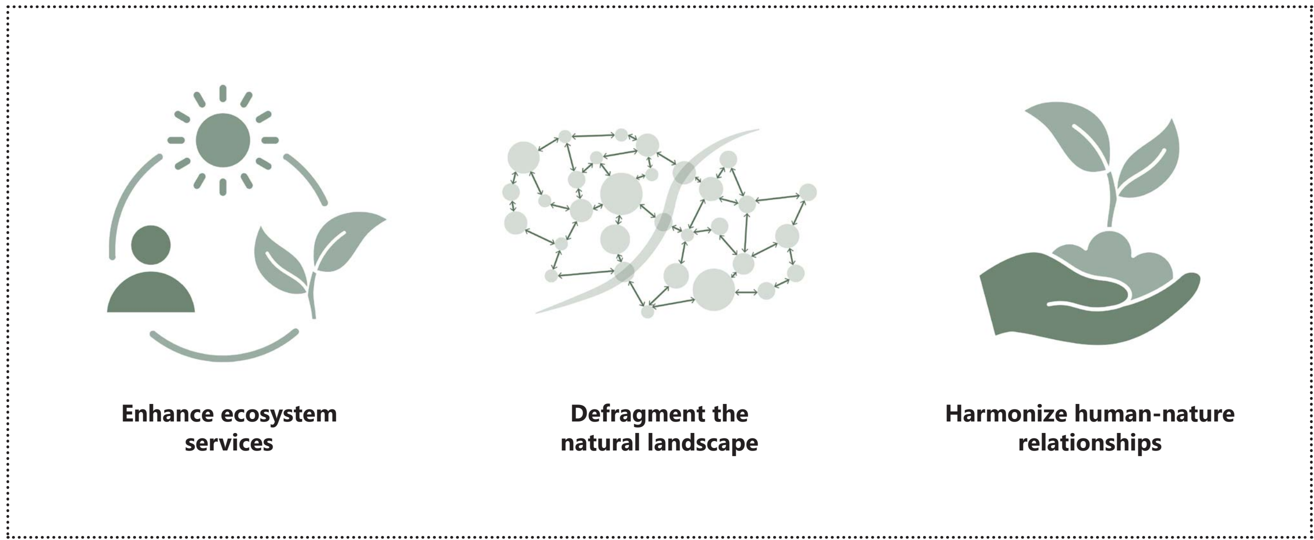
Problem statement
In the metropolitan region of Monterrey, Mexico, the juxtaposition of the urban sprawl and the natural protected areas accentuates the impact of the human-induced pressures on ecosystem services. As a result, the relationship between Monterrey's urban growth and its diminishing green spaces, together with its socio-political dynamics, has created an urgent need for extensive green infrastructure. The potentialities and efficacy of urban forestry are intertwined with a city's unique interplay of environmental characteristics and anthropogenic influences, shaping the urban landscape's fabric. Monterrey's challenge lies in harmoniously integrating urban forestry to revitalise ecosystem services, reconciling the relationship between the residents and their natural surroundings, all within a diversified system of care and a resilient framework for green-blue infrastructure.

Research question
"To what extent can urban forestry be upscaled in Monterrey, Mexico, to enhance ecosystem services, defragment the natural landscape, and harmonize the relationship between people and nature, aiming for ecological restoration using ecosystem-based solutions within an integrated system of care and a long-term plan for green-blue infrastructures?"

Sub-questions
[1] How can urban forestry and afforestation be defined, and what are best practices in arid climates?
[2] What would be the effectiveness of a metropolitan afforestation plan in Monterrey to deliver ecosystem services and their potential for scalability?
[3] How can ecosystem-based solutions be effectively incorporated into Monterrey's urban forestry plan, ensuring a sustainable system of care and long-term viability for green-blue infrastructures?
[4] What are the current challenges and barriers in expanding Monterrey's metropolitan green network, and how can urban forestry be strategically integrated to address these challenges?

Project framing

URBAN FORESTRY AND REGIONAL AFFORESTATION



Design assignment

Projected outcomes
The possible outcome of the design by research is an explorative design to find the potential capacities to connect landscape patches with the natural protected areas. This design exploration will result in:

- **A comprehensive literature review**
  This consists of a combination of theoretical and scientific texts, providing a broad spectrum of theories pertinent to urban forestry and landscape connectivity. This review will lay the groundwork for understanding the relationship between ecosystem services and the urban landscape.
- **Contextual analysis**
  An in-depth analytical framework, consisting of graphical analysis and cartographic interpretation, will be used to thoroughly understand Monterrey's ecological, social, and spatial dynamics. This analysis and superimposition will serve as a tool for recognizing the critical areas for intervention and potentialities within the urban landscape.
- **Forest design and framework proposal**
  The choice of the metropolitan scale is motivated by the need for an all-encompassing system of care to defragment the landscape. The strategic selection of various defined urban and landscape types for this project provides the opportunity to create an evolutionary design framework. This understanding will lead to design proposals for each recognised type, directly reacting to address their specific issues while adhering to a unified set of design criteria.
- **Forest catalogue**
  Additionally, a forest catalogue will be created to propose different types of forests addressing all the defined urban and landscape types, including landscape management techniques and stakeholders.

Goals for design interventions

- The design interventions will include up-scaling urban forestry and regional afforestation to defragment the region.
- The interventions will accommodate community engagement by addressing prevalent cultural practices and community values.
- The designs will focus on finding the potential capacities to connect landscape patches with the natural protected areas. This will be done to re-establish access to areas currently restricted without compromising the natural restoration of the landscape.
- The proposals will be designed to allow uncertainty, be resilient, and allow space for future discovery and adaptation.
- The intervention strategies will be scalable, with methodologies that can be adapted to other semi-arid cities facing similar challenges.

Lens and approaches

Integrative approach for urban forestry and landscape connectivity in Monterrey
This project will consist of a multi-dimensional methodological framework to comprehensively address the challenges and opportunities in enhancing Monterrey's urban forestry and landscape connectivity. The research consists of site-specific research, theoretical research and geological analysis. This is visualised in the methodological framework.

Lens and approaches

- **Analytical layer approach**
  This approach involves deconstructing the urban landscape into distinct layers (such as vegetation, water system and soil ecology) for detailed analysis. Each layer will be examined both independently and in combination with others to understand the complex interrelationships within the urban fabric.
- **Detailed inventory**
  A comprehensive inventory will be compiled to gain an in-depth understanding of all existing conditions. This includes superimposing current green spaces, urban fabric, natural areas, and socio-economic factors influencing the urban landscape. The inventory will serve as a foundational database for further analysis and decision-making.
- **Metropolitan approach**
  Recognizing the interconnectedness of the Monterrey metropolitan region, this approach will focus on understanding and designing solutions that consider the broader urban context. It includes analysing regional trends, urban growth patterns, and ecological networks in order to create an integral sensitive system.
- **System of care**
  A system of care will be developed, emphasizing the ongoing management of urban green spaces. This includes examining existing maintenance practices, community engagement strategies, and potential models for sustainable care and governance of urban forestry initiatives.
- **Socio-cultural values**
  A review of Monterrey's socio-cultural values will gain insights into the prevailing cultural practices, community values, and social dynamics. This will identify the diverse potential of new stakeholders who may contribute to the system of care. Doing so, it ensures that the local culture will be considered when planning the expansion and management of the city's green spaces, ranging from tree planting initiatives to the development of urban parks.
- **Trans-scalarity**
  The project will navigate across various spatial and temporal scales, from the microscopic details of individual species selection to the macroscopic view of the metropolitan green network. Temporally, the project will consider both the immediate impacts and long-term evolution of the proposed interventions.
- **Ecosystem understanding**
  In order to understand the ecoregion of Monterrey, a biophysical and biodiversity analysis will be done to be able to make a selection of trees and plants and to create forest planting strategies.
- **Potentialities and suitability analysis**
  By creating a superimposition based on soil ecology, a suitability analysis will be done to recognise the areas with potential. This will be both areas where it is easiest to intervene and where it is the most critical to intervene.
- **Addressing areas of potential impact**
  Special attention will be given to areas where interventions would be the most impactful. These are hot spots for the start of the project, where the forest will be planted first. It is most likely that a new forest will survive in these spots.

Methodology

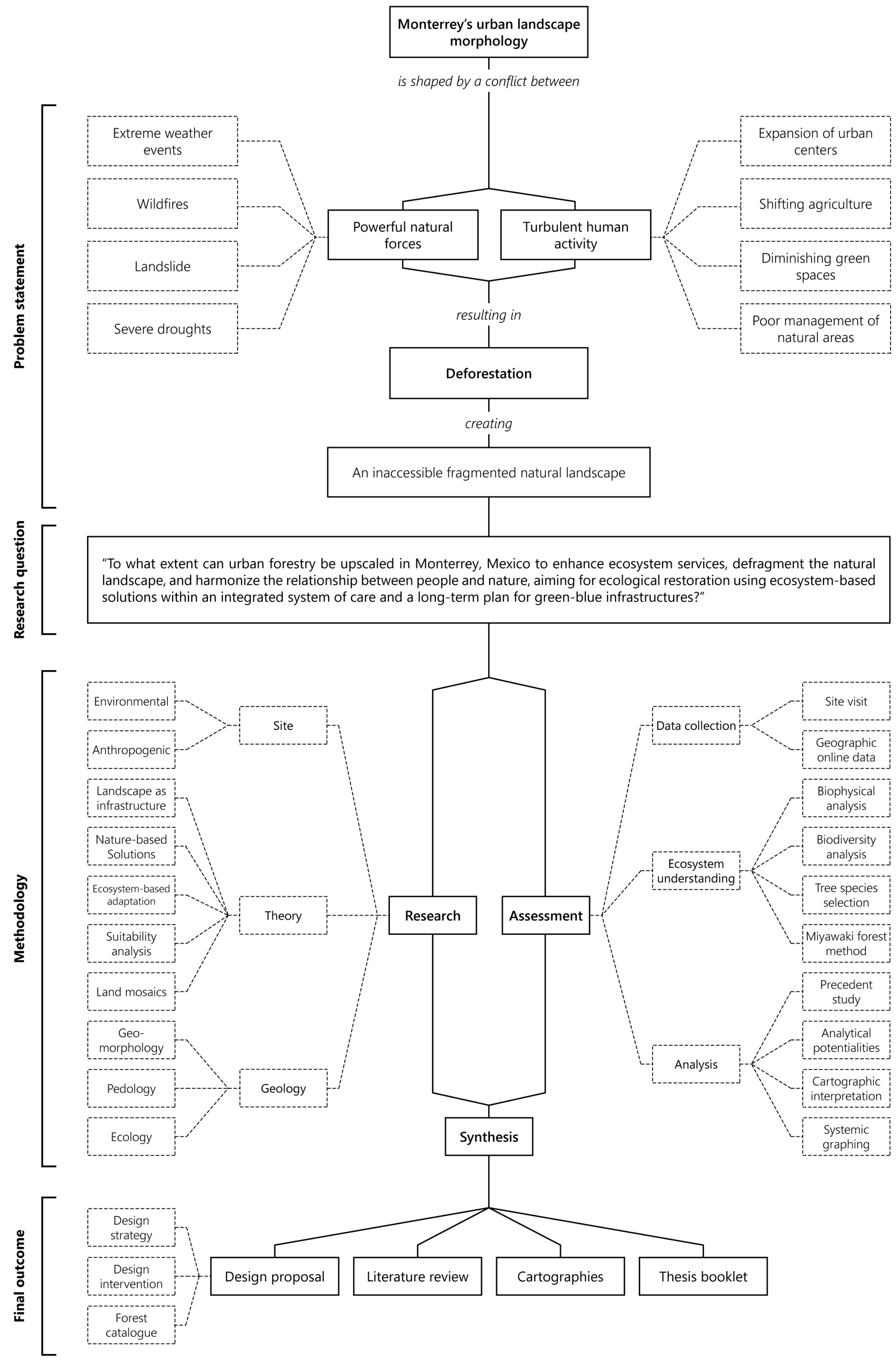
Methods

- **Graphical analysis**
  Visual tools will be used to analyse spatial patterns, landscape features, and urban dynamics. This includes the use of diagrams, thematic maps, and visualizations to interpret complex data and convey findings effectively.
- **Cartographic interpretation**
  Maps will be a critical tool for understanding the spatial distribution of various elements within the urban landscape. Cartographic interpretation will help in visualizing relationships, identifying trends, and spotting opportunities for intervention.
- **Data collection**
  A robust data collection process will include gathering quantitative and qualitative data through various sources like satellite imagery, urban planning documents, and environmental studies. Furthermore, Rob Roggema provided resources and data collected by the Monterrey Institute of Technology and Higher Education.
- **Precedent studies**
  Case studies will show how urban forestry and afforestation strategies are created in other semi-arid cities facing similar challenges.
- **Site visit**
  The location visit to Monterrey has been integral to gaining a tangible understanding of the physical conditions, social dynamics, and environmental context. This visit will inform the design process and ensure that proposals are grounded in the reality of Monterrey's urban landscape.

Through this methodological framework, the project aims to create a nuanced, informed, and practical approach to up-scaling urban forestry and enhancing landscape connectivity in Monterrey, addressing ecological, social, and spatial complexities within the urban environment.

Through a synthesis of all the research and assessment, a design proposal, literature review, cartographies, and a thesis booklet will be followed. This will lead to a design strategy, design interventions, and a forest catalogue presenting an evolutionary framework to find the potential capacities to connect landscape patches with natural protected areas. This is visualised in the methodology framework.

Methodology framework



Literature

Literature and more applied references
My research is divided into three essential research aspects: site-specific research, geology, and theoretical underpinnings.

The initial focus is on understanding Monterrey's environmental and anthropogenic context to understand the interplay between urban development and natural environments in the city. Furthermore, the research emphasizes geology, geomorphology, pedology, and ecology, to gain a robust understanding of Monterrey's physical and ecological characteristics. This scientific basis is used for formulating viable design strategies.

In the theoretical domain, the research draws inspiration from key works in landscape and urban planning. Work from Pierre Bélanger's "Landscape as Infrastructure" and theory on Nature-based Solutions will shape the conceptual framework. This is complemented by McHarg's "Suitability Analysis" principles and Richard Forman's "Land Mosaics", to gain insight in ecosystem-based adaptation.

Moreover, the research integrates practical examples and precedent case studies in urban forestry and green infrastructure, to find effective forest implementation methods, challenges encountered, and relevant best practices.

Relation between the graduation topic, the lab topic, and your master track
My thesis called "ArborMetropolis" on urban forestry and regional afforestation in Monterrey, Mexico, establishes a profound connection between the field of urban ecology and the MSc Landscape Architecture. My graduation project embodies the principles of urban ecology by focusing on the integration of natural ecosystems within urban environments, specifically through the implementation of green infrastructure and afforestation. It addresses the ecological, social, and spatial dynamics of Monterrey, aiming to enhance ecosystem services and improve the relationship between urban residents and their natural surroundings. This approach is deeply rooted in the MSc Landscape Architecture since it emphasizes a comprehensive understanding of landscapes as dynamic entities shaped by both human and natural forces. Moreover, the thesis aligns with the master track by focusing on creating resilient and ecologically integrated urban landscapes. By applying these principles, the thesis contributes to the broader discourse of landscape architecture, demonstrating how urban ecology can be strategically incorporated into urban planning and design to foster sustainable and liveable urban landscapes.

Relevance

Professional relevance
My graduation project on urban forestry in Monterrey offers a novel approach to landscape architecture, emphasizing the integration of green infrastructure within urban settings. It advocates for a multidisciplinary methodology, blending urban planning, environmental science, and social considerations, tailored to the unique challenges of arid urban landscapes. This project signifies a shift in professional practice, highlighting the need for landscape architects to not only design aesthetically pleasing spaces but also to create functional, ecological, and socially beneficial urban environments. It shows an approach to urban forestry with a nuanced understanding of local contexts, driving a paradigm shift towards more sustainable and resilient urban development.

Social relevance
The social implications of this project are profound, as it directly addresses the relationship between urban populations and their natural environment in Monterrey. By focusing on enhancing ecosystem services and expanding green spaces, the project confronts issues of environmental justice and accessibility to nature in urban areas. It brings to the forefront the importance of community engagement in urban planning, advocating for inclusive design that caters to the diverse needs of Monterrey's residents. The project emphasizes the symbiotic relationship between humans and nature and advocates for ethical considerations in urban design, especially when dealing with marginalized communities and delicate ecosystems.

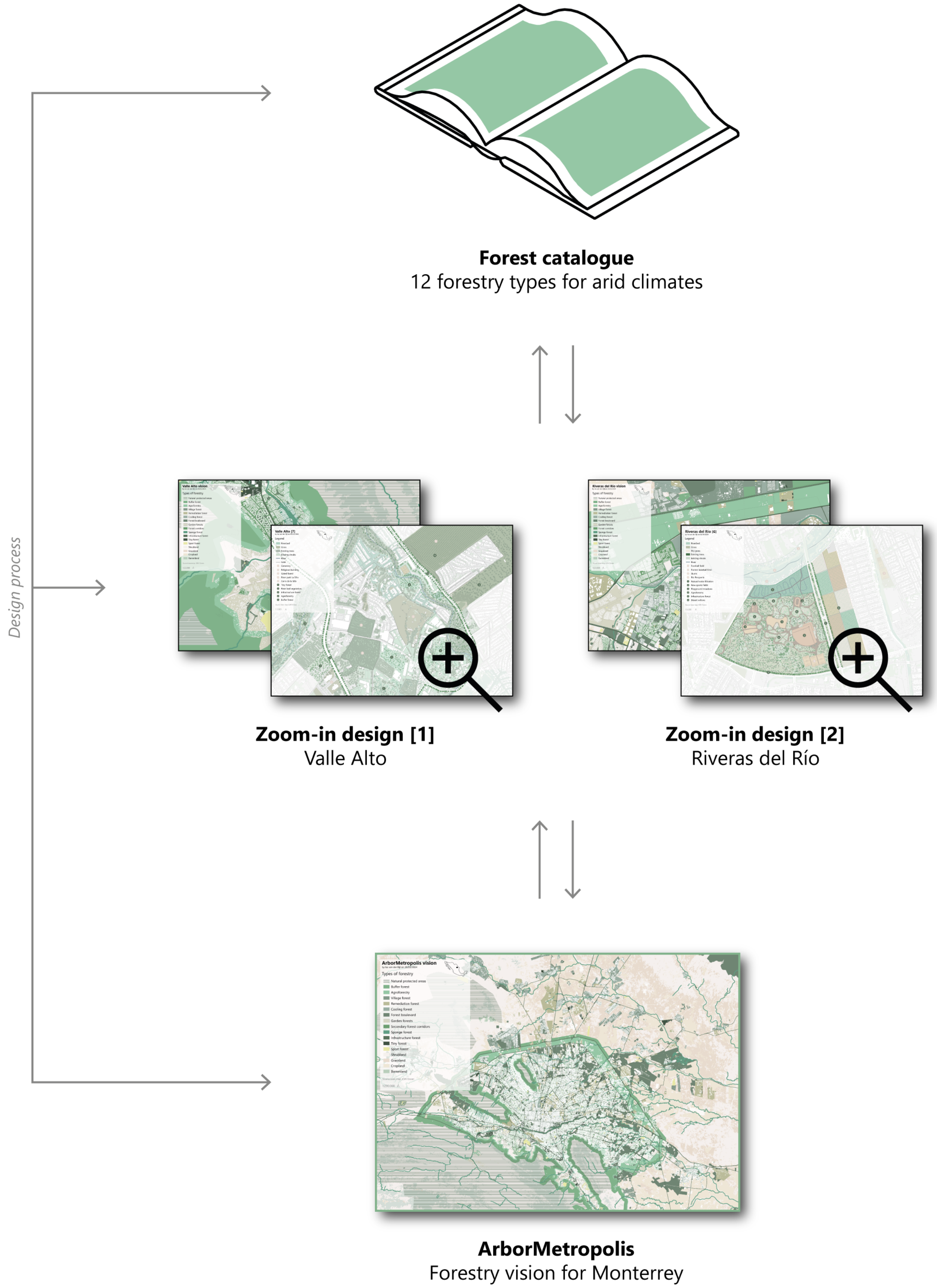
Scientific relevance
From a scientific perspective, this thesis bridges various disciplines to enrich the field of urban ecology and landscape architecture. It involves an extensive literature review and contextual analysis. By examining the specific environmental challenges of Monterrey, such as its arid climate and rapid urbanization, the project synthesizes diverse scientific research, ranging from ecological studies on arid landscapes to urban sociology. This interdisciplinary approach not only contributes to a deeper understanding of urban ecosystems but also advocates for new methodologies in landscape architecture, urban ecological design and sustainable urban development.

Own photograph.

4. Design strategy

Design framework

The design process has been an iterative one. By creating twelve forestry types, all with their design principles, the zoom-in locations were informed. Furthermore, the zoom-in designs informed the regional vision. Finally, the vision map also reflected on the forest catalogue and the zoom-in designs.



Design inventory

First, the relevant stakeholders are analysed to determine the necessary type of forestry for the site. Secondly, the urban and landscape contexts are examined. This design inventory identifies the current site conditions, ensuring the design process is well-informed and guided by these insights. This assures the design is relevant and site-specific.

STAKEHOLDERS

- Citizen
- Residents
- Companies
- Community
- Municipality
- Government

URBAN

- [1] Formal community
- [2] Informal community
- [3] Gated community
- [4] Infrastructure
- [5] City centre
- [6] Small isolated villages
- [7] Public services and industry

LANDSCAPE

- [A] Forest
- [B] Shrubland
- [C] Grassland
- [D] Cropland
- [E] Barren land
- [F] Water system
- [G] Urban vegetation
- [H] Natural protected area

FORESTRY

- Production forest
  - Agroforestry
  - Village forest
- Climate forest
  - Buffer forest
  - Sponge forest
  - Cooling forest
- Biodiversity forest
  - Tiny forest
  - Garden forest
- Health forest
  - Infrastructure forest
  - Remediation forest
- Recreation forest
  - Forest boulevard
  - Forest corridors
  - Sport forest

Stakeholders

To realize the ArborMetropolis project, multi-actor involvement is needed to ensure all stakeholders are aligned on the project's objectives and priorities. A diagram has been created to reflect existing forestry stakeholders in Monterrey and possible new stakeholders. The circles represent primary actors, secondary actors, and the wider environment, which can be categorized into private, public, and civic sectors.

The primary private actors include private companies, private landowners, and the Monterrey Metropolitan Environmental Fund (FAMM). The primary public sector consists of the twelve municipalities of the Monterrey Metropolitan Area, the National Institute of Ecology and Climate Change (INECC), and the National Park Cumbres de Monterrey (PNCM). The civic sector primarily consists of local residents, NGOs focusing on forestry, such as Reforestación Extrema, and other environmentally focused NGOs in Monterrey.

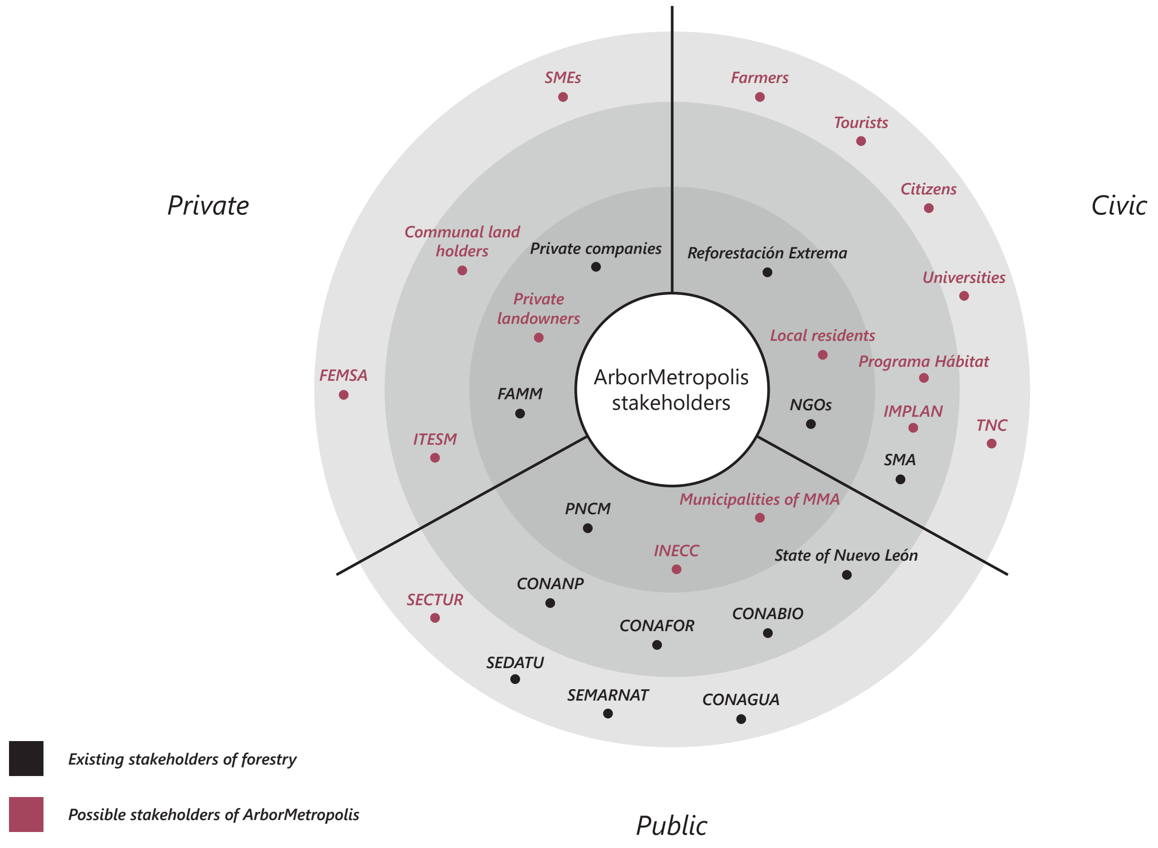
These are the nine most important stakeholders that have to collaborate, ranging from more Top-Down to more Bottom-Up initiatives. The Top-Down stakeholders are in the governmental public sector and will be involved in creating policies to implement large-scale interventions for long-term solutions. The Bottom-Up stakeholders, primarily in the civic section, are plot-related to initiate smaller and faster on-site interventions.

This framework emphasizes the empowerment of local actors as catalysts for change. The aim is to ensure active involvement from both the Top-Down and Bottom-Up stakeholders. This is done through policies and regulations, from natural protected areas to landscape patches. It also includes local practices and collaborative monitoring across different spatial scales of the transformation process.

When developing the new forests, the approach is to consider each forest patch as a separate project that first needs to be functioning and then jointly managed at its appropriate scale. This will be achieved through the use of a holistic shared vision guiding its ecological capacity and its expansion to the larger metropolitan scale.

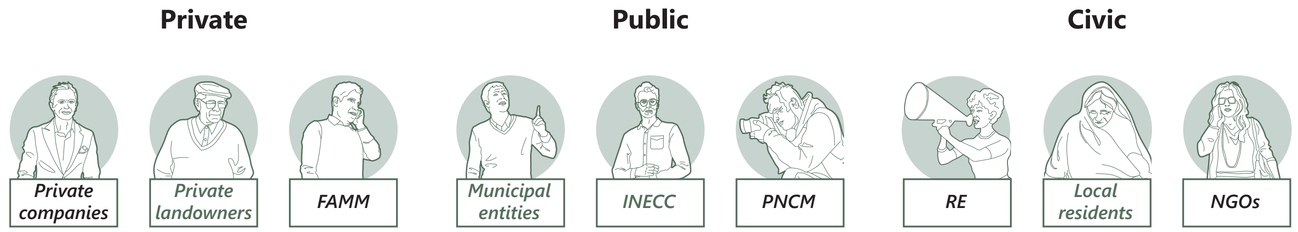
In chapter 6 "Design proposal", the stakeholders are related to the forestry types.

Stakeholders of ArborMetropolis



Adapted from Czischke, D. (2017). Collaborative housing and housing providers: towards an analytical framework of multi-stakeholder collaboration in housing co-production. *International Journal of Housing Policy*, 18(1), 55–81. https://doi.org/10.1080/19491247.2017.1331593

Stakeholder list



Private

Primary actors
- *Private companies*
- *Private landowners*
- *FAMM: Monterrey Metropolitan Environmental Fund*

Secondary actors
- *Communal land holders*
- *ITESM: Monterrey Institute of Technology and Higher Education*

Wider environment
- *SMEs: Local small and medium enterprises*
- *FEMSA: Fomento Económico Mexicano (a Mexican multinational beverage and retail company)*

Public

Primary actors
- *Municipalities of Monterrey Metropolitan Area*
- *INECC: National Institute of Ecology and Climate Change*
- *PNCM: National Park Cumbres de Monterrey*

Secondary actors
- *State of Nuevo León*
- *CONABIO: National Commission for the Knowledge and Use of Biodiversity*
- *CONAFOR: National Forestry Commission*
- *CONANP: National Commission of Natural Protected Areas*

Wider environment
- *CONAGUA: National Water Commission*
- *SEMARNAT: Secretariat of Environment and Natural Resources*
- *SEDATU: Secretariat of Agrarian, Land, and Urban Development*
- *SECTUR: Secretariat of Tourism*

Civic

Primary actors
- *RE: Reforestación Extrema*
- *Local residents*
- *NGOs: Non-Governmental Organizations*

Secondary actors
- *Progama Hábitat*
- *SMA: Secretariat of the Environment*
- *IMPLAN: Municipal Institute of Urban Planning and Coexistence of Monterrey*

Wider environment
- *Farmers*
- *Tourists*
- *Citizens*
- *Universities*
- *TNC: The Nature Conservancy*

Urban context and landscape

In the metropolitan area of Monterrey, a significant amount of data on public spaces and the built environment is either missing or embedded within governmental entities and not accessible to the public. Only in 2024, a long-term urban development plan for 2040 (image 1) was published, a precedent not set before (Gobierno de Monterrey & IMPLAN, 2024). Therefore, a manual study was conducted using Google Street View to identify the existing urban types. The following types were recognised:

[1] Formal community:
Formal street profiles including greenery, typically in higher-income neighbourhoods.

[2] Informal community:
Informal settlements, where houses are unfinished and streets appear less safe.

[3] Gated community:
Both low and high-income gated neighbourhoods, previously undocumented.

[4] Infrastructure:
All primary, secondary and tertiary roads.

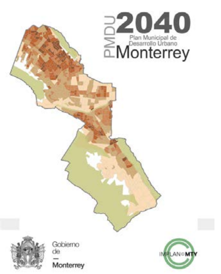
[5] City centre:
The historic city core.

[6] Isolated urban sprawl:
Areas that lack access to the city centre within a one-hour car ride.

[7] Public services and industry:
Large industrial sites, hospitals, shopping centres, and other public services.

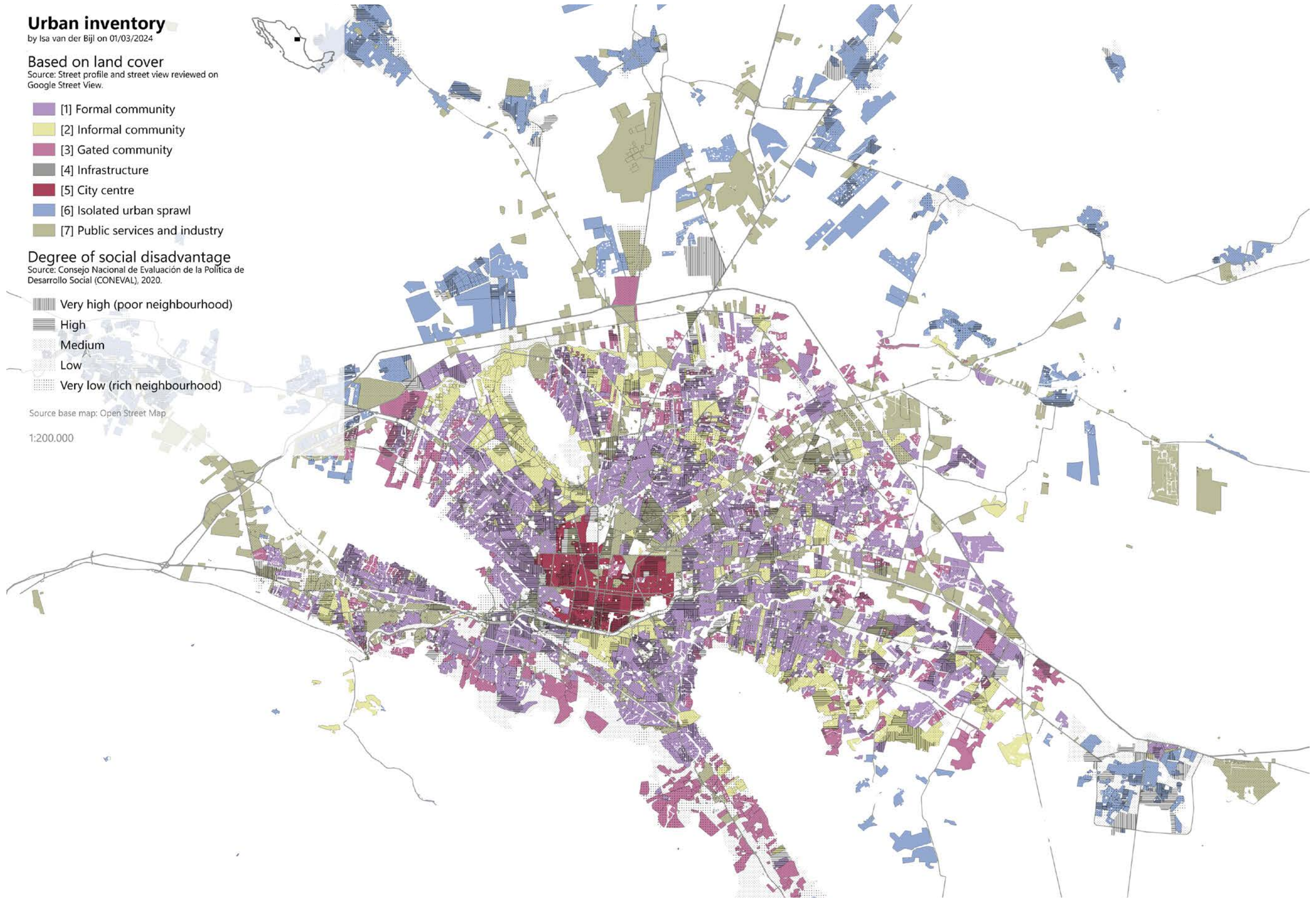
The "2040 Plan Municipal de Desarrollo Urbano Monterrey" (Gobierno de Monterrey & IMPLAN, 2024) outlines a plan for urban development until 2040. However, this plan does not address landscape regeneration or ecosystem-based adaptation. To fill this gap, a landscape inventory has been created, which will determine the specific types of forests that can be established in each location.

[1] 2040 Municipal Urban Development Plan Monterrey

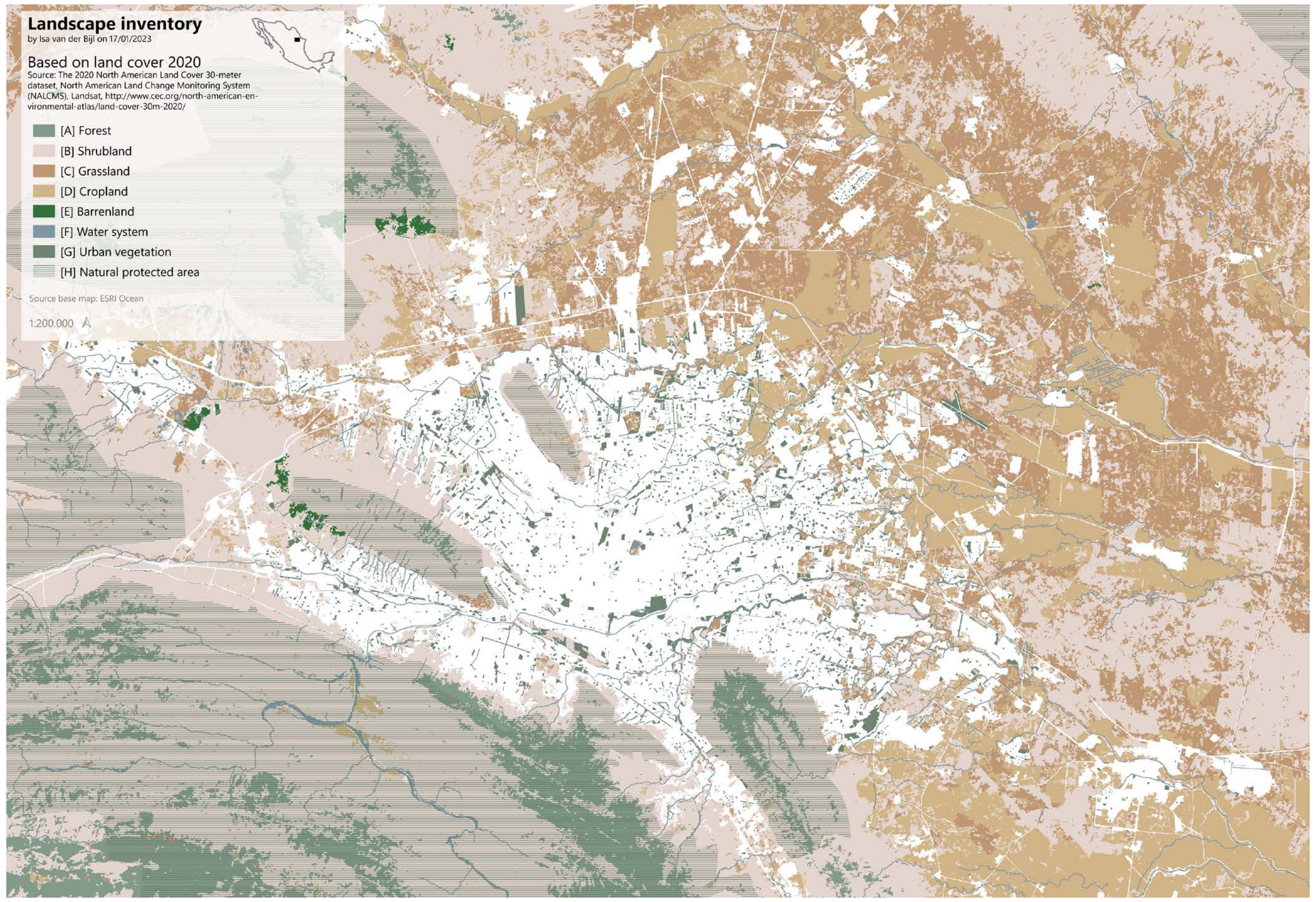


Gobierno de Monterrey & IMPLAN. (2024). *2040 Plan Municipal de Desarrollo Urbano Monterrey*. Retrieved May 19, 2024, from https://www.monterrey.gob.mx/pdf/portaln/Plan_municipa_de_desarrollo_urbano_monterey_2040.pdf

Urban



Landscape



Soil ecology

Soil ecology forms the basis of the project to identify areas suitable for natural forest regrowth. A suitability analysis based on Ian McHarg (image 1) was conducted by superimposing various soil ecology layers. The presence of multiple overlapping layers indicates a higher potential for successful natural forest regrowth. The layers used in this analysis include:

[1] Open soil:
Areas with open soil that already have some vegetation cover, but are not currently used for agriculture, are prime candidates for natural forest regrowth. The existing vegetation indicates that the soil can support plant growth.

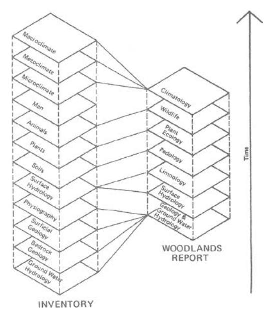
[2] Carbon sequestration rate:
Estimates the rate at which carbon could be sequestered in aboveground live biomass during the first thirty years of natural forest regrowth in potentially reforestable areas. Areas with higher potential sequestration rates should be prioritized to maximize climate mitigation benefits.

[3] Biodiversity intactness:
The impacts of forest change on local biodiversity intactness, globally measured. Areas with high biodiversity intactness are more likely to have preserved the native seed bank and soil microbiome to enable a diverse natural forest to regenerate.

[4] Forest carbon removals:
Forest carbon removals by forest sink mega grams of CO_2 removed/ha. Regenerating forests in these high-productivity areas can help restore the carbon sink that has been decreasing globally.

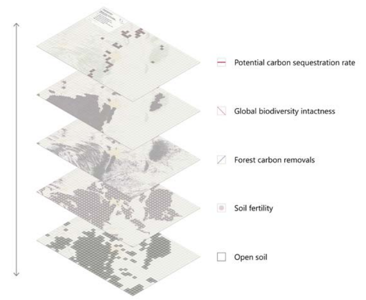
[5] Soil fertility:
High chance on soil fertility, based on the characteristics of the soil type. More fertile soils can support higher rates of biomass accumulation.

[1] Suitability analysis

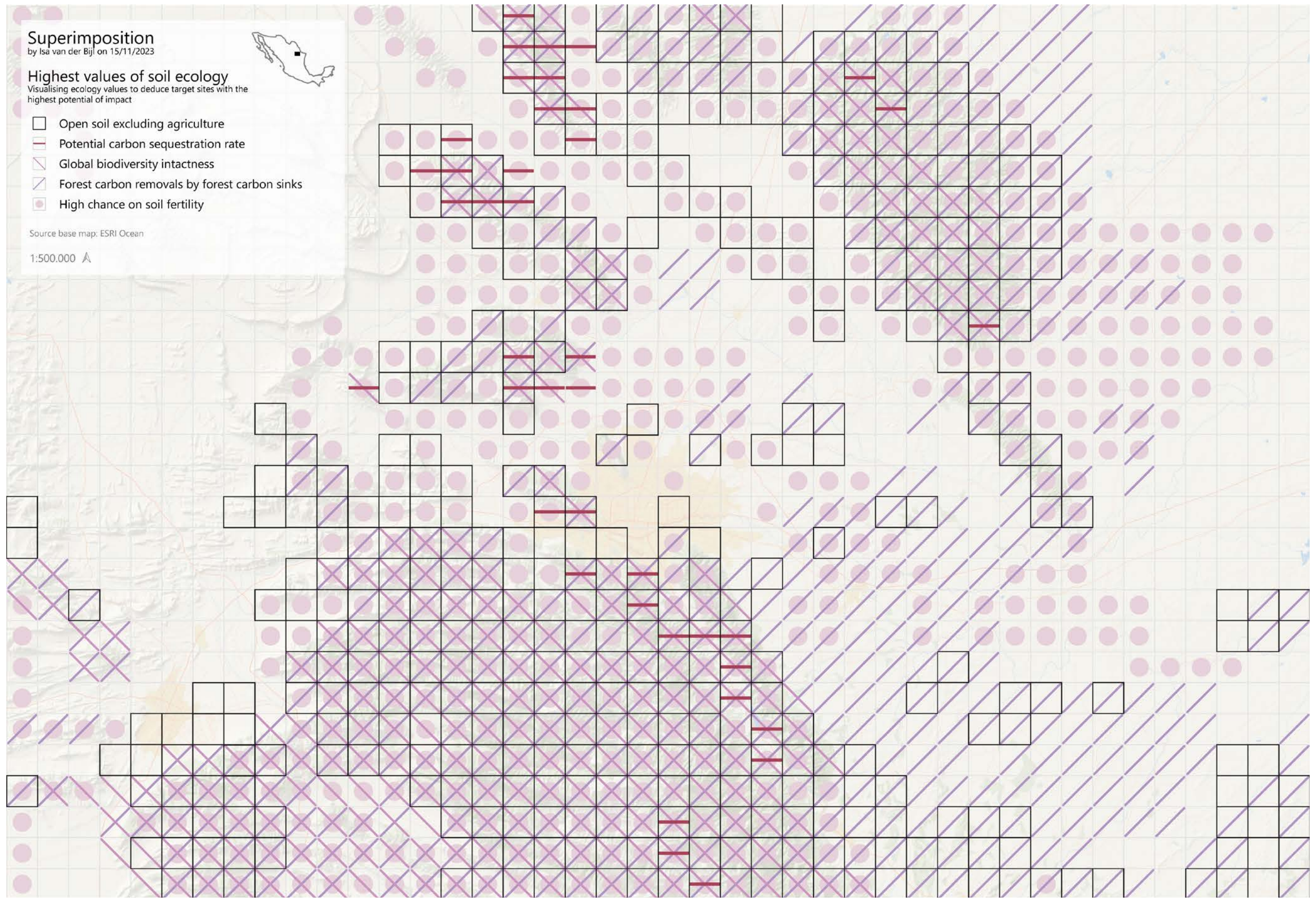


Cohen, W. J. (2019). The legacy of Design with Nature: from practice to education. *Socio-Ecological Practice Research*, 1(3–4), 339–345. https://doi.org/10.1007/s42532-019-00026-2

[2] Suitability analysis of soil ecology



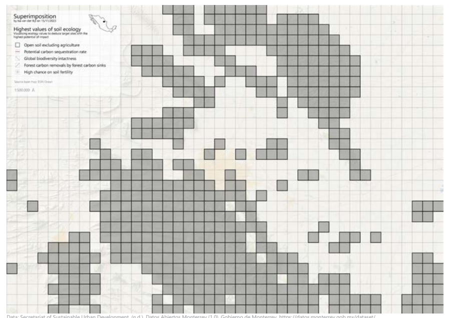
Superimposition



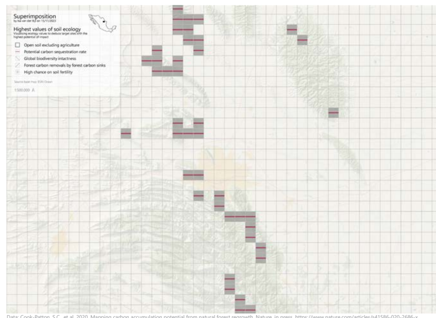
Suitability analysis

Superimposition of soil ecology layers:

[1] Open soil

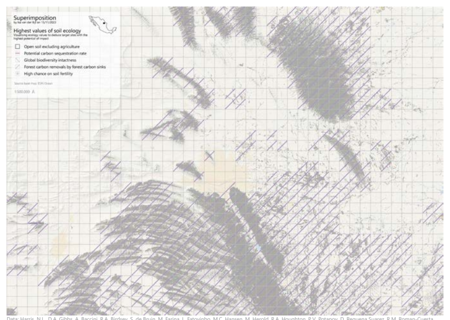


[2] Carbon sequestration rate

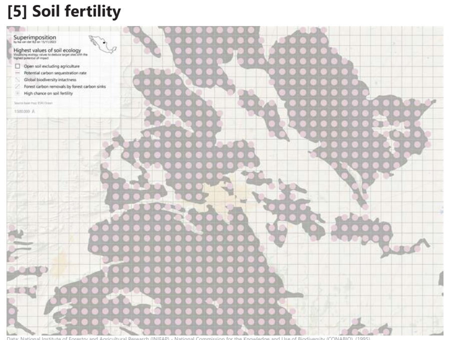


[3] Biodiversity intactness

[4] Forest carbon removals



[5] Soil fertility



Legend

- Open soil excluding agriculture
- Potential carbon sequestration rate
- Global biodiversity intactness
- Forest carbon removals
- High chance on soil fertility

Value map

Suitability analysis
By creating a superimposition based on soil ecology, a suitability analysis was conducted to identify areas with the highest potential for intervention. This analysis highlights both the easiest areas to intervene in and the most critical areas requiring intervention.

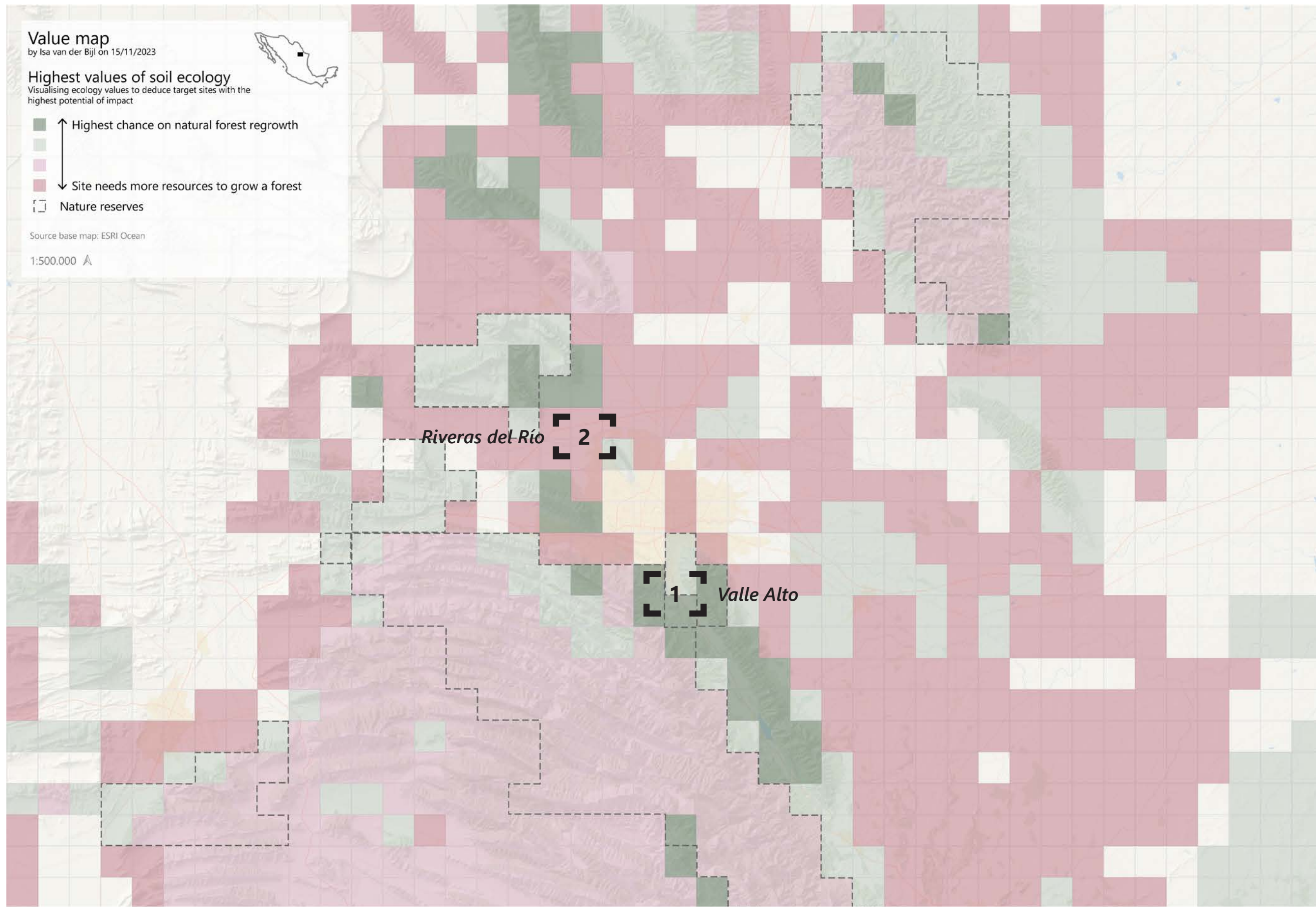
Potentialities
In the design phase, areas of potential impact will be addressed. Special attention will be given to hotspots where interventions would be the most impactful. These locations will be the starting points for the project, where forests will be planted first, as they have the highest likelihood of survival.

Value map
The value map illustrates areas with the highest chance on natural forest regrowth (green spots) and areas requiring more resources to grow a forest (red spots).

[1] Valle Alto
Valle Alto, located in the south-eastern part of Monterrey, is chosen because it lies between two nature reserves, suggesting that these reserves were likely connected in the past. Urbanization was introduced together with a highway that now separates the area. Restoring the forest here could potentially reconnect these nature reserves.

[2] Riveras del Río
Riveras del Río, in the north-western part, is chosen because it is located in a red spot, indicative of a more desert-like area requiring additional resources for forest growth. This location will demonstrate how a forest can be established in regions needing more effort, showcasing what it entails, its possible appearance, and its potential benefits.

Value map



Zoom-in locations based on soil ecology

Own photograph.

5. Forest catalogue

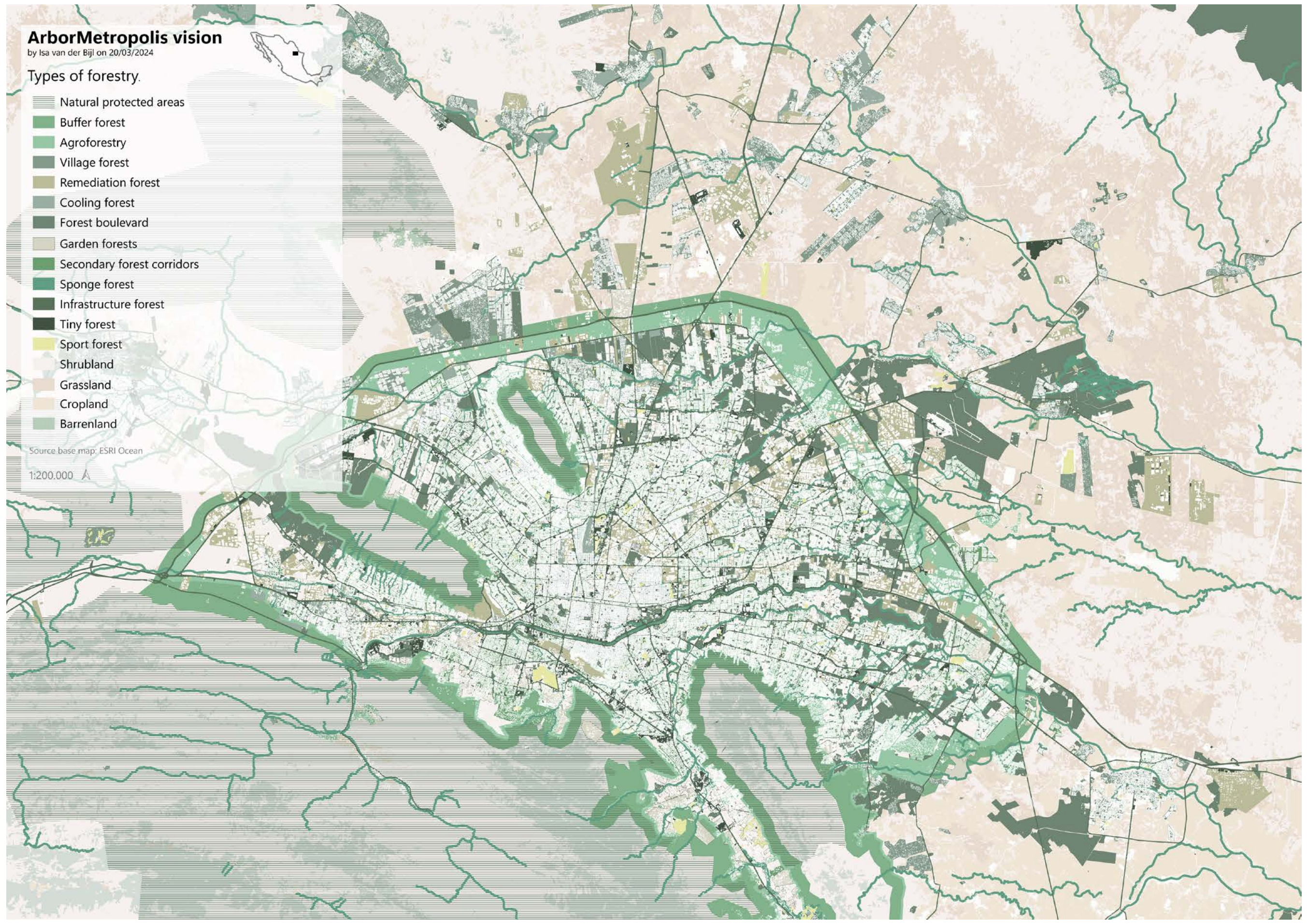
Forestry vision

The vision map for ArborMetropolis incorporates twelve strategically designed forestry types to establish an urban forest buffer around the city. These forestry zones are tailored to local conditions, soil ecology, stakeholder priorities, and the urban context to maximize benefits for both ecosystems and communities.

The key element is the ring of forestry types encircling the urban sprawl. This green belt creates an artificial buffer between the existing urban area and surrounding agricultural lands. Maintaining this barrier helps contain urban sprawl, preserve open space, support local food production, and provide accessible parkland for city residents.

Each of the twelve forestry types is designed to deliver specific ecosystem services based on analysis of the landscape. Matching tree species and planting strategies to local soil conditions and microclimates, within each forestry type, optimizes tree growth and climate resilience.

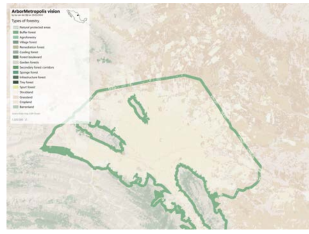
Vision map ArborMetropolis

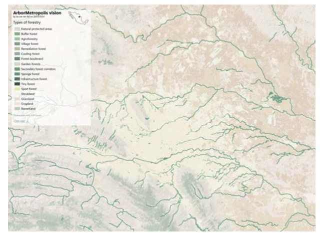


Forestry types


Agroforestry


Village forest


Buffer forest


Sponge forest


Cooling forest


Tiny forest


Garden forest


Infrastructure forest


Remediation forest


Forest boulevard


Forest corridors


Sport forest

Forestry types

Flux (2023) has created multiple forestry objectives for forests of the future. This is used as an inspiration for ArborMetropolis by selecting five of the main categories which are suitable for arid climates, which include:

[1] **Production forestry**
This objective focuses on using forests for building materials and food production. It aims to maximize the economic benefits of forests by sustainably harvesting timber and other forest products. Production forestry is often the primary goal of traditional forest management plans.

[2] **Climate forestry**
Climate forestry prioritizes the role of forests in mitigating climate change through CO_2 absorption, cooling, and water buffering. It seeks to enhance the carbon sequestration potential of forests and their resilience to climate impacts.

[3] **Biodiversity forestry**
The biodiversity objective emphasizes protecting and restoring forest ecosystems and wildlife habitats. It focuses on maintaining ecological connectivity, connecting habitat patches, and ensuring sufficient canopy cover for biodiversity.

[4] **Health forestry**
Health forestry recognizes the public health benefits provided by urban and peri-urban forests. It prioritizes air purification to reduce pollution and soil remediation to address contamination. This is done by planting trees near polluting sources, such as industries and highways, and incorporating phytoremediation.

[5] **Recreation forestry**
This objective manages forests for human physical and mental well-being by facilitating sports, relaxation, and nature experiences. It involves developing recreational infrastructure, trails, and facilities to enable public access and engagement with forests. Recreation forestry can support eco-tourism, environmental education, and health benefits.

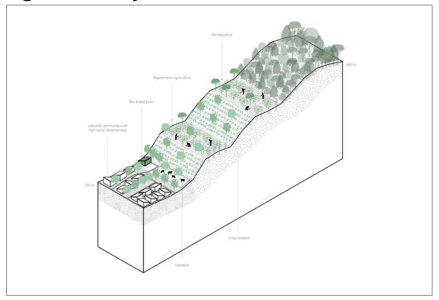
In summary, ArborMetropolis will strategically incorporate these five forestry objectives inspired by Flux (2023) to be suitable for semi-arid cities. Spatial analysis and stakeholder input can help prioritize objectives in different areas to maximize benefits to both ecosystems and communities.

[1] Main forestry objective

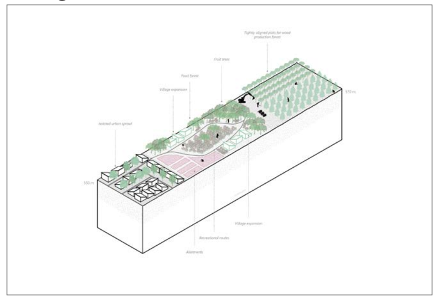
Production forestry
Climate forestry
Biodiversity forestry
Health forestry
Recreation forestry

PRODUCTION FORESTRY

Agroforestry

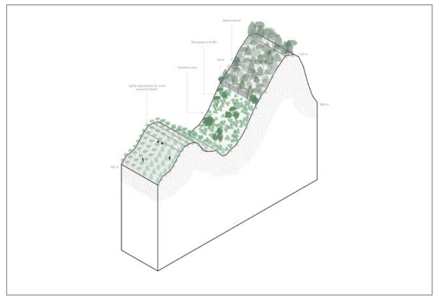


Village forest

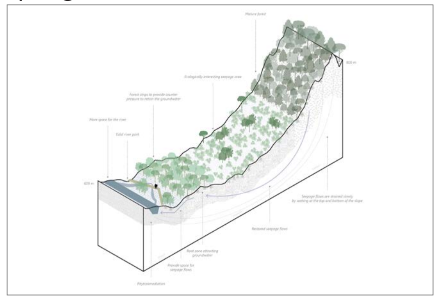


CLIMATE FORESTRY

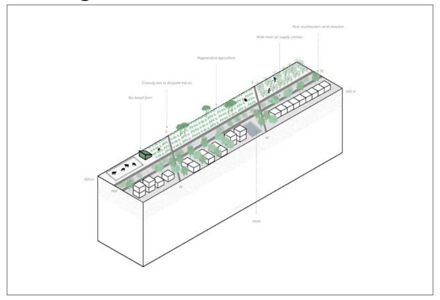
Buffer forest



Sponge forest

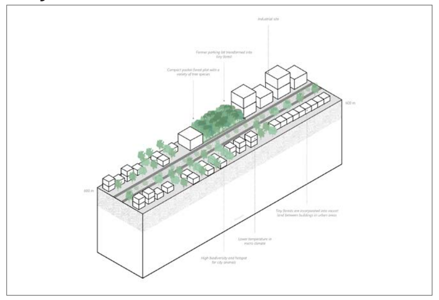


Cooling forest

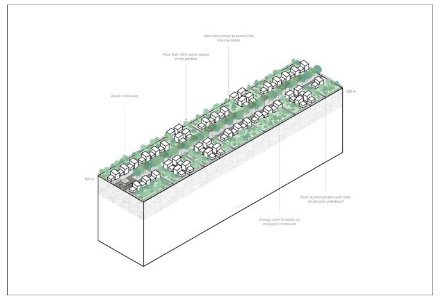


BIODIVERSITY FORESTRY

Tiny forest

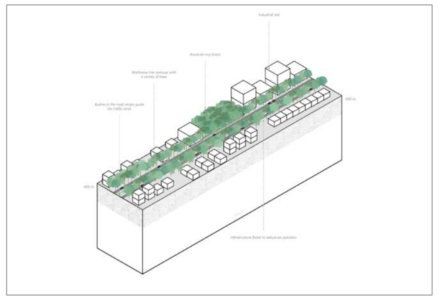


Garden forest

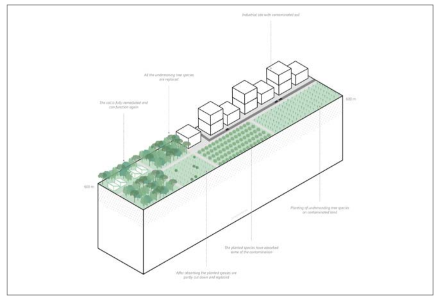


HEALTH FORESTRY

Infrastructure forest

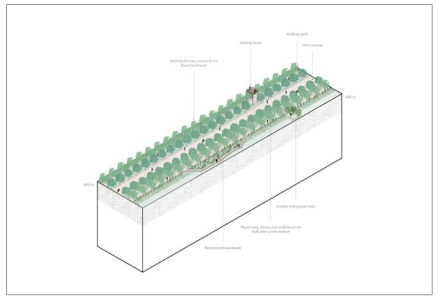


Remediation forest

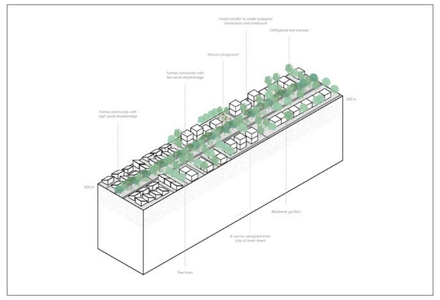


RECREATION FORESTRY

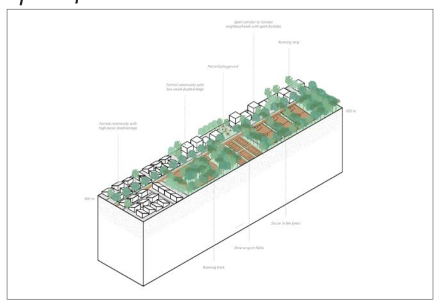
Forest boulevard



Forest corridor



Sport forest



Forest types categorization

The twelve forestry types in Monterrey are categorized based on their context, location, scale and scope to enable ecological connectivity using the patch-corridor-matrix model from Forman and Wilson (1995). The context is divided into natural, agricultural, urban or industrial.

Categorizing the forestry types by context ensures they are tailored to the specific conditions and needs of natural, agricultural, urban or industrial areas in Monterrey. For example, forestry practices in natural contexts would focus on biodiversity conservation, while in urban settings, the emphasis may be on recreation and pollution reduction.

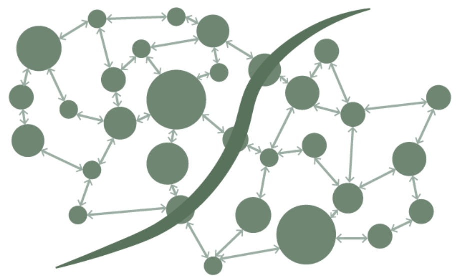
The patch-corridor-matrix model views the total landscape as a mosaic of discrete patches, corridors and the background matrix (image 3). Patches are relatively homogeneous areas that differ from their surroundings, such as forest stands, while corridors are strips of land that connect patches, like riparian zones. The matrix is the dominant land cover type in which patches and corridors are embedded.

The backbone, continuum and patch scales reflect different levels of ecological connectivity. Backbone refers to large, continuous tracts of forest that form the foundation of the landscape network. Continuum represents a gradient of forest cover that allows movement and gene flow. Patches are smaller forest fragments that can serve as stepping stones between larger areas (image 2).

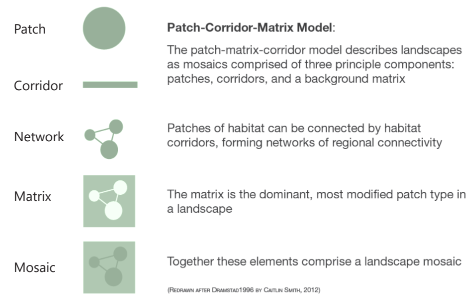
[1] Context of the forest

- *Natural context*
- *Agricultural context*
- *Urban context*
- *Industrial context*

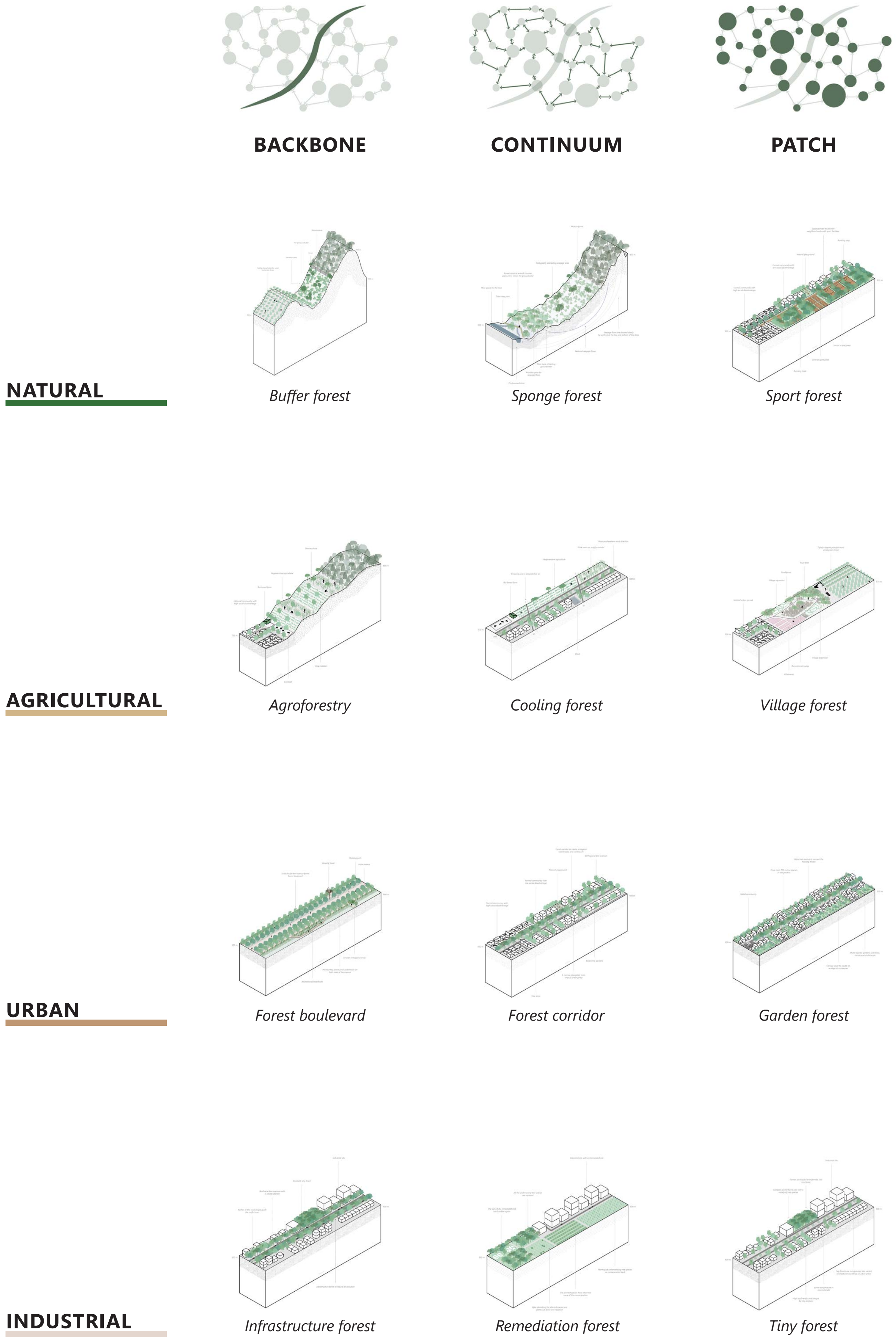
[2] Scale and scope: Backbone-continuum-patch model



[3] Patch-corridor-matrix model by Forman and Wilson (1995)



Smith, C. (2013, April 15). *Landscape patterns* [Slide show; PDF]. https://www.albertapcf.org/rsu_docs/landscape-patterns-presentation-02-may13.pdf



Ecosystem services

According to McMichael et al. (2005), "Ecosystem services are indispensable to the well-being of all people in all places". Ecosystem services are the benefits that people obtain from ecosystems, including food, natural fibres, a steady supply of clean water, regulation of pests and diseases, medicinal substances, recreation, and protection from natural hazards such as floods (McMichael et al., 2005).

There are four categories of ecosystem services (McMichael et al., 2005):

[1] Provisioning services
Tangible products obtained from ecosystems, such as food and wood production.

[2] Regulating services
Benefits from regulation of ecosystem processes, including air and water purification, climate regulation, erosion control, and buffering of natural hazards.

[3] Cultural services
Non-material benefits from ecosystems, such as recreation, a sense of place, education, and health benefits.

[4] Supporting services
Services necessary for the production of all other ecosystem services, such as soil formation and nutrient cycling. These support the other three categories.

Per forest type, the ecosystem services are examined and shown in table 2.

[1] Ecosystem services and human well-being linkages

- *Provisioning services*
- *Regulating services*
- *Cultural services*
- *Supporting services*

[2] Ecosystem services per type

Ecosystem services	Provisioning services				Regulating services									
	Food production	Wood production	Forest products	Food security	Water flow and quality regulation	Erosion control	Landslide protection	Water storage and retention	Flood protection	Micro climate control	Urban heat island mitigation	Air quality improvement	Soil remediation	Noise reduction
1. Agroforestry	X	X	X	X		X	X							
2. Village forest	X	X	X	X										
3. Buffer forest		X	X		X	X	X			X		X		X
4. Sponge forest					X		X	X	X				X	
5. Cooling forest										X	X	X		
6. Tiny forest										X	X	X		X
7. Garden forest										X	X			
8. Infrastructure forest											X	X	X	X
9. Remediation forest			X									X	X	
10. Forest boulevard														
11. Forest corridor										X	X	X		
12. Sport forest														

Ecosystem services	Cultural services								Supporting services						
	Recreation	Creation of jobs	Sense of place	Education	Community engagement	Ecotourism	Physical health benefits	Mental health benefits	Soil formation	Nutrient cycling	Soil stability	Waste decomposition	Detoxification of pollutants	Habitat provision	Species movement
1. Agroforestry		X			X				X	X	X				
2. Village forest	X	X	X	X	X									X	
3. Buffer forest									X	X					X
4. Sponge forest	X					X						X	X		X
5. Cooling forest							X	X					X		
6. Tiny forest			X	X										X	
7. Garden forest			X		X			X						X	X
8. Infrastructure forest							X		X				X		X
9. Remediation forest		X		X					X			X	X		
10. Forest boulevard	X		X			X	X	X						X	X
11. Forest corridor	X		X		X		X	X	X					X	X
12. Sport forest	X		X	X	X	X	X	X						X	X

Agroforestry
- Food production
- Wood production
- Forest products
- Food security
- Erosion control
- Landslide protection
- Creation of jobs
- Community engagement
- Soil formation
- Nutrient cycling
- Soil stability

Village forest
- Food production
- Wood production
- Forest products
- Food security
- Recreation
- Creation of jobs
- Sense of place
- Community engagement
- Education
- Nutrient cycling
- Habitat provision

Buffer forest
- Wood production
- Forest products
- Water flow and quality regulation
- Erosion control
- Landslide protection
- Micro climate control
- Air quality improvement
- Noise reduction
- Soil formation
- Nutrient cycling
- Soil stability
- Species movement

Sponge forest
- Water flow and quality regulation
- Landslide protection
- Water storage and retention
- Flood protection
- Soil remediation
- Recreation
- Ecotourism
- Soil stability
- Waste de-composition
- Detoxification of pollutants
- Species movement

Cooling forest
- Micro climate control
- Urban heat island mitigation
- Air quality improvement
- Physical health benefits
- Mental health benefits
- Detoxification of pollutants

Tiny forest
- Micro climate control
- Urban heat island mitigation
- Air quality improvement
- Noise reduction
- Sense of place
- Education
- Habitat provision

Garden forest
- Micro climate control
- Urban heat island mitigation
- Sense of place
- Community engagement
- Mental health benefits
- Habitat provision
- Species movement

Infrastructure forest
- Urban heat island mitigation
- Air quality improvement
- Soil remediation
- Noise reduction
- Physical health benefits
- Soil formation
- Detoxification of pollutants
- Species movement

Remediation forest
- Forest products
- Air quality improvement
- Soil remediation
- Creation of jobs
- Education
- Soil formation
- Waste de-composition
- Detoxification of pollutants

Forest boulevard
- Recreation
- Sense of place
- Ecotourism
- Physical health benefits
- Mental health benefits
- Habitat provision
- Species movement

Forest corridor
- Micro climate control
- Urban heat island mitigation
- Air quality improvement
- Recreation
- Sense of place
- Community engagement
- Physical health benefits
- Mental health benefits
- Soil formation
- Habitat provision
- Species movement

Sport forest
- Recreation
- Sense of place
- Education
- Community engagement
- Ecotourism
- Physical health benefits
- Mental health benefits
- Habitat provision
- Species movement

Agroforestry

Agroforestry is the intentional integration of trees and shrubs into crop and animal farming systems. It encompasses regenerative agriculture practices such as bio-based farming, permaculture, and crop rotation and can include specific techniques like alley cropping, where crops are grown between rows of trees. Agroforestry focuses on sustainable food and wood production and is implemented in informal communities to foster community engagement, create jobs, and improve livelihoods.

Agricultural backbone

Ecosystem services

Food production	Wood production	Forest products	Food security	Erosion control	Landslide protection	Creation of jobs	Community engagement	Soil formation	Nutrient cycling	Soil stability

Agroforestry species

Layer 1

Layer 2

Junglas mollis [1]
Sabal mexicana [2]

Layer 3

Quercus virginiana [3]
Quercus fusiformis
Ebenopsis ebano [4]
Celtis laevigata
Ehretia anacua
Sapindus saponaria

Prosopis glandulosa
Chilopsis linearis
Parkinsonia aculeata [5]
Sargentia greggii
Sideroxylon celastrinum
Caesalpinia mexicana

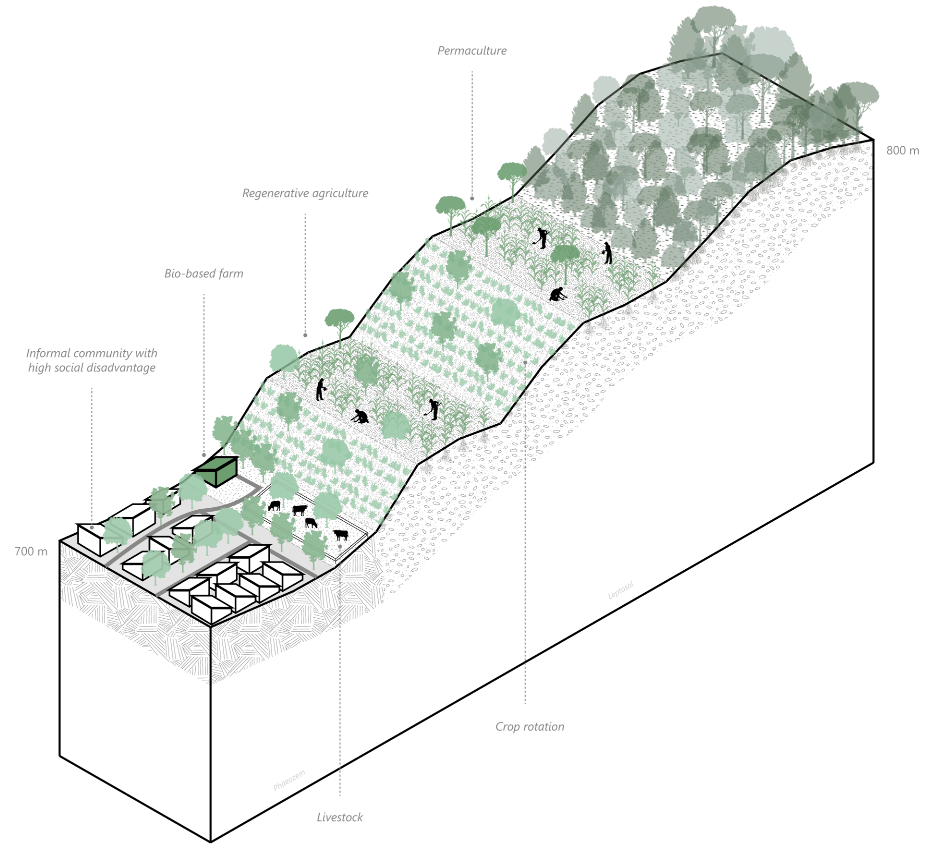
Parkinsonia texana

Layer 4

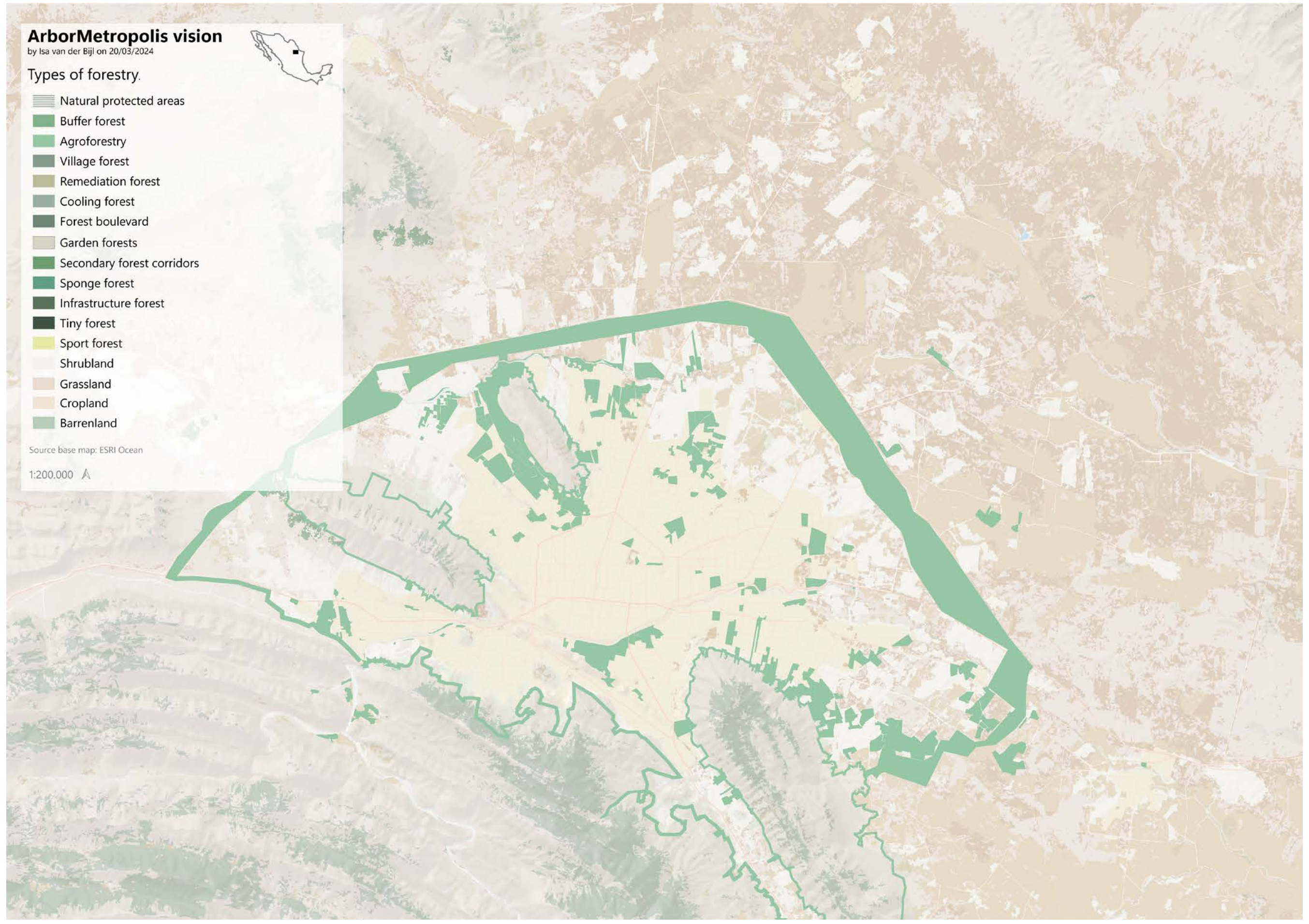
Acacia farnesiana [6]
Cordia boissieri
Diospyros texana
Yucca filifera
Acacia rigidula
Sophora secundiflora

Acacia berlandieri
Dodonaea viscosa
Celtis ehrenbergiana
Leucophyllum frutescens [7]
Larrea tridentata [8]
Agave americana [9]

Agroforestry type



Agroforestry location



Village forest

Village forests are located in the isolated urban sprawl around the city. While village expansion is possible, it is carefully planned in conjunction with the establishment of food forests and the planting of fruit trees (Flux, 2023). Additionally, there are recreational routes. Further from the village centre, there are tightly aligned plots dedicated to wood production, which also give structure to the landscape (Flux, 2023). The primary focus of this approach is to enhance the self-sufficiency and resilience of the villages by creating a reliable source of food security through the integration of diverse food-producing trees and shrubs within the community.

Agricultural patch

Ecosystem services

Food production	Wood production	Forest products	Food security	Recreation	Creation of jobs	Sense of place	Community engagement	Education	Nutrient cycling	Habitat provision

Agroforestry species

Layer 1

Layer 2

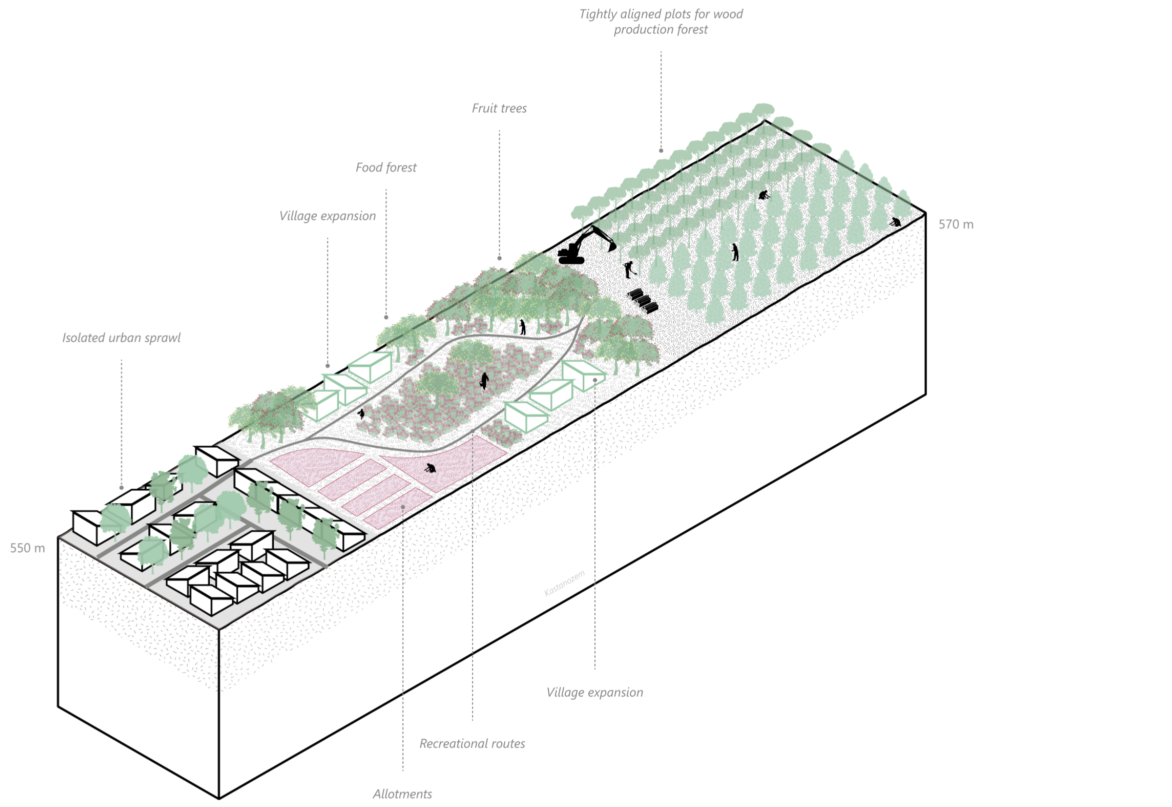
Junglas mollis [1]
Quercus polymorpha [2]

Layer 3

Quercus virginiana [3]
Quercus fusiformis [4]
Ebenopsis ebano [5]
Prosopis glandulosa [6]

Layer 4

Village forest type



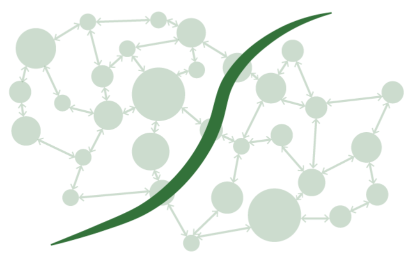
Adapted from Flux (2023).

Agroforestry location

Buffer forest

The buffer forest is an essential component of the green belt surrounding the city. Buffer forests act as a transition zone between a nature reserve and a city edge. They serve as protective zones that use tree groups to safeguard adjacent nature reserves and manage wood production areas (Flux, 2023). By establishing a robust buffer forest around a natural protected area, the amount of polluting chemicals and other harmful substances entering the sensitive ecosystem is significantly reduced (Flux, 2023). Buffer forests also provide valuable ecosystem services, such as erosion control, soil formation and air quality improvement.

Natural backbone



Ecosystem services

Wood production	Forest products	Water flow and quality regulation	Erosion control	Landslide protection	Micro climate control	Air quality improvement	Noise reduction	Soil formation	Nutrient cycling	Soil stability	Species movement

Buffer forest species

Layer 1

Platanus occidentalis mexicana [1]
Populus tremuloides [2]

Layer 2

Junglas mollis
Sabal mexicana [3]

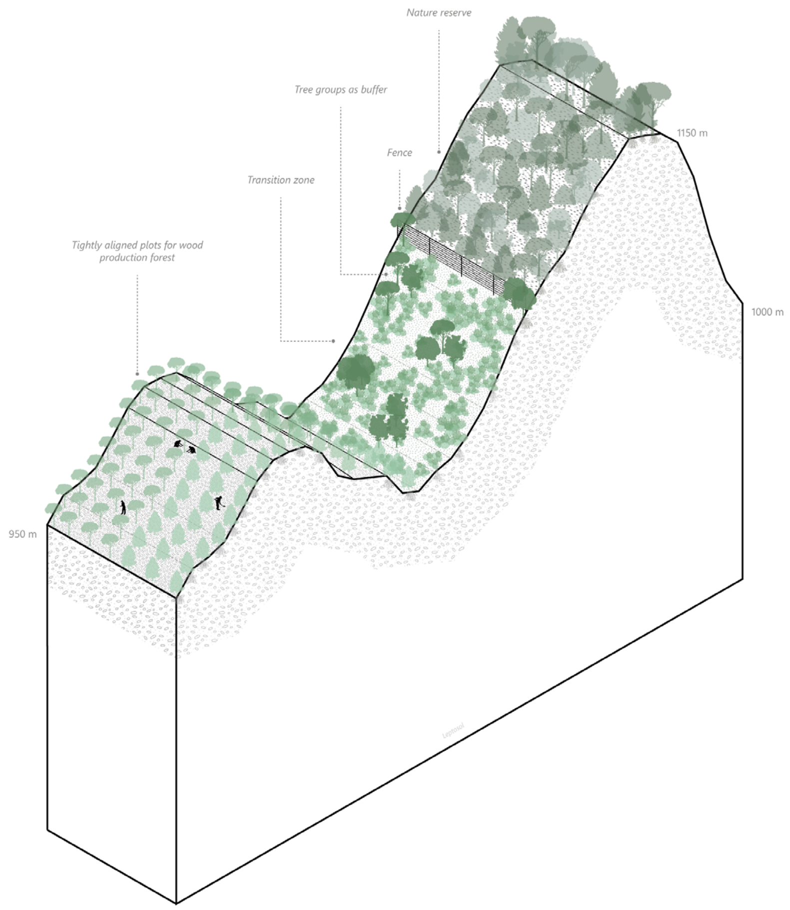
Layer 3

Quercus virginiana
Quercus fusiformis
Ebenopsis ebano
Celtis laevigata [4]
Ehretia anacua [5]
Sapindus saponaria
Prosopis glandulosa
Chilopsis linearis
Parkinsonia aculeata
Sargentia greggii
Sideroxylon celastrinum
Caesalpinia mexicana
Parkinsonia texana

Layer 4

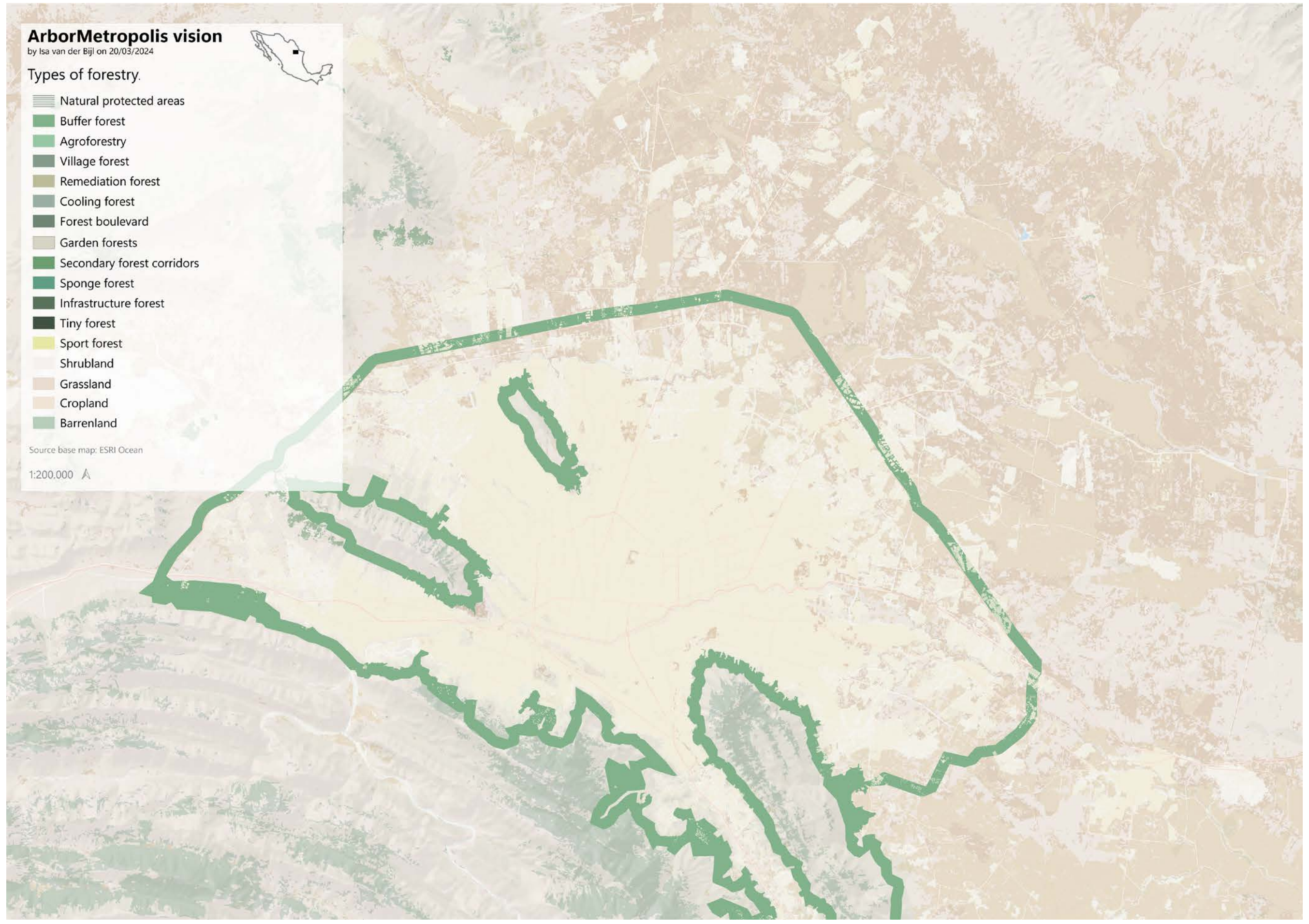
Acacia farnesiana
Cordia boissieri
Diospyros texana
Yucca filifera [6]
Acacia rigidula
Sophora secundiflora
Acacia berlandieri
Dodonaea viscosa [7]
Celtis ehrenbergiana [8]
Leucophyllum frutescens
Larrea tridentata

Buffer forest type



Adapted from Flux (2023).

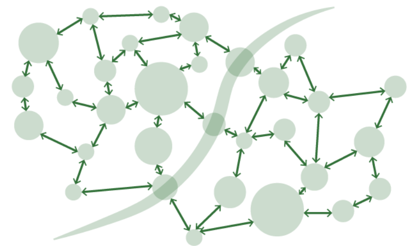
Buffer forest location



Sponge forest

Sponge forests act as natural water absorbers, with mature trees and forest strips managing groundwater and seepage. Creating more space for the river to overflow and restore seepage flows. Seepage flows at the bottom of slopes drain too quickly, causing high water discharge peaks and exacerbating drought (Flux, 2023). Sponge forests are planted at the slope base to increase water retention. These forests utilize hydraulic lift, where deep tree roots transfer water from wet soil layers to drier surface layers (Flux, 2023). Sponge forests also have high soil organic matter and soil life, further improving water retention. Following the landscape's contours, sponge forests serve as attractive recreational routes (Flux, 2023).

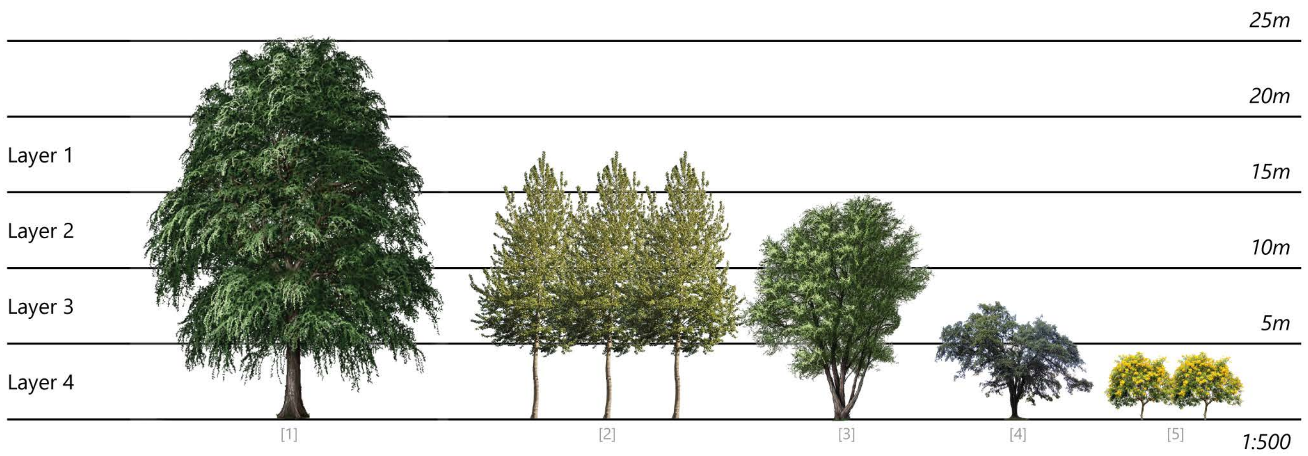
Natural continuum



Ecosystem services

Water flow and quality regulation	Landslide protection	Water storage and retention	Flood protection	Soil remediation	Recreation	Ecotourism	Soil stability	Waste de-composition	Detoxification of pollutants	Species movement

Sponge forest species



Layer 1

Taxodium mucronatum [1]
Platanus occidentalis mexicana
Populus tremuloides [2]

Layer 2

Junglas mollis
Salix nigra [3]

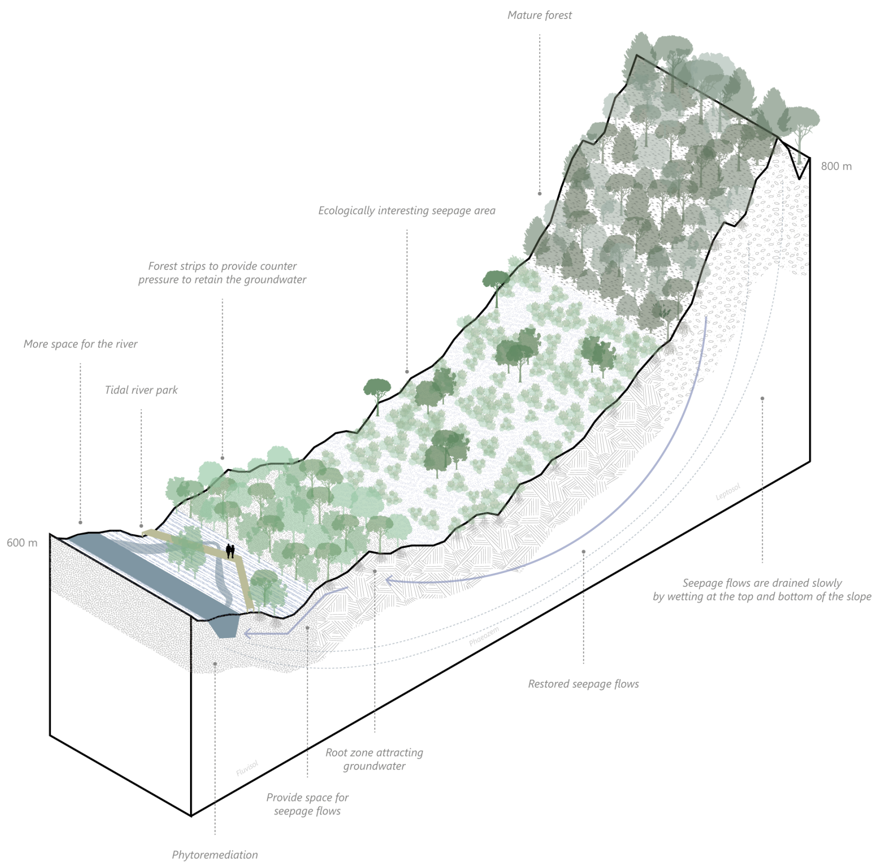
Layer 3

Quercus virginiana
Ulmus crassifolia [4]
Sapindus saponaria
Sargentia greggii

Layer 4

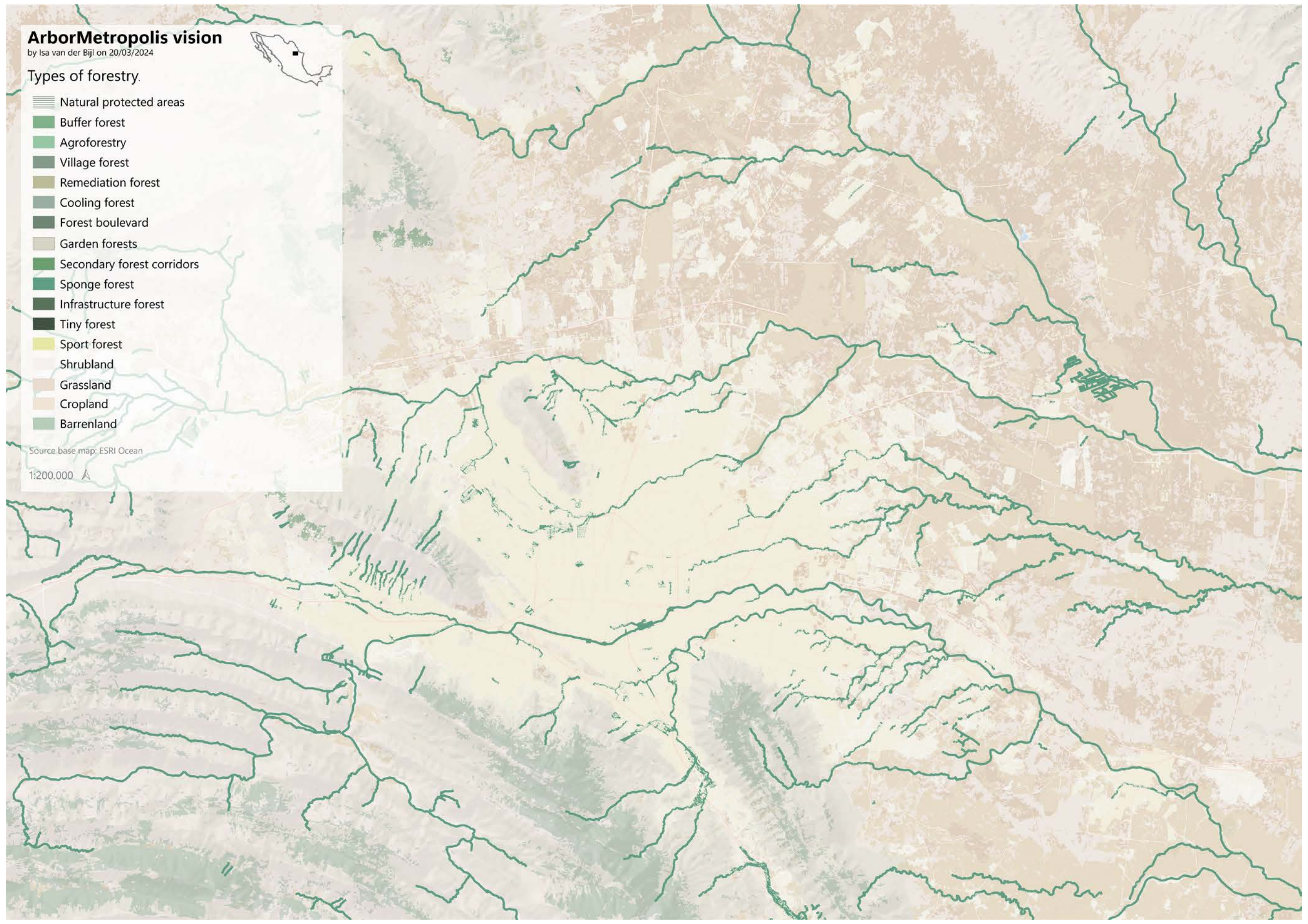
Tecoma stans [5]

Sponge forest type



Adapted from Flux (2023).

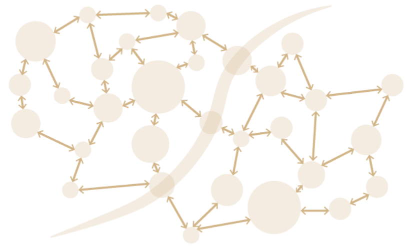
Sponge forest location



Cooling forest

The rising global temperatures are leading to more frequent and prolonged periods of extreme heat, particularly in densely populated urban environments. This persistent heat, both during the day and night, can cause heat stress, resulting in various health issues (Flux, 2023). A cooling forest makes use of the main wind direction, a wide main air supply corridor and a crossing axis to dissipate hot air (Flux, 2023). By incorporating these natural elements, together with wadis, a cooling forest can effectively lower the local temperature and positively impact the perceived wind and air current, creating a more comfortable urban environment for residents (Flux, 2023). They are located in the warmest areas of Monterrey.

Agricultural continuum



Ecosystem services

Micro climate control	Urban heat island mitigation	Air quality improvement	Physical health benefits	Mental health benefits	Detoxification of pollutants

Cooling forest species

Layer 1

Platanus occidentalis mexicana [1]

Layer 2

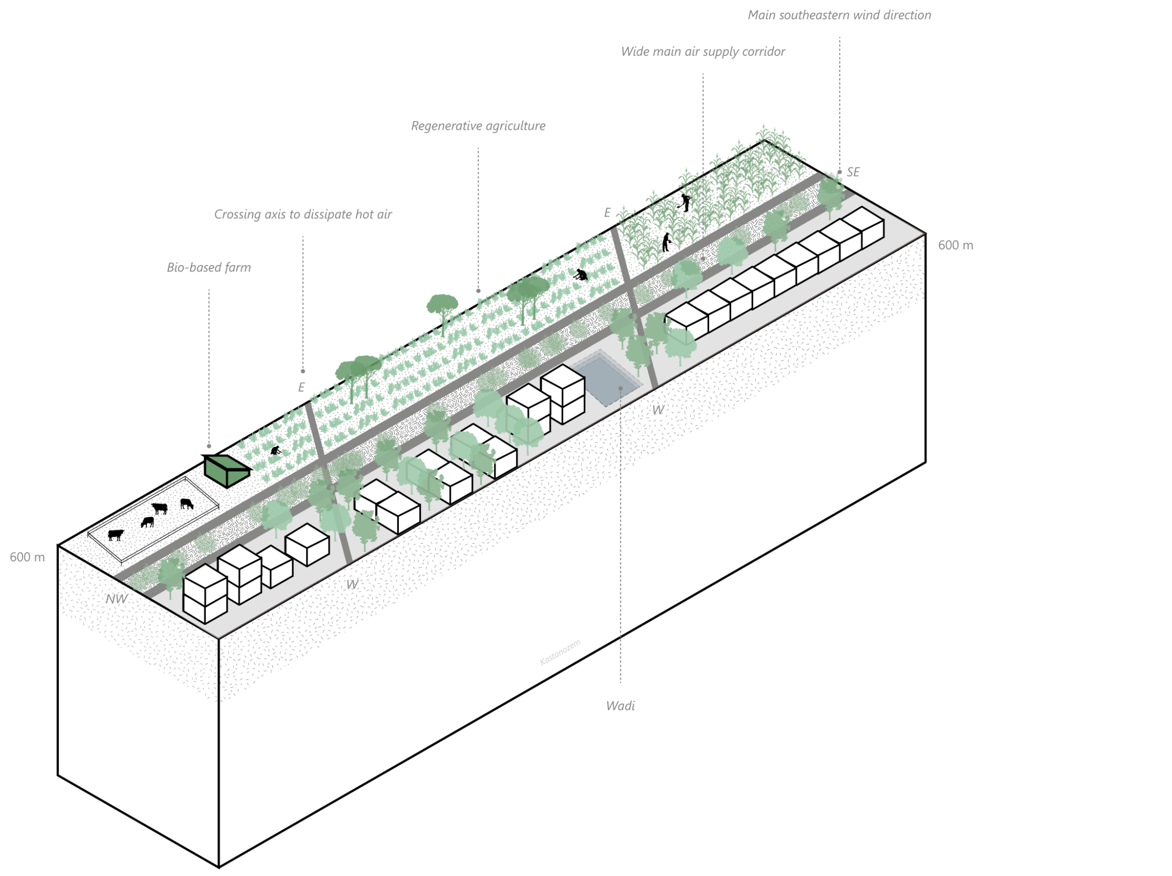
Quercus polymorpha [2]

Layer 3

Quercus virginiana
Quercus canbyi
Quercus graciliformis
Quercus fusiformis [3]
Ulmus crassifolia [4]
Ebenopsis ebano
Celtis laevigata [5]
Ehretia anacua [6]
Sapindus saponaria
Sargentia greggii

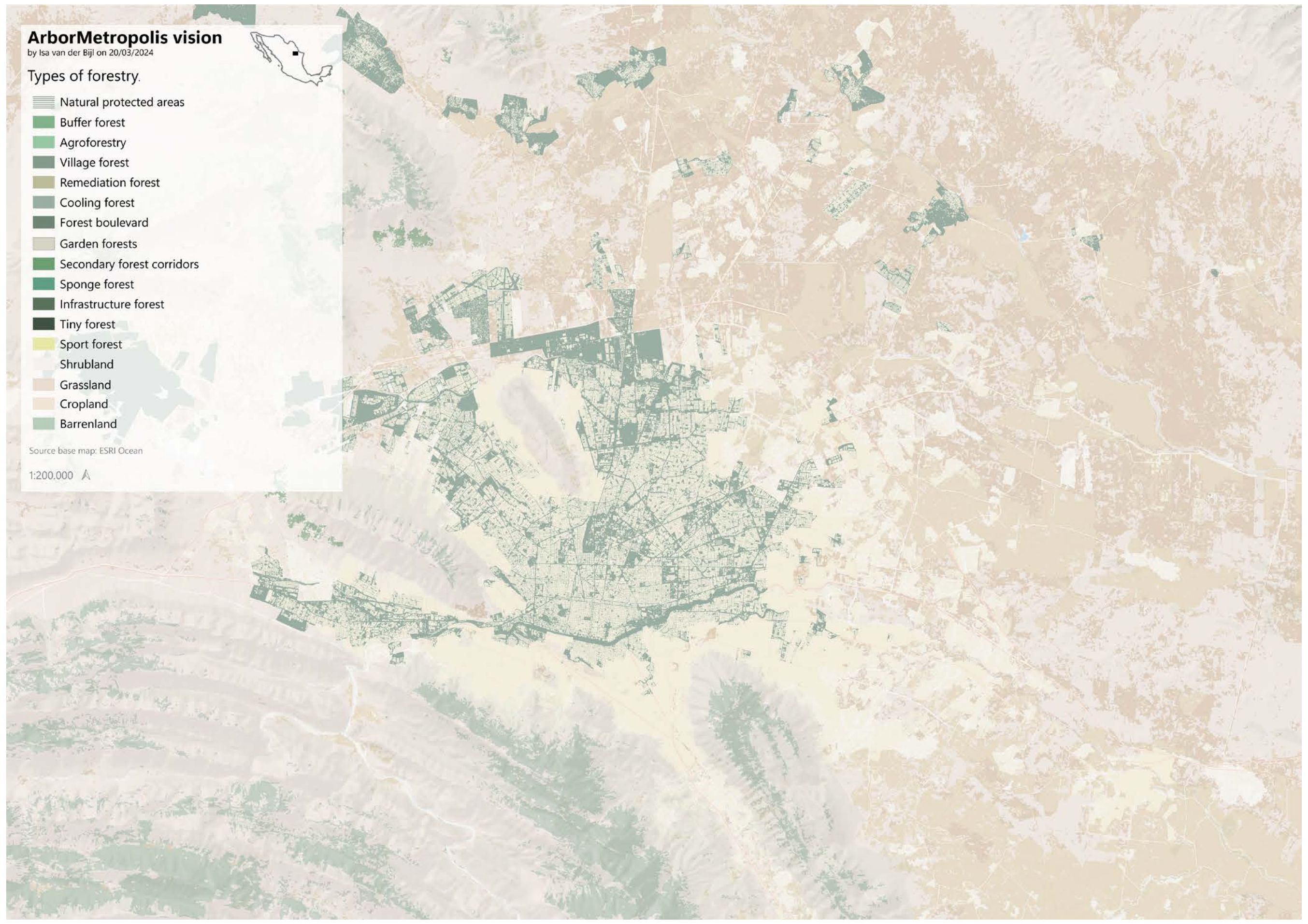
Layer 4

Cooling forest type



Adapted from Flux (2023).

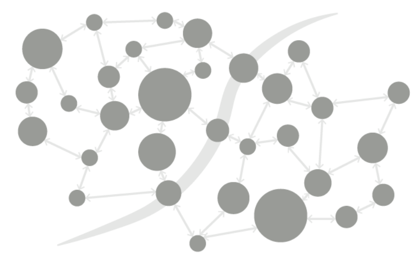
Cooling forest location



Tiny forest

Obsolete industrial areas often include large parking lots and vacant spaces, presenting an opportunity for revitalization through the introduction of tiny forests. These compact pockets of forest are designed to host a high level of biodiversity in a small space (Flux, 2023). By strategically transforming underutilized urban spaces into tiny forests, cities can create a cooler microclimate and mitigate the urban heat island effect. Moreover, tiny forests enhance the nature experience of city residents (Flux, 2023). In addition to benefiting human inhabitants, these urban oases also serve as valuable habitats for various urban animals, offering them a place to thrive within the city landscape (Flux, 2023).

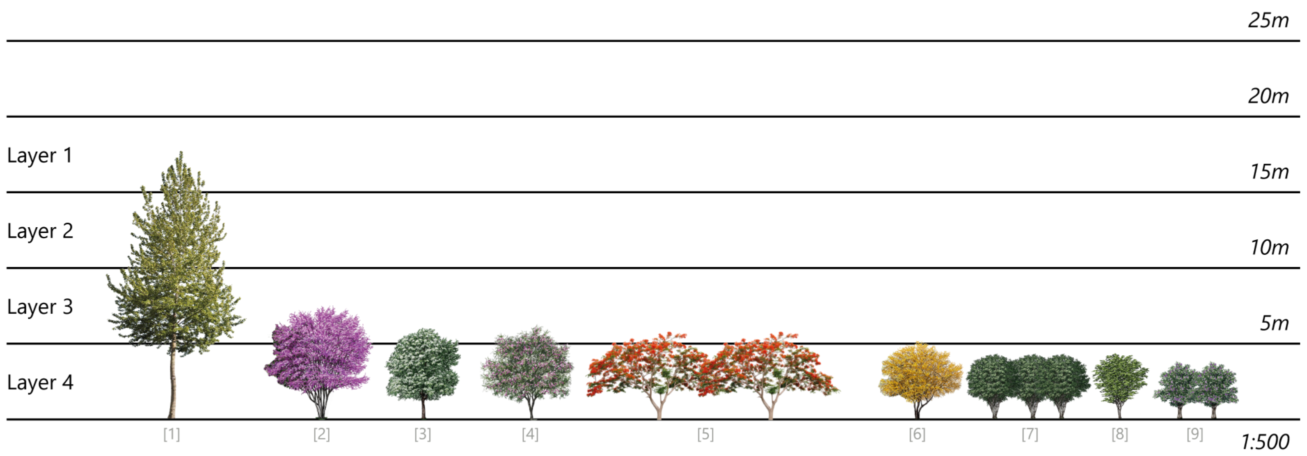
Industrial patch



Ecosystem services

Micro climate control	Urban heat island mitigation	Air quality improvement	Noise reduction	Sense of place	Education	Habitat provision

Tiny forest species



Layer 1

Platanus occidentalis mexicana
Populus tremuloides [1]

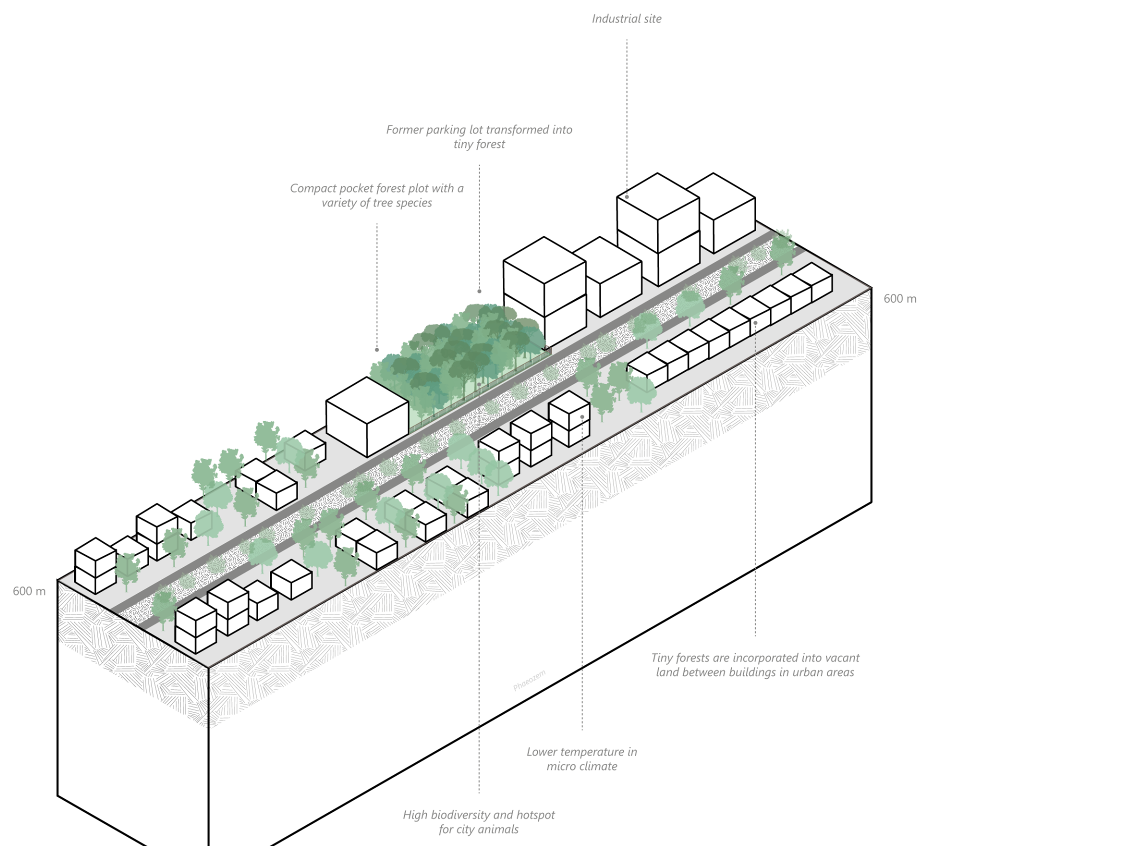
Layer 2

Layer 3

Ebenopsis ebano
Celtis laevigata
Cercis canadensis var. mexicana [2]
Ehretia anacua [3]
Sapindus saponaria
Chilopsis linearis [4]
Sargentia greggii
Caesalpinia mexicana [5]

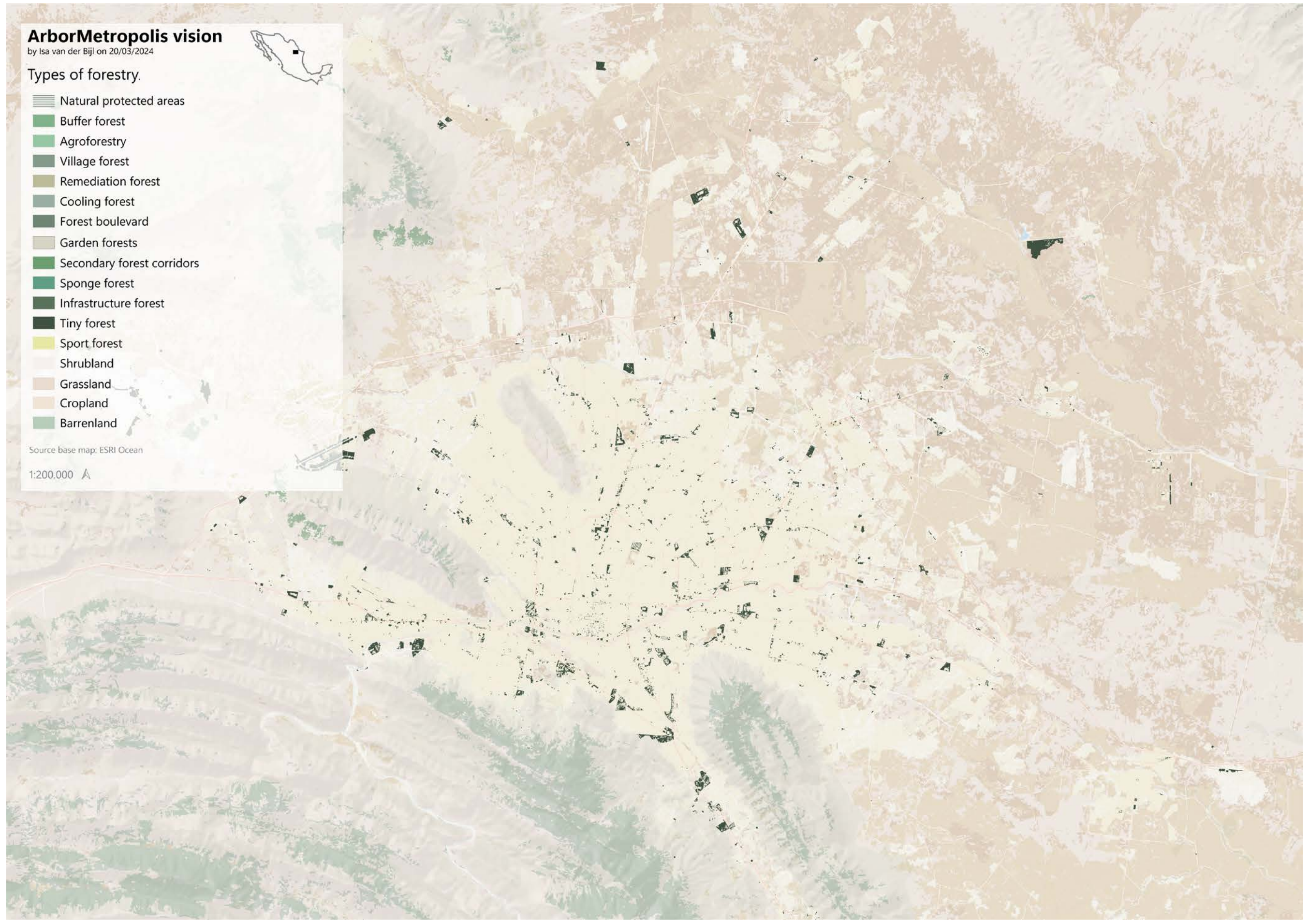
Layer 4

Acacia farnesiana [6]
Cordia boissieri
Diospyros texana [7]
Ungnadia speciosa [8]
Tecoma stans
Sophora secundiflora [9]



Adapted from Flux (2023).

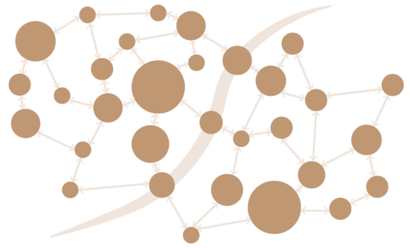
Tiny forest location



Garden forest

Garden forests are strategically located within gated communities, which often lack native tree species and sufficient greenery. To enhance the ecological value and connectivity of these communities, a main tree avenue can be created to link the housing blocks, utilizing canopy cover to establish an ecological continuum. The goal is to have 70% or more native species and develop multi-layered gardens with trees, shrubs, and underbrush. Garden forests can provide benefits, such as a sense of place, community engagement, habitat provision, and fauna movement.

Urban patch



Ecosystem services

Micro climate control	Urban heat island mitigation	Sense of place	Community engagement	Mental health benefits	Habitat provision	Species movement

Garden forest species

Layer 1

Taxodium mucronatum
Platanus occidentalis mexicana
Quercus rysophylla [1]
Populus tremuloides

Layer 2

Junglas mollis
Carya illinoensis
Pinus pseudostrobus [2]
Salix nigra
Quercus polymorpha
Pinus teocote
Sabal mexicana

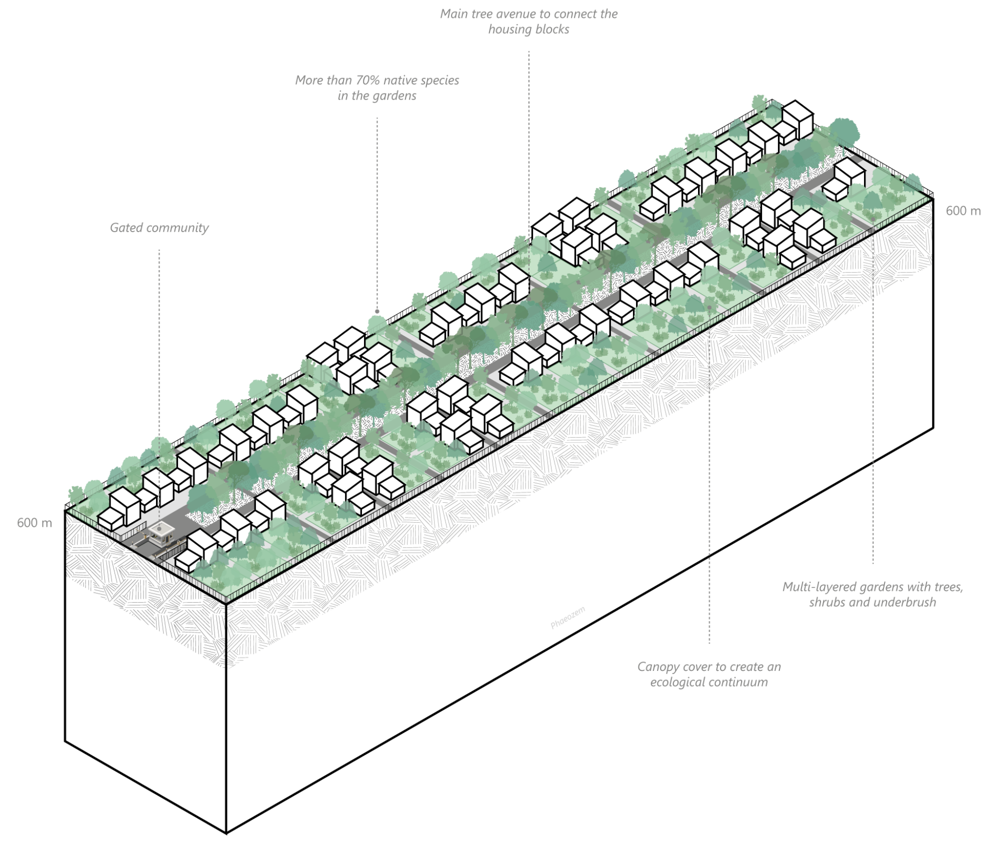
Layer 3

Quercus virginiana
Quercus canbyi
Quercus laceyi
Quercus graciliformis
Quercus fusiformis
Ulmus crassifolia
Ebenopsis ebano
Celtis laevigata
Cercis canadensis var. mexicana
Ehretia anacua
Cornus florida var. urbiniana [3]
Sapindus saponaria
Prosopis glandulosa [4]
Chilopsis linearis
Pinus cembroides
Parkinsonia aculeata
Sargentia greggii
Sideroxylon celastrinum [5]
Caesalpinia mexicana
Parkinsonia texana

Layer 4

Acacia farnesiana
Arbutus texana [6]
Cordia boissieri
Diospyros texana
Ungnadia speciosa
Tecoma stans
Yucca filifera
Acacia rigidula
Sophora secundiflora
Acacia berlandieri
Dodonaea viscosa
Celtis ehrenbergiana [7]
Fouquieria splendens
Leucophyllum frutescens
Larrea tridentata
Opuntia engelmannii
Agave americana
Lantana camara
Dasylirion texanum
Asclepias curassavica [8]
Agave lecheguilla
Lupinus texensis
Echinocereus enneacanthus

Garden forest type

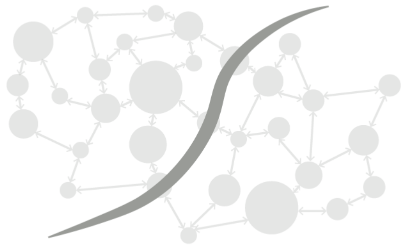


Garden forest location

Infrastructure forest

Monterrey has an extensive network of highways and roads to support its growing population and economy. However, the city faces significant air pollution challenges, with high levels of particulate matter (PM) and other pollutants posing health risks to residents. By introducing an infrastructure forest efforts are made to improve the air quality by creating biodiverse tree avenues with bushes in the road verges guiding the traffic lanes. Therefore, these tree avenues can remove PM particles. Implementing these infrastructure forests does not only contribute to cleaner air but also provides additional benefits such as urban cooling, soil remediation, and noise reduction.

Industrial backbone



Ecosystem services

Urban heat island mitigation	Air quality improvement	Soil remediation	Noise reduction	Physical health benefits	Soil formation	Detoxification of pollutants	Species movement

Infrastructure forest species

Layer 1

Platanus occidentalis mexicana [1]

Layer 2

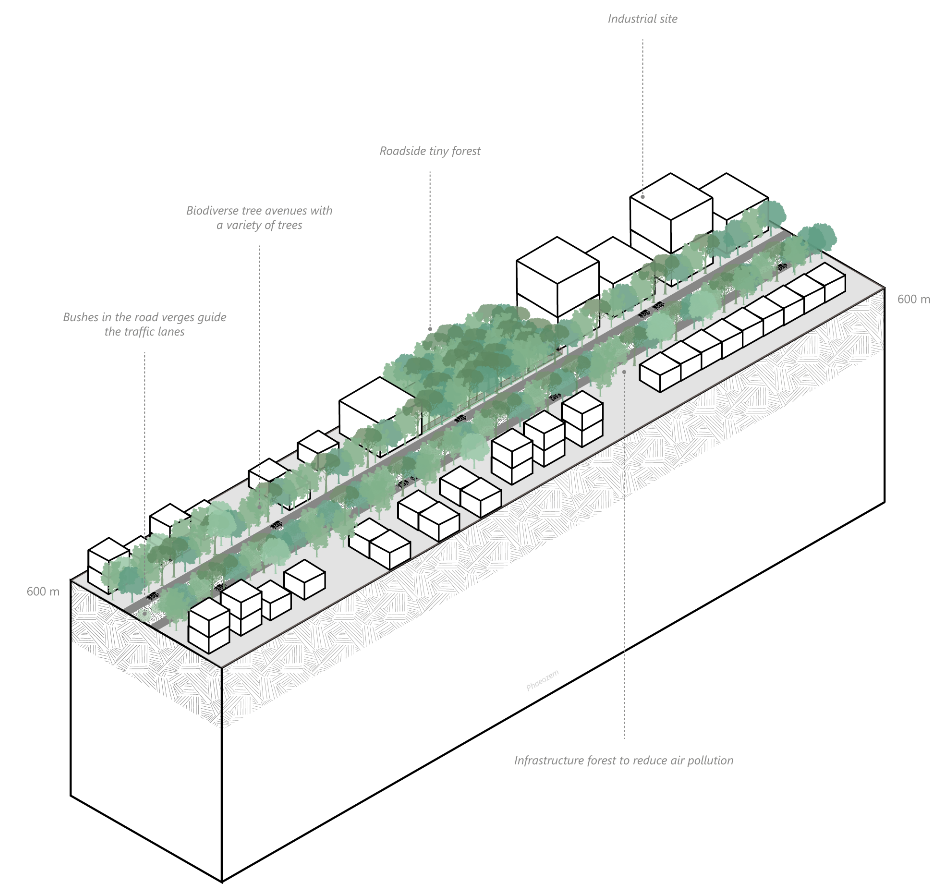
Quercus polymorpha [2]

Layer 3

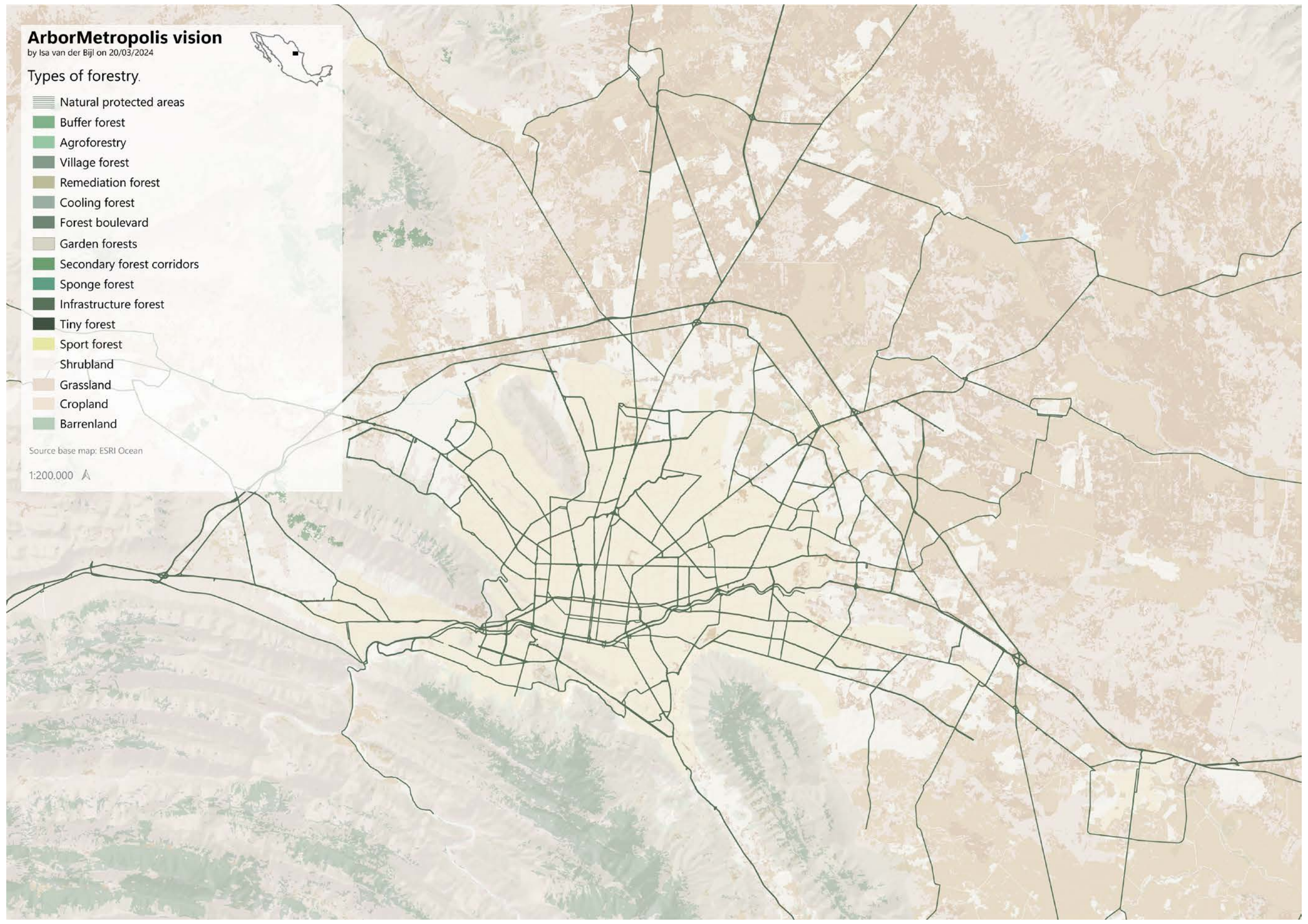
Quercus virginiana
Quercus canbyi
Quercus laceyi [3]
Quercus graciliformis
Quercus fusiformis
Ulmus crassifolia [4]
Ebenopsis ebano
Ehretia anacua [5]
Prosopis glandulosa [6]

Layer 4

Infrastructure forest type



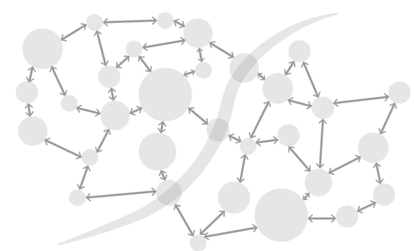
Infrastructure forest location



Remediation forest

Remediation forests are planned to remediate contaminated soil over time. Flux (2023) states that the soil must be remediated before other functions, such as nature development, can take place. Initial forest planting consists of undemanding species. Due to the rapid growth and high water use of these species, the soil and groundwater are replaced. Secondly, after the planted species have absorbed some of the contamination, the species are partly cut down and replaced by species suitable for production. The land is now fully remediated and also suitable for other functions, such as building some small houses.

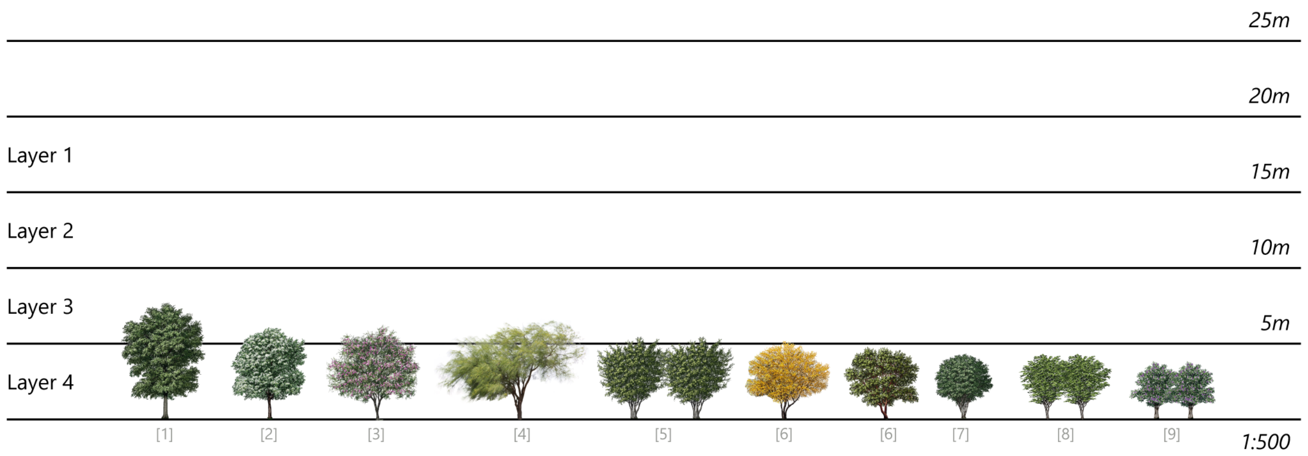
Industrial continuum



Ecosystem services

Forest products	Air quality improvement	Soil remediation	Creation of jobs	Education	Soil formation	Waste de-composition	Detoxification of pollutants

Remediation forest species



Layer 1

Layer 2

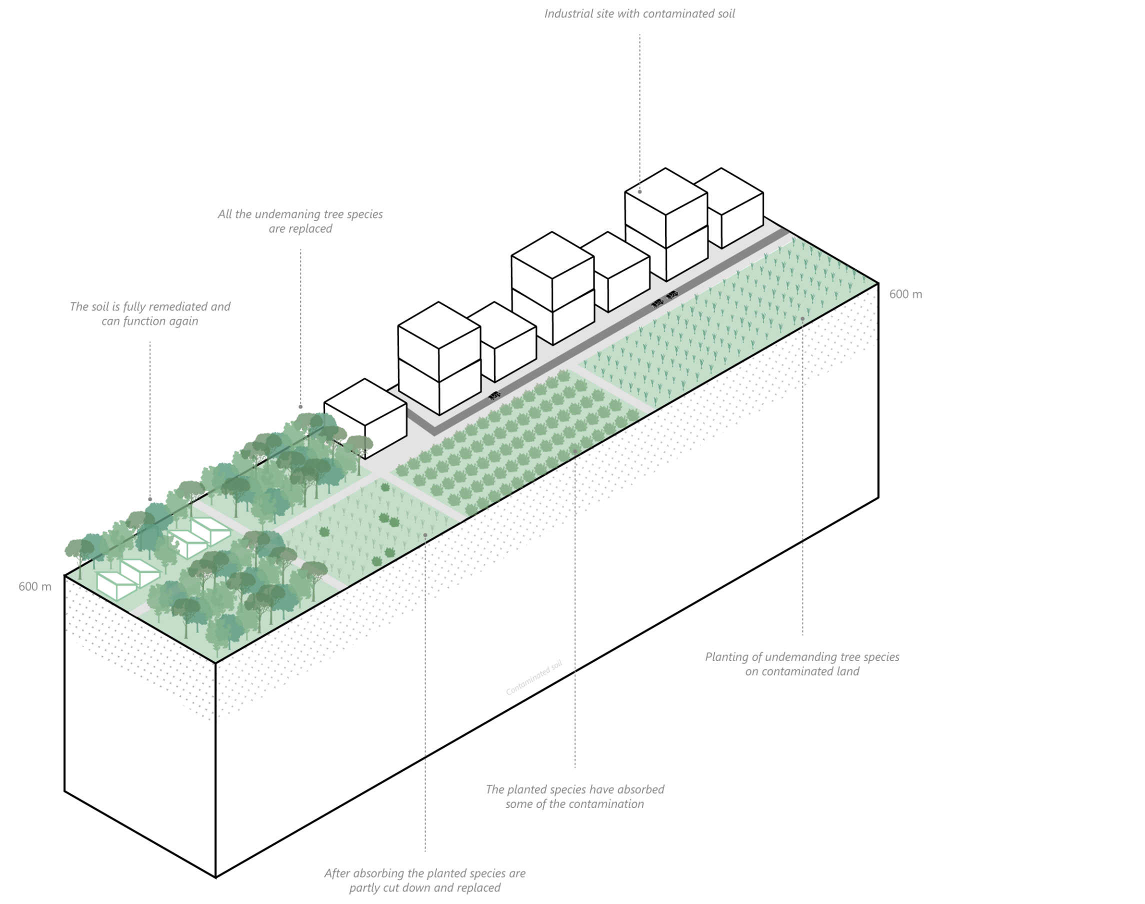
Layer 3

Celtis laevigata [1]
Ehretia anacua [2]
Sapindus saponaria
Prosopis glandulosa
Chilopsis linearis [3]
Pinus cembroides
Parkinsonia aculeata [4]
Sargentia greggii
Sideroxylon celastrinum [5]
Caesalpinia mexicana
Parkinsonia texana

Layer 4

Acacia farnesiana [6]
Arbutus texana [7]
Cordia boissieri
Diospyros texana
Ungnadia speciosa [8]
Tecoma stans
Acacia rigidula
Sophora secundiflora [9]
Acacia berlandieri
Dodonaea viscosa
Celtis ehrenbergiana

Remediation forest type



Adapted from Flux (2023).

Remediation forest location

Forest boulevard

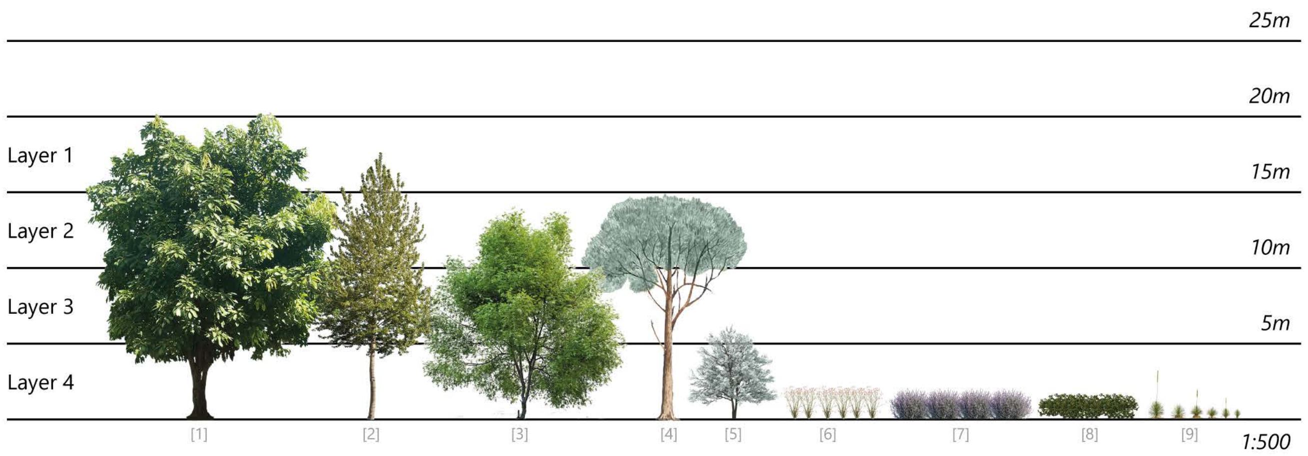
Forest boulevards serve as a transitional zone between the urban environment and the surrounding agricultural landscape, aiming to expand and enhance the existing core green elements within the city (Flux, 2023). These green corridors form a network designed for recreation, featuring amenities such as recreational boardwalks and viewing towers. The layout of the forest boulevard consists of main avenues with smaller orthogonal trails, creating space for recreational functions (Flux, 2023). Solid double tree lines characterize the main avenue, while the outer edges of the boulevard are composed of a diverse mix of trees, shrubs, and underbrush (Flux, 2023). Pedestrians and cyclists are the primary users.

Urban backbone

Ecosystem services

Recreation	Sense of place	Ecotourism	Physical health benefits	Mental health benefits	Habitat provision	Species movement

Forest boulevard species



Layer 1

Taxodium mucronatum
Platanus occidentalis mexicana
Quercus rysophylla [1]
Populus tremuloides [2]

Layer 2

Junglas mollis
Carya illinoensis [3]
Pinus pseudostrobus [4]
Salix nigra
Quercus polymorpha
Pinus teocote
Sabal mexicana

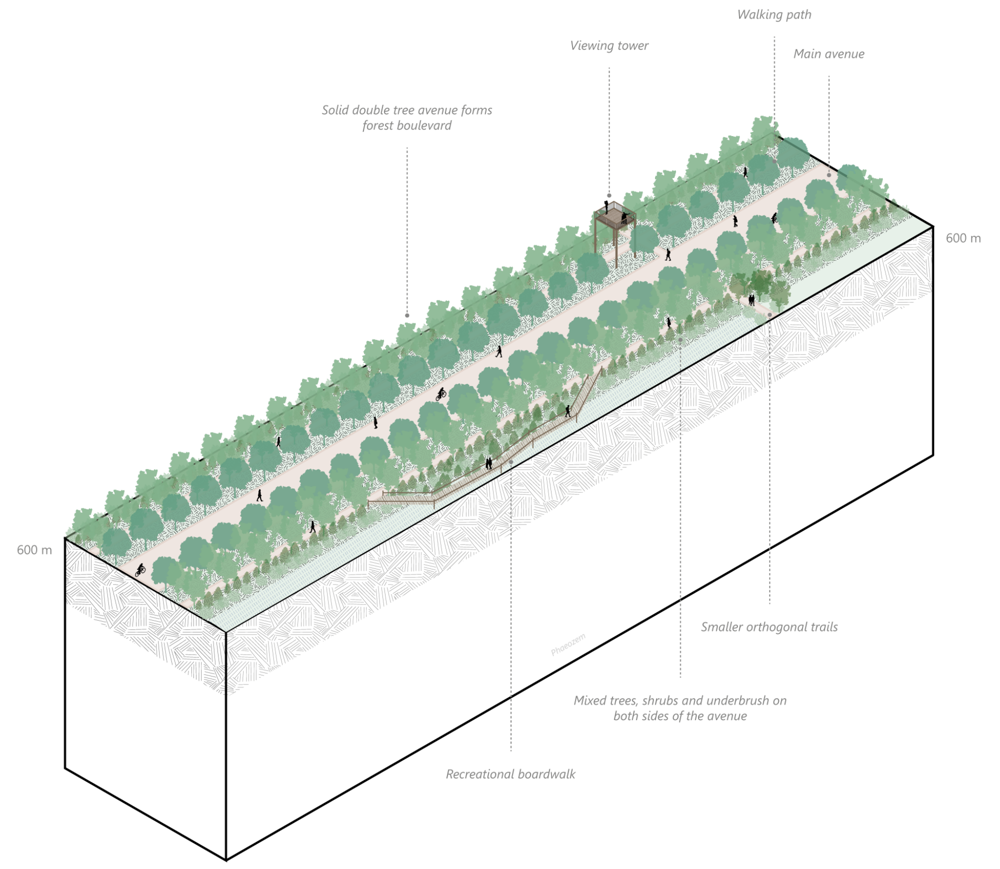
Layer 3

Quercus virginiana
Quercus canbyi
Quercus laceyi
Quercus graciliformis
Quercus fusiformis
Ulmus crassifolia
Ebenopsis ebano
Celtis laevigata
Cercis canadensis var. mexicana
Ehretia anacua
Cornus florida var. urbiniana [5]
Sapindus saponaria
Prosopis glandulosa
Chilopsis linearis
Pinus cembroides
Parkinsonia aculeata
Sargentia greggii
Sideroxylon celastrinum
Caesalpinia mexicana
Parkinsonia texana

Layer 4

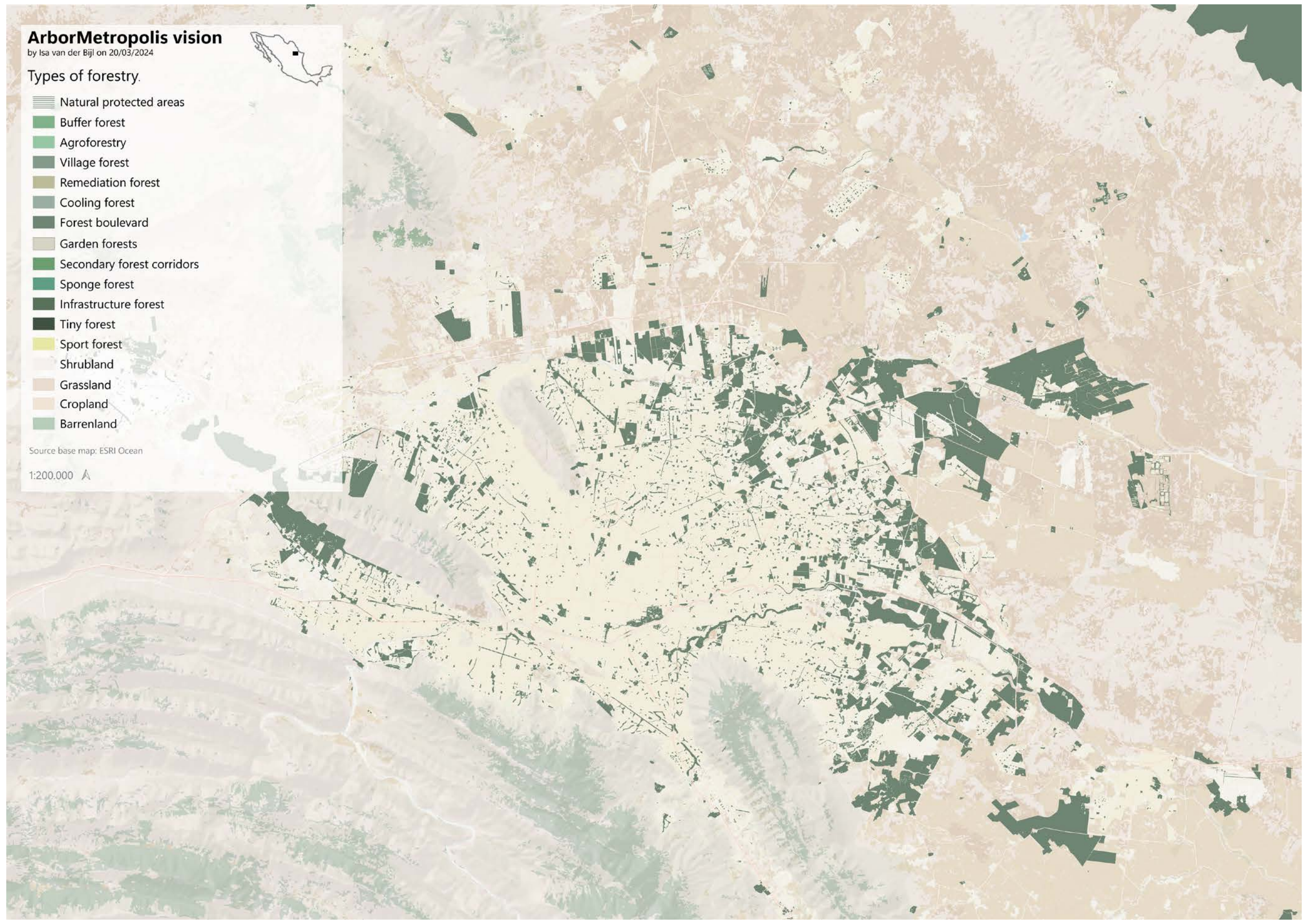
Acacia farnesiana
Arbutus texana
Cordia boissieri
Diospyros texana
Ungnadia speciosa
Tecoma stans
Yucca filifera
Acacia rigidula
Sophora secundiflora
Acacia berlandieri
Dodonaea viscosa
Celtis ehrenbergiana
Fouquieria splendens [6]
Leucophyllum frutescens [7]
Larrea tridentata [8]
Opuntia engelmannii
Agave americana
Lantana camara
Dasylirion texanum [9]
Asclepias curassavica
Agave lecheguilla
Lupinus texensis
Echinocereus enneacanthus

Forest boulevard type



Adapted from Flux (2023).

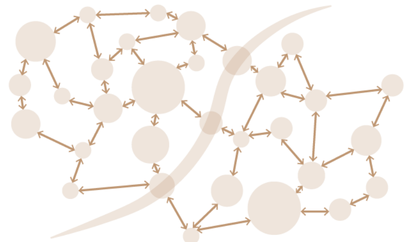
Forest boulevard location



Forest corridor

Forest corridors are located in formal communities with both high and low social disadvantage. These green spaces consist of a main structural component accompanied by orthogonal tree lanes that branch out from the primary corridor. The main strip is designed as a narrow and elongated linear forest, which can incorporate natural playgrounds and recreational amenities. The goal is to create an ecological continuum and connectivity. It also helps with engaging people from the front door and has benefits for human physical and mental health. By linking fragmented habitats and green spaces, these corridors facilitate species movement.

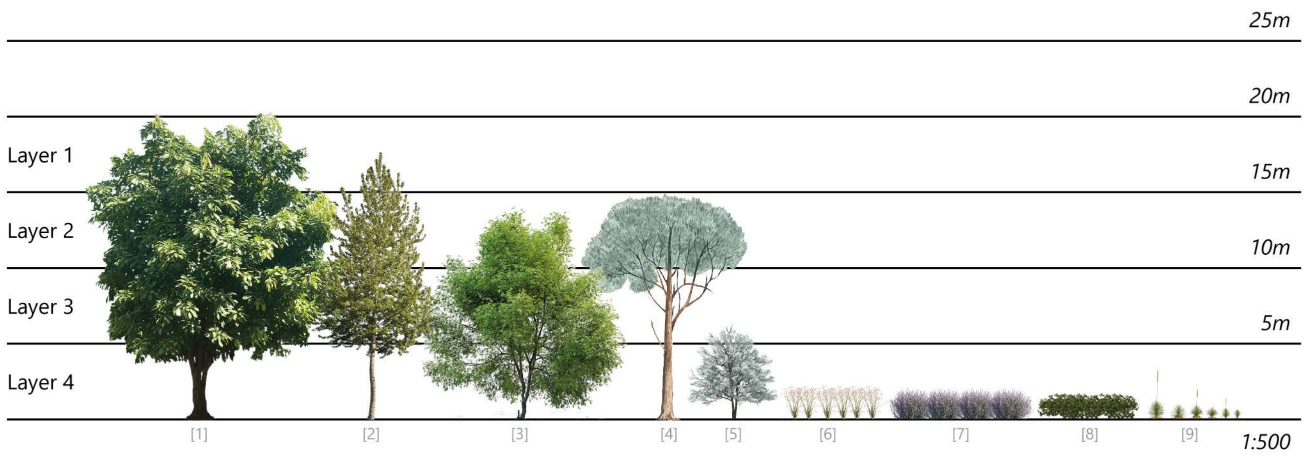
Urban continuum



Ecosystem services

Micro climate control	Urban heat island mitigation	Air quality improvement	Recreation	Sense of place	Community engagement	Physical health benefits	Mental health benefits	Soil formation	Habitat provision	Species movement

Forest corridor species



Layer 1

Taxodium mucronatum
Platanus occidentalis mexicana
Quercus rysophylla [1]
Populus tremuloides [2]

Layer 2

Junglas mollis
Carya illinoensis [3]
Pinus pseudostrobus [4]
Salix nigra
Quercus polymorpha
Pinus teocote
Sabal mexicana

Layer 3

Quercus virginiana
Quercus canbyi
Quercus laceyi
Quercus graciliformis
Quercus fusiformis
Ulmus crassifolia
Ebenopsis ebano
Celtis laevigata
Cercis canadensis var. mexicana
Ehretia anacua
Cornus florida var. urbiniana [5]
Sapindus saponaria
Prosopis glandulosa
Chilopsis linearis
Pinus cembroides
Parkinsonia aculeata
Sargentia greggii
Sideroxylon celastrinum
Caesalpinia mexicana
Parkinsonia texana

Layer 4

Acacia farnesiana
Arbutus texana
Cordia boissieri
Diospyros texana
Ungnadia speciosa
Tecoma stans
Yucca filifera
Acacia rigidula
Sophora secundiflora
Acacia berlandieri
Dodonaea viscosa
Celtis ehrenbergiana
Fouquieria splendens [6]
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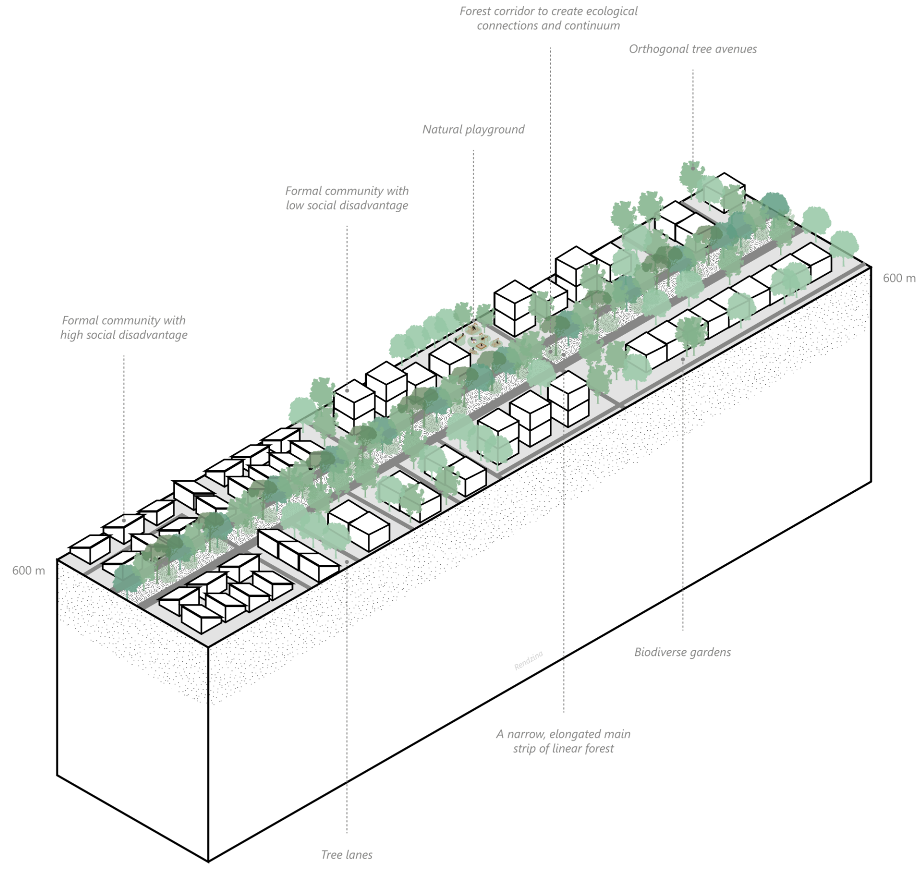
Opuntia engelmannii
Agave americana
Lantana camara
Dasylirion texanum [9]
Asclepias curassavica
Agave lecheguilla
Lupinus texensis
Echinocereus enneacanthus

Forest corridor type

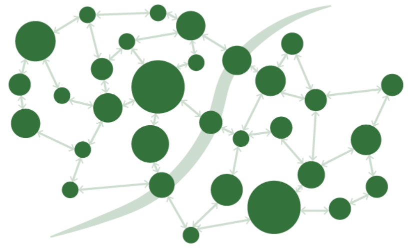


Forest corridor location

Sport forest

Sport forests are strategically located around existing sports facilities, creating a cohesive and accessible network for physical activity and recreation. The design incorporates a main sports corridor that extends into the surrounding neighbourhood, providing a direct connection from residents' front doors to the various sporting amenities. Central to this corridor is a running strip that serves as the backbone of the sport forest, linking all the facilities together and fostering a strong sense of place. By ensuring easy access from the residential area, people are engaged in physical activity and adopt healthier lifestyles.

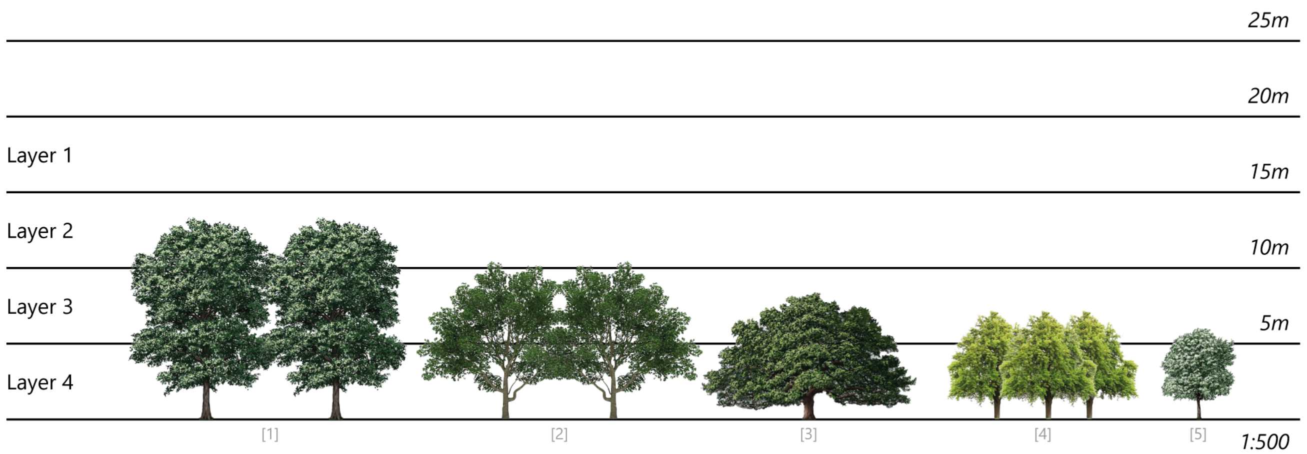
Natural patch



Ecosystem services

Recreation	Sense of place	Education	Community engagement	Ecotourism	Physical health benefits	Mental health benefits	Habitat provision	Species movement

Sport forest species



Layer 1

Layer 2

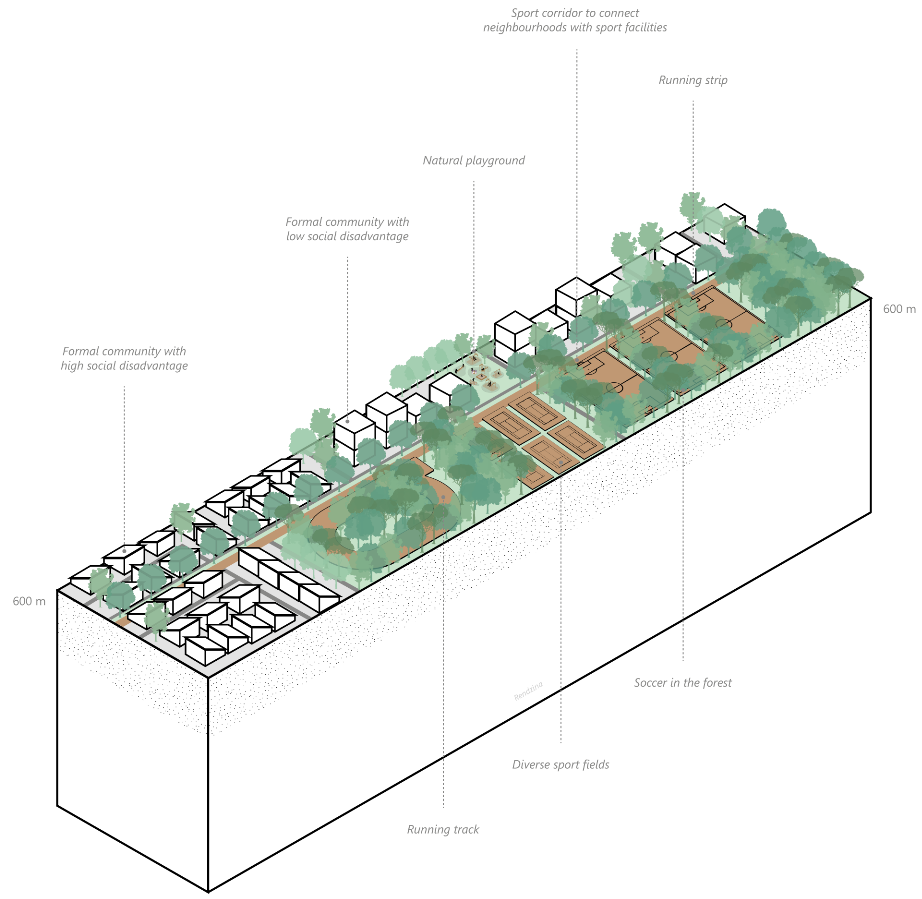
Quercus polymorpha [1]

Layer 3

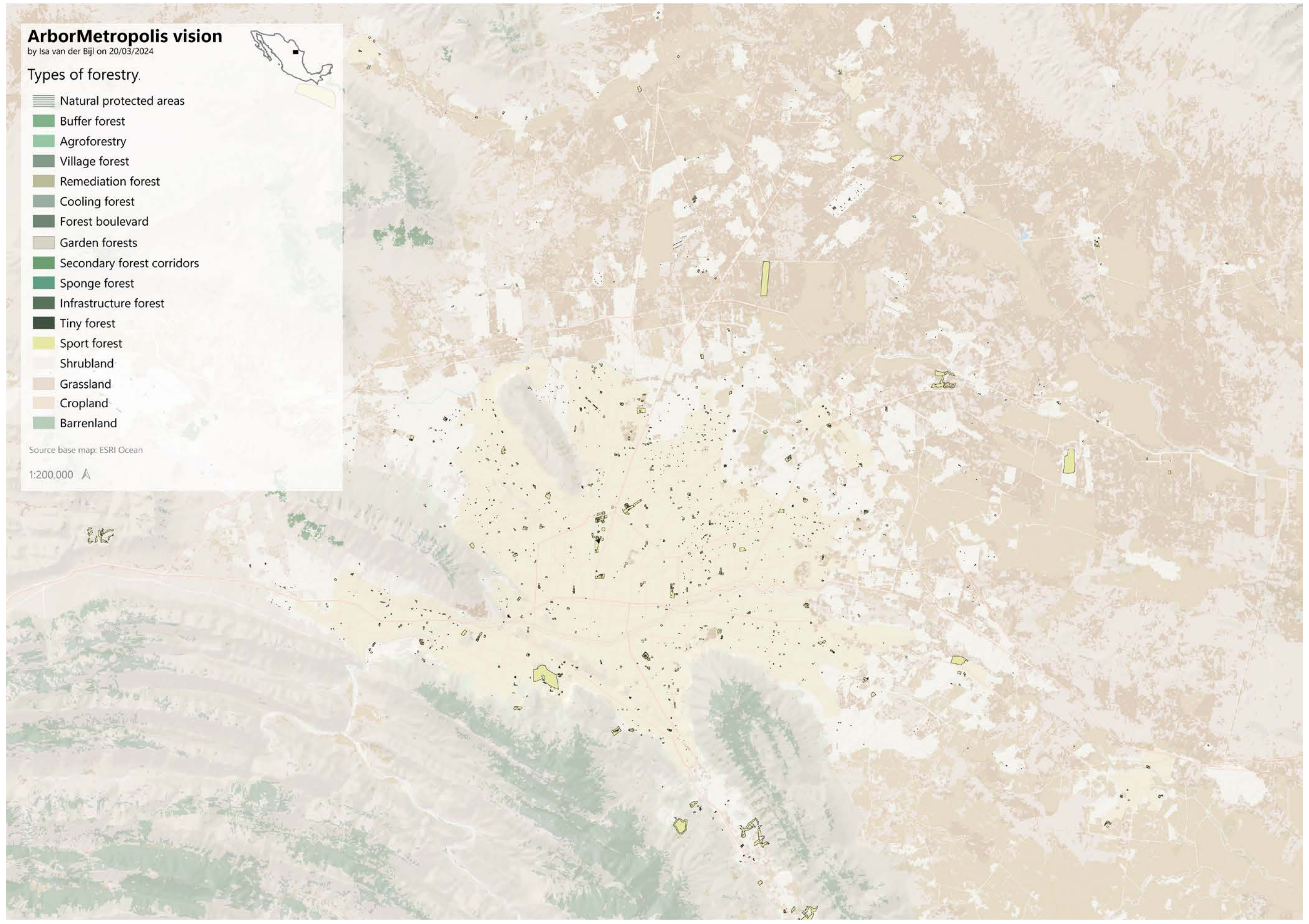
Quercus virginiana [2]
Quercus fusiformis [3]
Ebenopsis ebano [4]
Ehretia anacua [5]
Sargentia greggii

Layer 4

Sport forest type



Sport forest location



Tree species selection

To select the appropriate tree species per type, Oswaldo Zurita Zaragoza was personally contacted. Using his expertise and his book "Guía de árboles y otras plantas nativas en la zona Metropolitana de Monterrey" (2009), the forest types were reviewed, and the correct tree species were identified for each type, as shown in table 1.

Tree categories

Great sized trees

Platanus occidentalis mexicana

Medium to dense shade

Ehretia anacua

With special appeal

Cercis canadensis var. mexicana

Shrubs and wildflowers

Lantana camara

From the desert

Opuntia engelmannii

[1] Tree species selection data (O. Zurita Zaragoza, personal communication, April 24, 2024)

Category	Spanish name	Scientific name	Soil drainage	Age	Height	Width	Spacing	Agroforestry	Villlage forest
Great sized trees	Ahuehuete o sabino	*Taxodium mucronatum*	Slow	150+	25	15	20		
	Alamillo	*Populus tremuloides*	Medium-slow	30-80	18	15	20		
	Álamo de río o sicomoro	*Platanus occidentalis mexicana*	Medium-slow	150+	25	12	15		
	Encino de asta	*Quercus rysophylla*	Fast-medium	150+	20	10	12		
	Encino roble	*Quercus polymorpha*	Fast-medium	150+	14	9	10		x
	Encino siempreverde	*Quercus virginiana*	Fast-medium	150+	10	12	12	x	x
	Nogal de nuez encarcelada	*Junglas mollis*	Medium-slow	150+	15	12	12	x	x
	Nogal de nuez lisa	*Carya illinoensis*	Fast-medium	150+	15	12	14		
	Palma sabal	*Sabal mexicana*	Medium	80-150	12	4	8	x	
	Pino blanco	*Pinus pseudostrobus*	Fast-medium	80-150	15	8	10		
	Pino teocote	*Pinus teocote*	Fast-medium	80-150	13	7	9		
	Sauce de río	*Salix nigra*	Slow	30-80	15	15	20		
Medium to dense shade	Anacua	*Ehretia anacua*	Fast	80-150	6	6	8	x	
	Ébano	*Ebenopsis ebano*	Fast-medium	150+	7	6	8	x	x
	Encino blanco	*Quercus graciliformis*	Fast-medium	150+	8	8	10		
	Encino bravo	*Quercus fusiformis*	Fast	150+	8	12	12	x	x
	Encino duraznillo	*Quercus canbyi*	Fast-medium	150+	9	8	8		
	Encino memelito	*Quercus laceyi*	Fast-medium	150+	9	7,5	9		
	Olmo	*Ulmus crassifolia*	Fast	150+	8	7	8		
	Palo blanco	*Celtis laevigata*	Medium	30-80	7	6	9	x	
With special appeal	Anacahuita	*Cordia boissieri*	Medium	80-150	4,5	4	5,5	x	
	Chaparro prieto	*Acacia rigidula*	Fast	10-30	4	3	4	x	
	Chapote amarillo	*Sargentia greggii*	Medium	10-30	5,5	4	6	x	
	Chapote negro	*Diospyros texana*	Fast-medium	30-80	4,5	6	5	x	
	Colorín	*Sophora secundiflora*	Fast	30-80	4	3	4,5	x	
	Coma	*Sideroxylon celastrinum*	Fast-medium	80-150	5,5	4,5	5	x	
	Corona de San Pedro	*Cornus florida var. urbiniana*	Fast	30-80	6	5	7		
	Duraznillo	*Cercis canadensis var. mexicana*	Fast	10-30	7	5,5	6		
	Hierba del potro	*Caesalpinia mexicana*	Medium	10-30	5,5	4	5	x	
	Huizache	*Acacia farnesiana*	Medium-slow	30-80	5	5	6	x	
	Jaboncillo	*Sapindus saponaria*	Fast	10-30	6	5	6,5	x	
	Madroño	*Arbutus texana*	Fast	30-80	5	3	4		
	Mezquite	*Prosopis glandulosa*	Slow	80-150	6	7	7	x	x
	Mimbre	*Chilopsis linearis*	Fast	30-80	6	5	6	x	
	Monilla	*Ungnadia speciosa*	Medium	10-30	4,5	4	5		
	Palo verde	*Parkinsonia texana*	Medium	10-30	5,5	4,5	6	x	
	Pino piñonero	*Pinus cembroides*	Medium	30-80	6	4,5	4,5		
	Retama	*Parkinsonia aculeata*	Slow	10-30	6	6	7	x	
	Tronadora	*Tecoma stans*	Medium	10-30	4,5	3	4		
Shrubs and wildflowers	Cenizo	*Leucophyllum frutescens*	Fast-medium	10-30	1,5	1,5	1,5	x	
	Dodónea	*Dodonaea viscosa*	Medium	10-30	2,5	2,5	2	x	
	Granjeno	*Celtis ehrenbergiana*	Fast-medium	10-30	2,5	2	2,5	x	
	Guajillo	*Acacia berlandieri*	Medium	10-30	3	3	3,5	x	
	Lantana	*Lantana camara*	Medium	<10	1	0,8	1		
	Lupino	*Lupinus texensis*	Medium	<10	0,4	0,3	0		
	Pastos nativos	*Bouteloua curtipendula, gracilis, dactyloides*	Medium	<10	-	-	-		
	Veintiunilla	*Asclepias curassavica*	Medium	10-30	0,7	0,7	0,6		
From the desert	Biznaga	*Echinocactus, Ferocactus y Melocactus sp.*	Medium	30-80	0,7	0,5	1		
	Gobernadora	*Larrea tridentata*	Medium	10-30	1,5	1,6	1,6	x	
	Lechuguilla	*Agave lecheguilla*	Medium	10-30	0,6	0,8	0,8		
	Maguey cenizo	*Agave americana*	Medium	10-30	1,2	2	2	x	
	Nopal de monte	*Opuntia engelmannii*	Medium	10-30	1,5	1,5	1,5		
	Ocotillo	*Fouquieria splendens*	Medium	10-30	2	1,8	2,5		
	Palma yuca	*Yucca filifera*	Medium	150+	4,5	3,5	4		
	Pitahaya	*Echinocereus enneacanthus*	Medium	10-30	0,4	0,8	1		
	Sotol	*Dasylirion texanum*	Medium	10-30	0,8	1,3	1,3		

Spanish name	Buffer forest	Sponge forest	Cooling forest	Tiny forest	Garden forest	Infrastructure forest	Remediation forest	Forest boulevard	Forest corridor	Sport forest	Valle Alto	Riveras del Río
Ahuehuete o sabino		x			x			x	x		x	
Alamillo	x	x		x	x			x	x		x	
Álamo de río o sicomoro	x	x	x	x	x	x		x	x		x	
Encino de asta					x			x	x			
Encino roble			x		x	x		x	x	x	x	x
Encino siempreverde	x	x	x		x	x		x	x	x	x	x
Nogal de nuez encarcelada	x	x			x			x	x		x	x
Nogal de nuez lisa					x			x	x			
Palma sabal	x				x			x	x			x
Pino blanco					x			x	x			
Pino teocote					x			x	x			
Sauce de río		x			x			x	x		x	
Anacua	x		x	x	x	x	x	x	x	x	x	x
Ébano	x		x	x	x	x		x	x	x		x
Encino blanco			x		x	x		x	x		x	
Encino bravo	x		x		x	x		x	x	x	x	x
Encino duraznillo			x		x	x		x	x		x	
Encino memelito					x	x		x	x		x	
Olmo		x	x		x	x		x	x		x	
Palo blanco	x		x	x	x		x	x	x			x
Anacahuita	x			x	x		x	x	x		x	x
Chaparro prieto	x				x		x	x	x			
Chapote amarillo	x	x	x	x	x		x	x	x	x	x	x
Chapote negro	x			x	x		x	x	x			x
Colorín	x			x	x		x	x	x		x	x
Coma	x				x		x	x	x			
Corona de San Pedro					x			x	x			
Duraznillo				x	x			x	x			
Hierba del potro	x			x	x		x	x	x			x
Huizache	x			x	x		x	x	x			x
Jaboncillo	x	x	x	x	x		x	x	x		x	x
Madroño					x		x	x	x			
Mezquite	x				x	x	x	x	x			x
Mimbre	x			x	x		x	x	x			x
Monilla				x	x		x	x	x		x	
Palo verde	x				x		x	x	x			
Pino piñonero					x		x	x	x			
Retama	x				x		x	x	x			x
Tronadora		x		x	x		x	x	x			
Cenizo	x				x			x	x			x
Dodónea	x				x		x	x	x			x
Granjeno	x				x		x	x	x			x
Guajillo	x				x		x	x	x			x
Lantana					x			x	x			
Lupino					x			x	x			
Pastos nativos					x			x	x			
Veintiunilla					x			x	x			
Biznaga					x			x	x			
Gobernadora	x				x			x	x			x
Lechuguilla					x			x	x			
Maguey cenizo	x				x			x	x			x
Nopal de monte					x			x	x			
Ocotillo					x			x	x			
Palma yuca					x			x	x			x
Pitahaya					x			x	x			
Sotol					x			x	x			

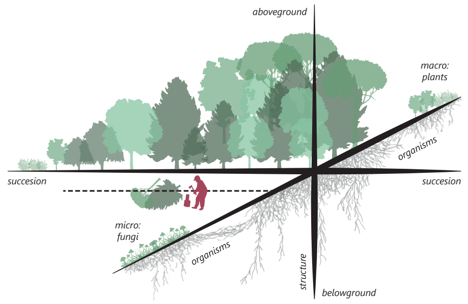
Planting methods

Miyawaki method:
The Miyawaki method involves densely planting a diverse mix of native tree seedlings to establish a mature forest ecosystem quickly. The key steps are:
[1] Seedlings of native tree species that would naturally grow in the area (potential natural vegetation) are planted very densely, at about three seedlings per square meter. The trees are planted randomly, not in rows, to mimic a natural forest (Urban Forests, 2023).
[2] After about three years, the seedlings undergo natural selection as they compete for resources. During this period, the trees most adapted to the local conditions grow rapidly (Urban Forests, 2023).
[3] Within 15-20 years of the initial planting, the fast-growing trees form an early-successional forest with a dense canopy layer, resembling a young version of a mature natural forest (Urban Forests, 2023).

The high density and diversity of trees (image 1), along with the use of native species, allow Miyawaki forests to grow about ten times faster and become 30 times denser compared to conventional plantation forests (Urban Forests, 2023). After the first 2-3 years of weeding and watering, they become self-sustaining and require no further maintenance (Urban Forests, 2023). Miyawaki forests can be created even in small urban spaces, providing a host of ecological benefits like supporting biodiversity, improving air and water quality, reducing temperatures, and sequestering carbon.

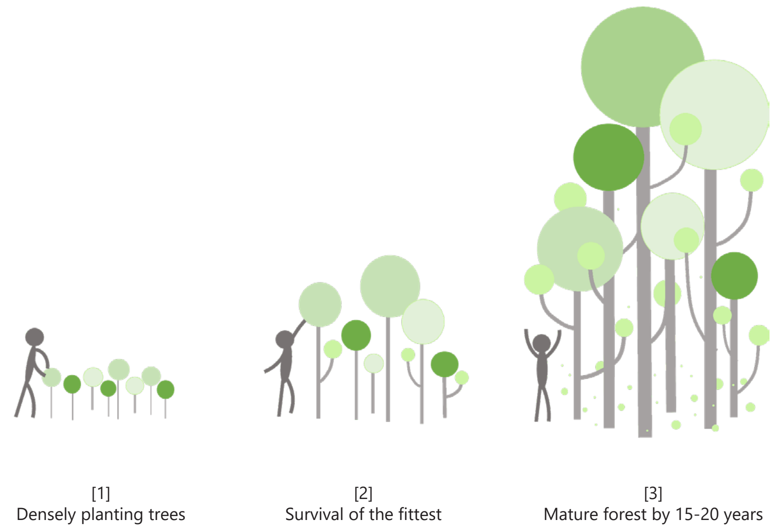
Planting trees in Monterrey step-by-step (Zaragoza, 2009):
[1] Dig a hole as deep as the root ball and three times its width at the desired planting location, and soften and separate the extracted soil.
[2] Moisten the root ball and gently loosen the roots after removing the tree from its container.
[3] Spread the rooting agent in the hole and place the tree in the centre with the top of the root ball level with the ground.
[4] Insert two perforated 1-meter PVC pipes beside the roots and fill them with gravel and water every three days in summer and weekly in winter to help the roots grow.
[5] Fill the hole with the separated soil, putting the bottom soil around the deepest roots first, and compact.
[6] If needed, stabilize a small tree with stakes placed away from the trunk and root ball. Secure the tree to the stakes with hose pieces to avoid damaging the trunk.

[1] Planting diverse species



Adapted from: Graf-Morgen, V. (2016). *Soil stability*. Waldvissen. Accessed on January 14, 2024: https://www.waldwissen.net/en/forest-ecology/protective-function/soil-and-rock-slide/plant-diversity-protects-against-landslides

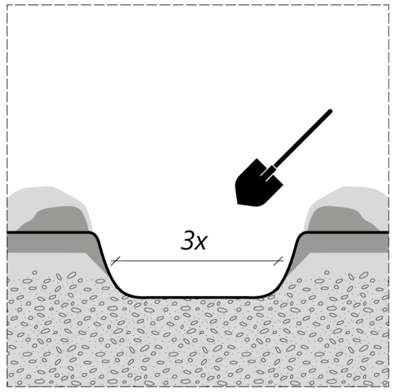
Miyawaki forest planting method



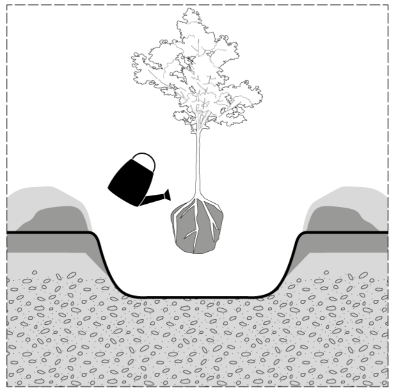
Urban Forests. (2023, November 14). Urban Forests use the Miyawaki method to create native forests. https://urban-forests.com/miyawaki-method/

Planting trees in Monterrey

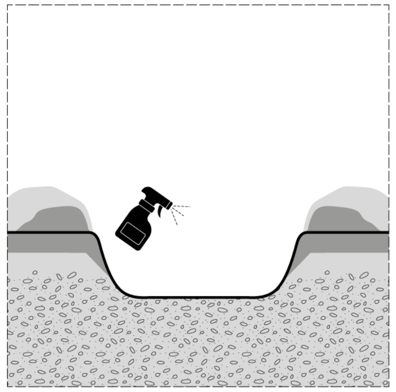
[1] Dig and loosen the soil



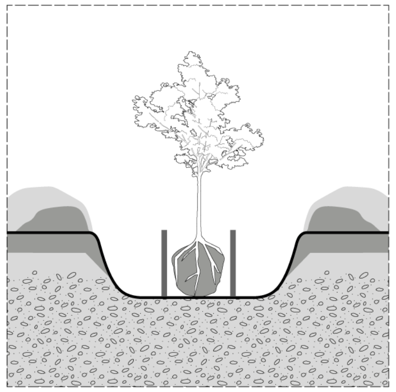
[2] Prepare root ball



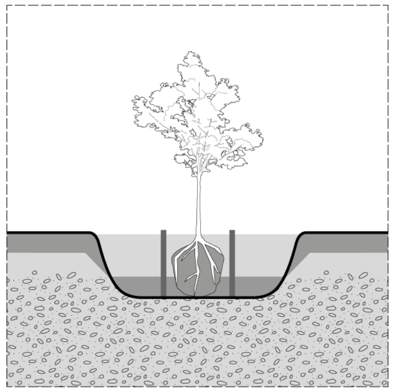
[3] Apply rooting agent



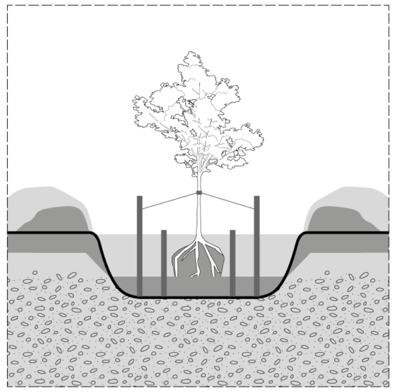
[4] Install watering pipes



[5] Fill and compact the soil



[6] Secure the tree



Redrawn from Zaragoza, O. Z. (2009). *Guía de árboles y otras plantas nativas en la zona Metropolitana de Monterrey*. Fondo Editorial de NL.

Best practices

Africa Wood Grow

The goal of Africa Wood Grow (image 1) is to promote agroforestry practices in Africa that restore degraded land, improve livelihoods, enhance food security, and help mitigate climate change by conserving existing forests, slowing deforestation, and growing new trees (Africa Wood Grow Foundation, 2023).

When a farmer joins the Community-Based Organization, they begin the process of adopting agroforestry on their land:

[1] The farm is fenced using local materials to keep out animals like goats that could damage the trees.
[2] Soil and water conservation measures are implemented, such as digging pits and contour trenches, to prevent erosion and collect rainwater. Example farms have utilities installed for water and power access.
[3] Tree planting occurs just prior to the rainy season in November.
[4] The trees are closely monitored, and any that do not survive are replaced before the short April rains.

Once established, the trees are pruned to maintain their health and allow more light to reach crops growing underneath. The pruned branches provide firewood, reducing the need to cut other local trees. As a result, the rate of tree cutting in the area has declined in recent years (Africa Wood Grow Foundation, 2023).

Metropolitan forest Madrid

The Madrid Metropolitan Forest (image 2) is an ambitious project that aims to create a 75-kilometre green belt around the city, connecting existing parks and green spaces with newly forested areas (Romero-Muñoz et al., 2023). The Metropolitan Forest will provide recreational opportunities for citizens, such as pedestrian and cycling paths, children's playgrounds, and sports facilities. By creating a mosaic of different forests and ecosystems, the forest will promote a more sustainable and livable urban environment for Madrid's residents (Ayuntamiento de Madrid, 2023).

Other practices

In addition, Valencia will develop three new forest resource management plans (image 3) in the regions of Castellón, Valencia, and Alicante, which will involve the sustainable management and conservation of over 25,000 hectares of forest land (Vielca, 2023). Furthermore, there is a green belt project in the arid city of Hermosillo, Mexico, which aims to improve urban sustainability and resilience through soil reconditioning, stormwater management, and landscape design (Zuniga-Teran et al., 2022).

[1] Africa Wood Grow

Africa Wood Grow Foundation. (2020, June 13). *Media - Africa Wood Grow*. Africa Wood Grow. Retrieved May 21, 2024, from https://africawoodgrow.com/media/

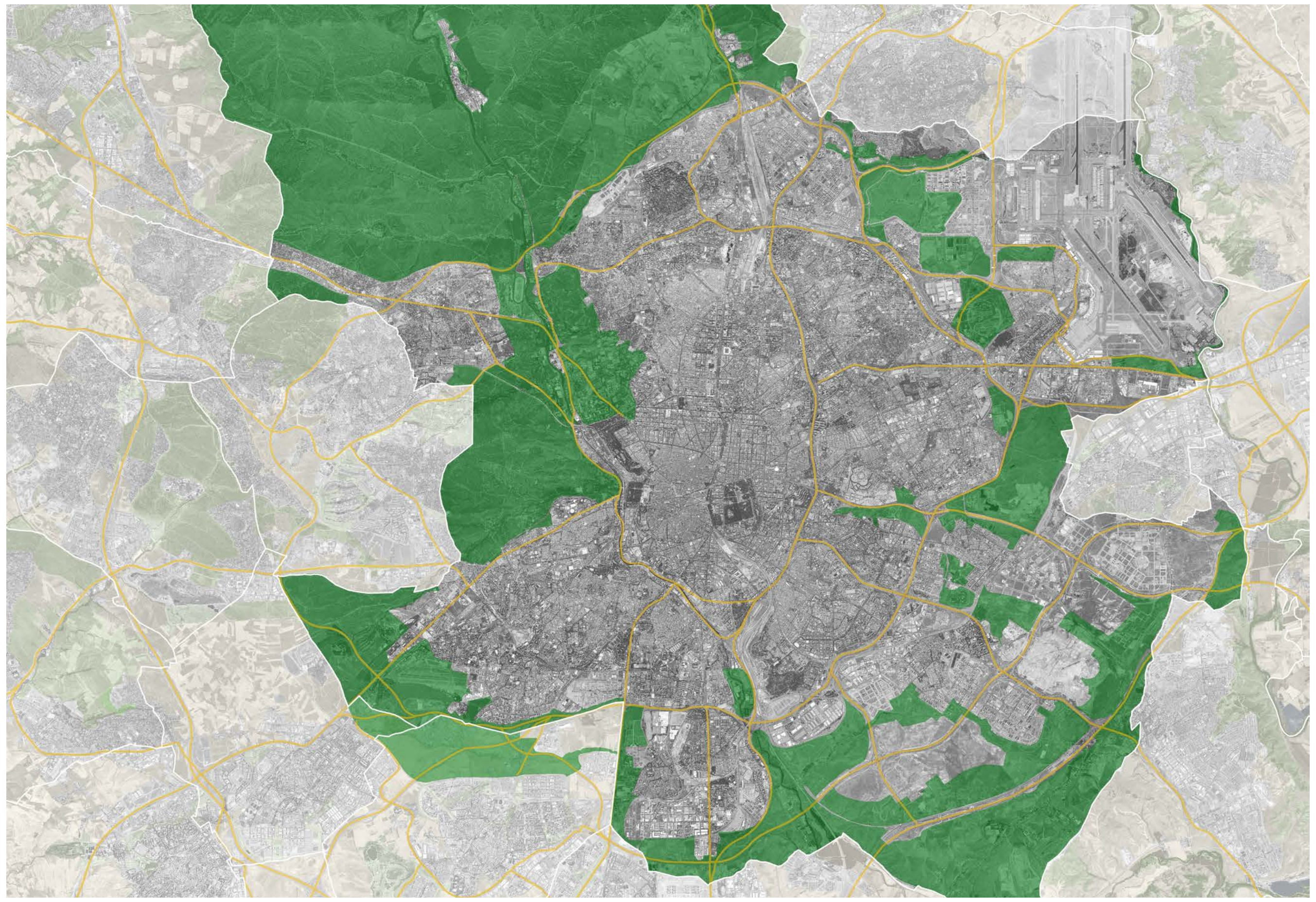
[2] Planting trees in Madrid

Ayuntamiento de Madrid. (2023). Bosque Metropolitano. *Bosque Metropolitano Madrid*. Retrieved May 21, 2024, from https://bosquemetropolitano.madrid.es/

[3] Forestry plan of the Valencian Community

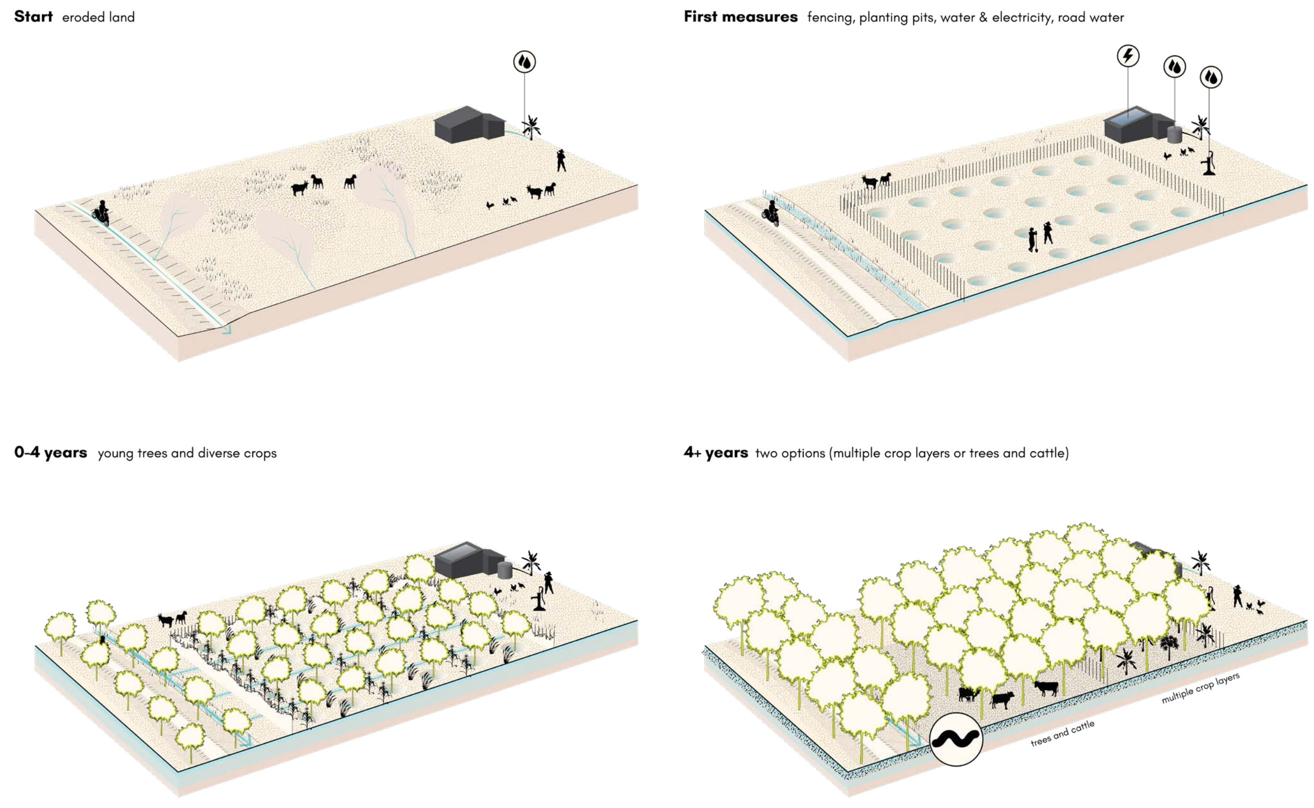
Vielca. (2023, April 21). *Three new forest resource management plans awarded*. Vielca Ingenieros. Retrieved May 21, 2024, from https://www.vielca.com/en/sin-categorizar/three-new-forest-resource-management-plans-awarded

Metropolitan forest Madrid



Ayuntamiento de Madrid. (2023). Bosque Metropolitano. *Bosque Metropolitano Madrid*. Retrieved May 21, 2024, from https://bosquemetropolitano.madrid.es/

Africa Wood Grow agroforestry farms



Africa Wood Grow Foundation. (2023, July 21). *How we work - Africa Wood Grow*. Africa Wood Grow. https://africawoodgrow.org/how-we-work/

Own photograph.

6. Design proposal

6.1 Valle alto

Valle Alto is an affluent suburb located in the south-eastern part of Monterrey. It is known for its upscale residential neighbourhoods, gated communities, and country clubs, attracting many wealthy families and professionals. The area has beautiful natural surroundings, including the iconic "Cerro de la Silla" mountain. Valle Alto is home to the "Parque Natural La Estanzuela", a popular outdoor recreation area with hiking trails, streams, and waterfalls. Moreover, it has Río la Silla natural park. It also hosts the "Club de Golf Valle Alto", a prestigious private golf club. The suburb has strict design restrictions and landscaped streets, contributing to its exclusive and well-maintained character.

This location is chosen because it lies between two nature reserves, "Parque National Cumbres de Monterrey" and "Monumento Natural Cerro de la Silla". This suggests that these reserves were likely connected in the past. Urbanization was introduced together with the "México 85" highway that now separates the area. Restoring the forest here could potentially reconnect these nature reserves.

Existing situation

Main urban and landscape typologies

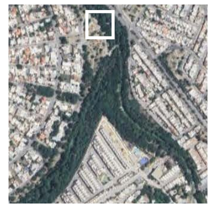

[1]
Formal community


[2]
Informal community


[3]
Gated community

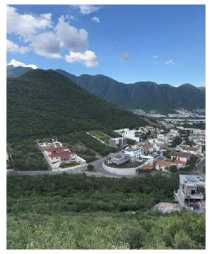

[7]
Public services and industry


[F]
Water system


[G]
Urban vegetation


Plaza de Santo Domingo


Santa Anita street


Community Rincon de las Aves around a hill


Gated forest


River that leads to Chipinque


Río la Silla natural park

Google Maps. (2023, June). *22 C. Pl. de Santo Domingo* [Street view]. Retrieved January, 30, 2024. Google Maps. https://maps.app.goo.gl/dX9ebMXSakmzxPU48

Google Maps (2022, December). *1515 Sta. Anita* [Street view]. Retrieved January, 30, 2024. Google Maps. https://maps.app.goo.gl/D3xPyqN8NwAPMqdg8

Villa Roa, L. (2019, July). *Rincon de las Aves* [Street view]. Retrieved January, 30, 2024. Google Maps. https://maps.app.goo.gl/GnggZznwvpgtHa8Q9

Google Maps. (2021, June). *5517 Loma de Los Pinos* [Street view]. Retrieved April, 3, 2024. Google Maps. https://maps.app.goo.gl/Q4sNzr83jRLwxnb1A

De Loss, S. (2021, April). *Cañada del Pinal*. Wikiloc: Trails of the World. https://www.wikiloc.com/hiking-trails/canada-del-pinal-70378625/photo-46333612

Dávila, A. (2017, March). *Río la Silla natural park* [Street view]. Retrieved January, 30, 2024. Google Maps. https://maps.app.goo.gl/JANap6BGRenvPEE37

Site conditions

This matrix illustrates the site conditions of the main typologies of Valle Alto. The matrix is created to provide an overview of the differences in the landscape layers. What strikes the most are the large flood and landslide zones together with the forest cover loss. This shows that the system is weakening. However, there remains potential to restore the former forest ecological connectivity because the biodiversity intactness is still visible and the forest carbon removals as well. These indicators suggest the possibilities for establishing a new forest network.

Height lines

- Height lines (interval 5m)

Vegetation

- Shrubland
- Urban vegetation
- Grassland
- Cropland

Soil

- Phaeozem
- Fluvisol
- Luvisol
- Leptosol
- Regosol

Watersystem

- Primary waterways
- Flood zones
- Landslide zones

Tree cover in 2000

- High
- Low

Forest cover loss 2000-2020

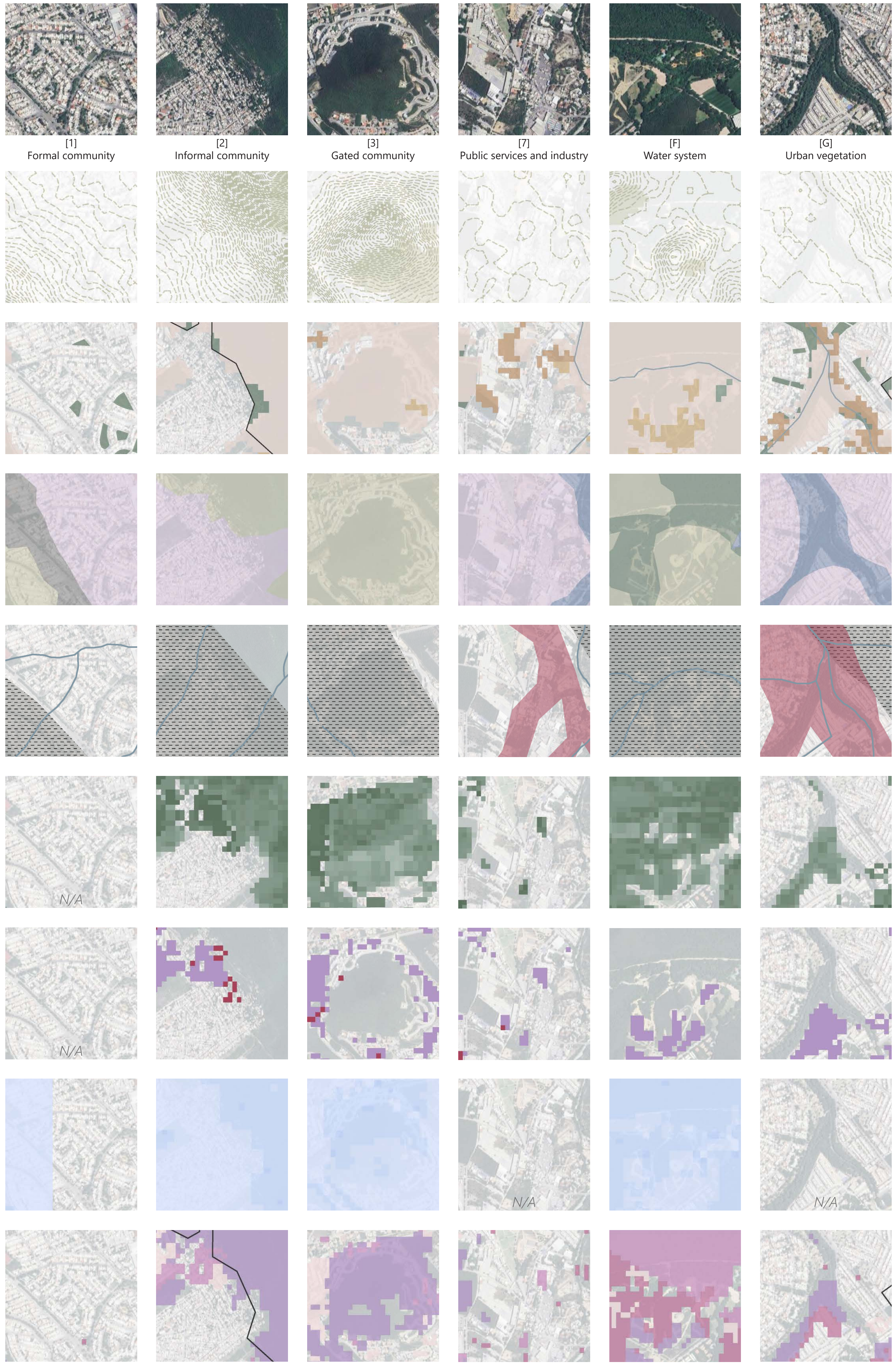
- Due to wildfire
- Due to non-fire drivers (urbanisation)

Biodiversity intactness

- High
- Low

Forest carbon removal

- High
- Low



Soil types

In Valle Alto, there are numerous soil types.

[1] Leptosols
Leptosols are very shallow soils with minimal development, formed typically on hard rock or highly calcareous materials (Brandt, 2015). They are the most extensive soil group in Mexico, covering a third of the country (SEMARNAT, 2008). Leptosols are found in all climatic regions and altitudes, particularly in mountainous and highly eroded areas. Their agricultural potential is limited mainly to forestry due to the shallow depth and inability to hold water (Brandt, 2015).

[2] Phaeozems
Phaeozems are dark soils with high organic matter content that form from unconsolidated sediments like loess under temperate and humid climates with tall grasslands or forests. Phaeozems have high agricultural potential for growing grains and vegetables when there is adequate moisture, but can be prone to erosion (SEMARNAT, 2008).

[3] Luvisols
Luvisols form in well-drained sites under forest vegetation and sub-humid to humid climates. Luvisols are considered fertile soils and are widely used for agriculture, including wheat, soy bean and cotton production (Krizic, n.d.).

[4] Fluvisols
Fluvisols are genetically young soils. Fluvisols occupy river valleys and deltas like the alluvial plains in Monterrey (SEMARNAT, 2008). Many dryland crops are grown on fluvisols, often with some form of water control (The Editors of Encyclopaedia Britannica, 2000).

[5] Regosols
Regosols are poorly developed soils derived from unconsolidated materials (Krizic, n.d.). Regosols are found stretching across the Western and Southern Sierra Madre (SEMARNAT, 2008). Regosols can form crusts and limit plant growth and water infiltration, making them vulnerable to erosion when vegetation is cleared.

In summary, Valle Alto contains a diversity of soil types, with leptosols in the surrounding mountains, phaeozems and luvisols in areas with grassland and forest, fluvisols in the river valleys, and regosols in parts of the Sierra Madre. The varied topography and climatic conditions of the region contribute to this range of soil characteristics.

[1] Soil types

Softer soil types
Rocky soil types

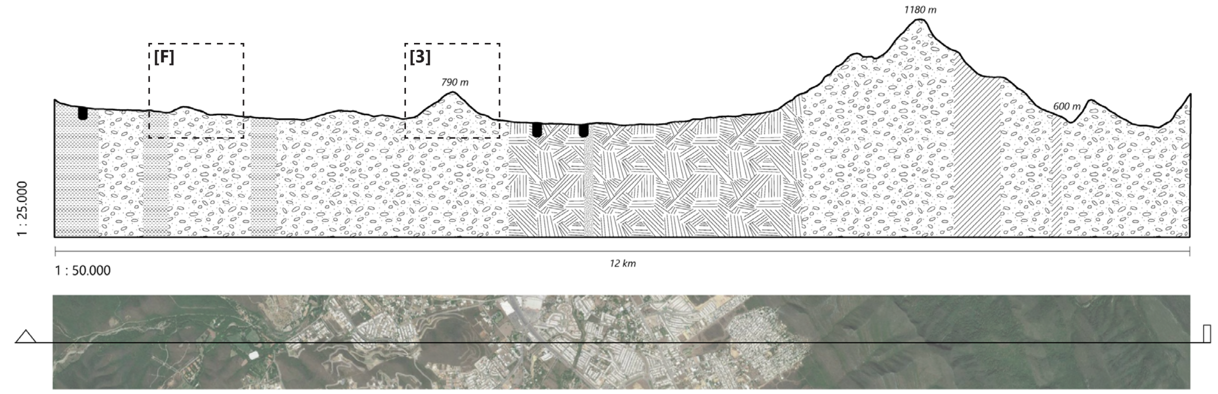
Soils with limitations to root growth
Leptosol *(thin or with many coarse fragments)*

Pronounced accumulation of organic matter in the mineral topsoil
Phaeozem *(dark topsoil, no secondary carbonates (unless very deep), high base status)*

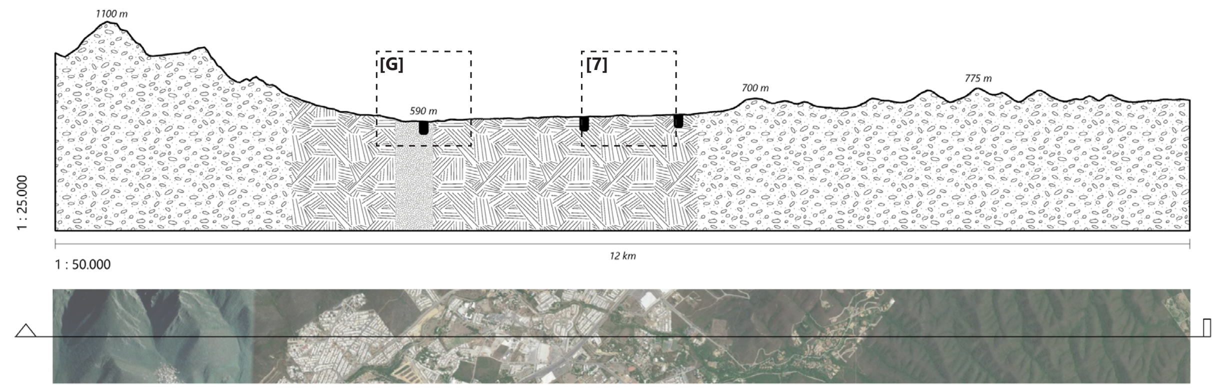
Soils with clay-enriched subsoil
Luvisol *(high-activity clays, exchangeable base cations)*

Soils with little or no profile differentiation
Fluvisol *(stratified fluviatile, marine or lacustrine sediments)*
Regosol *(no significant profile development)*

Soil sections

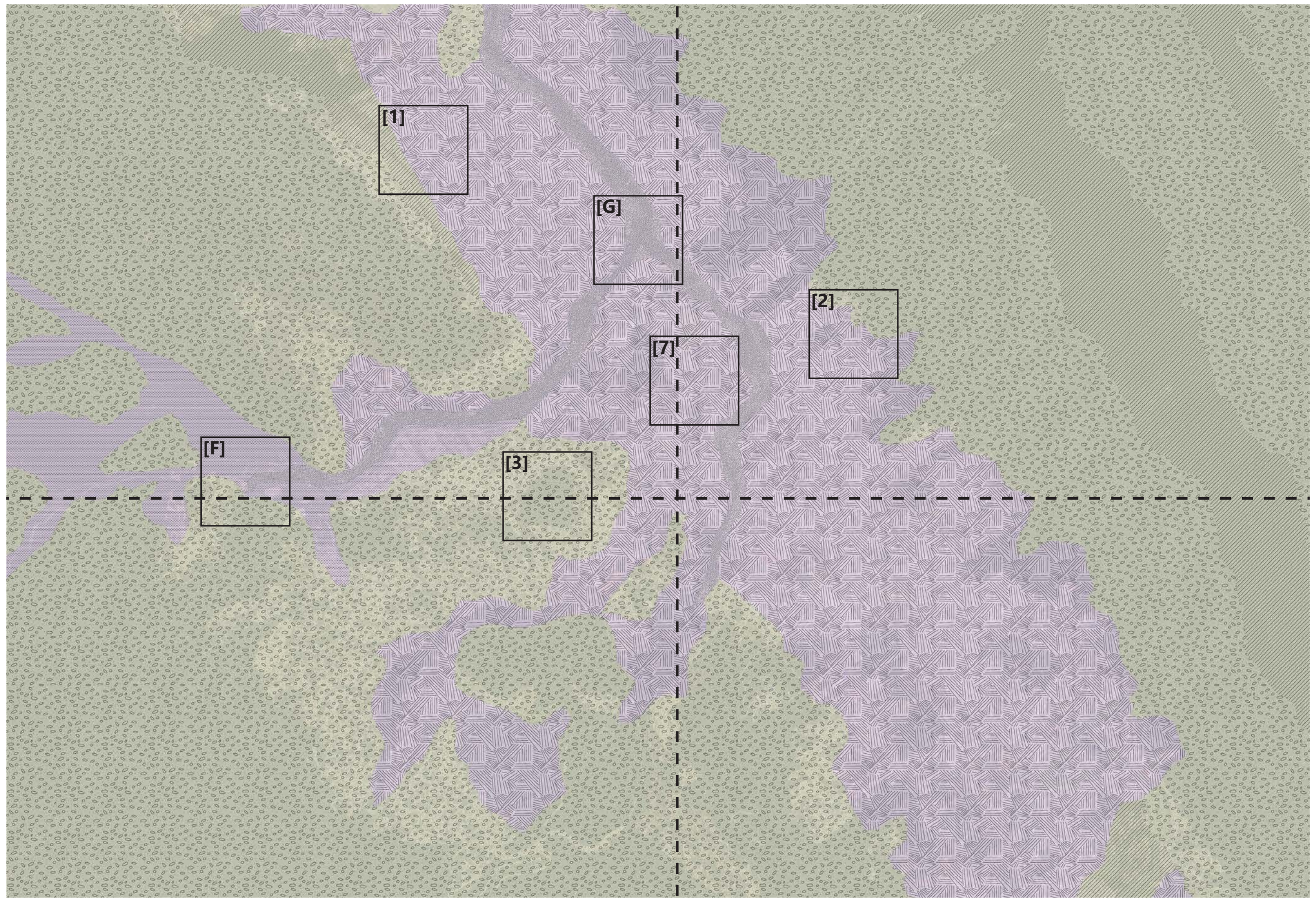


Transverse



Longitudinal

Soil types

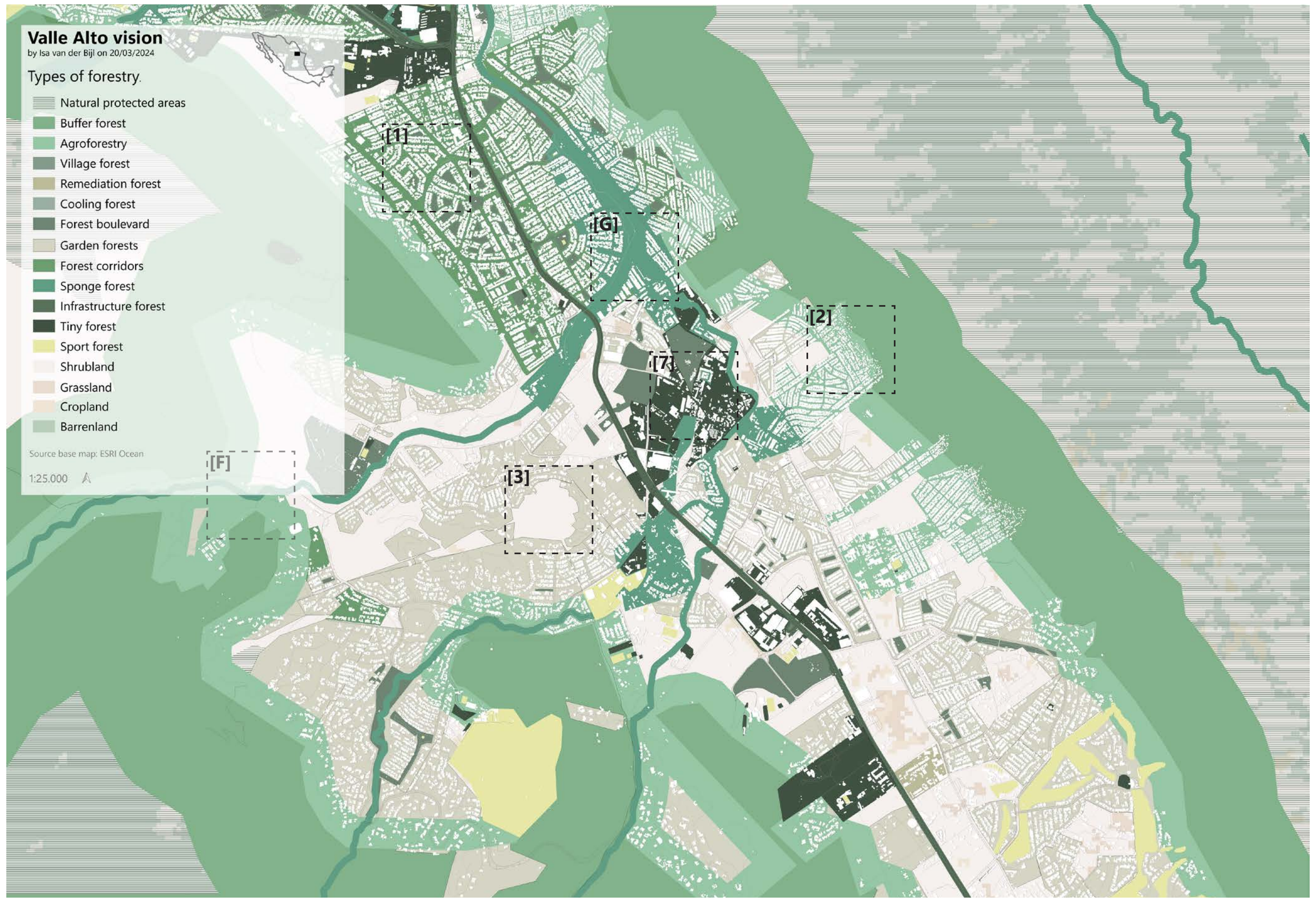


Forestry vision

In order to propose a forestry vision for Valle Alto, a selection of forest types has been made based on the existing urban context and landscape. For example, the formal communities will be extended with forest corridors, the gated communities will have garden forests, and the nature reserves will be protected by buffer forests and agroforestry. This approach aims to create an ecological continuum and a sensitive new green network, also connecting to the green belt surrounding the city. For the detailed design, the area currently occupied by public services and industry (location 7) has been identified to show what a tiny forest could look like.

This forestry vision is meant to show the possibilities over time. In order to create a forest network systemically and with care, the miyawaki method is going to be used. Seedlings of native trees that would naturally grow in the area are planted densely, and after three years the trees most adapted to the local conditions will grow rapidly (Urban Forests, 2023). After 15-20 years a mature natural forest will be flourishing in Valle Alto.

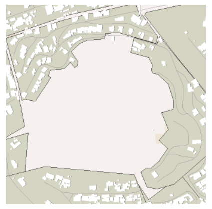
Valle Alto vision



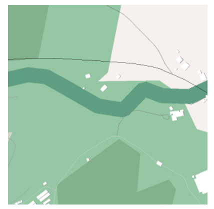
Valle Alto forest types


[1]
Formal community

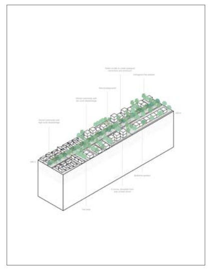

[2]
Informal community

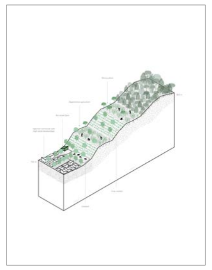

[3]
Gated community

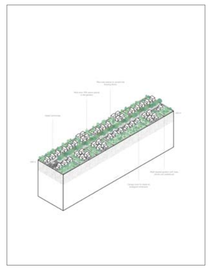

[7]
Public services and industry

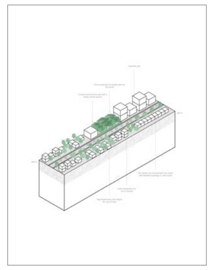

[F]
Water system

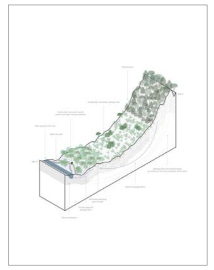

[G]
Urban vegetation

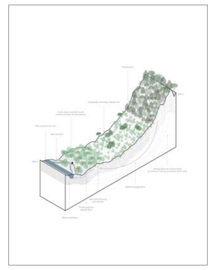

Forest corridor


Agroforestry


Garden forest


Tiny forest


Sponge forest


Sponge forest

Tiny forest

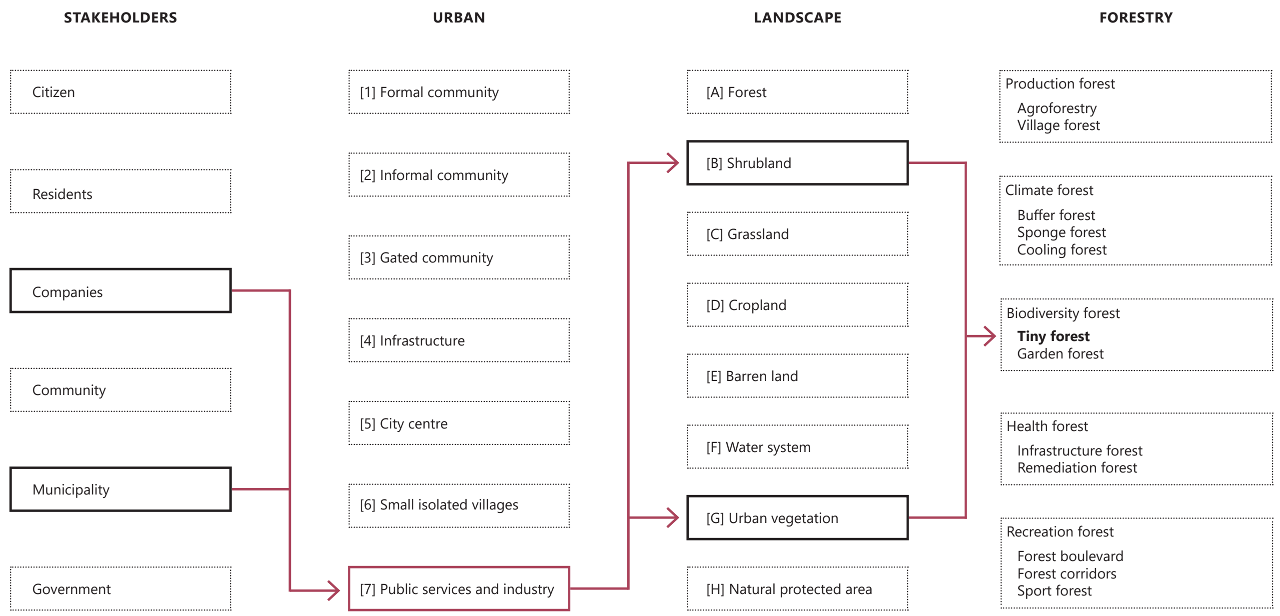
This zoom-in location in Valle Alto includes Gayosso cemetery [1], Monterrey Mexico Temple [2], Gated forests [3] (image 1), Río la Silla natural park [4], and on the border, the nature reserve Cerro de la Silla [5].

In order to create an ecological continuum, the plan proposes transforming vacant lots and industrial areas into tiny forests [1]. To extend the Río de Silla riverpark, more riverbed vegetation will be planted [2] as a sponge forest. Moreover, the México 85 highway will become an infrastructure forest [3]. Lastly, to create a better transition and protect the nature reserve Cerro de la Silla, agroforestry and buffer forests will be introduced. This approach aims to enhance biodiversity, manage water flows, and improve the quality of life for residents by bringing nature into the region.

[1] Gated private forest (location 7)

Google Maps. (2021, June). *5517 Loma de Los Pinos* [Street view]. Retrieved April, 3, 2024. Google Maps. https://maps.app.goo.gl/Q4sNzr83jRLwxnb1A

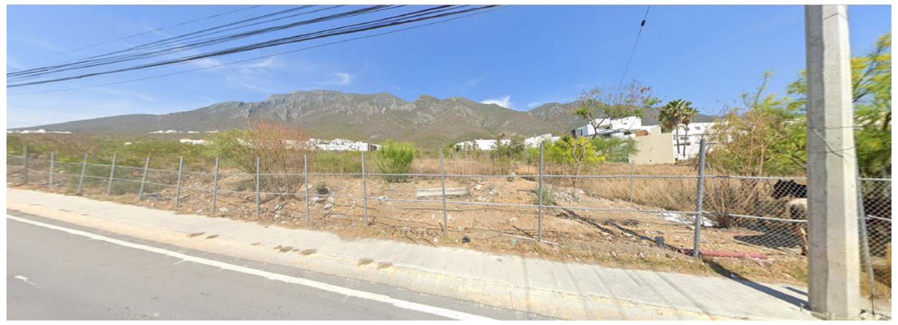
Design strategy

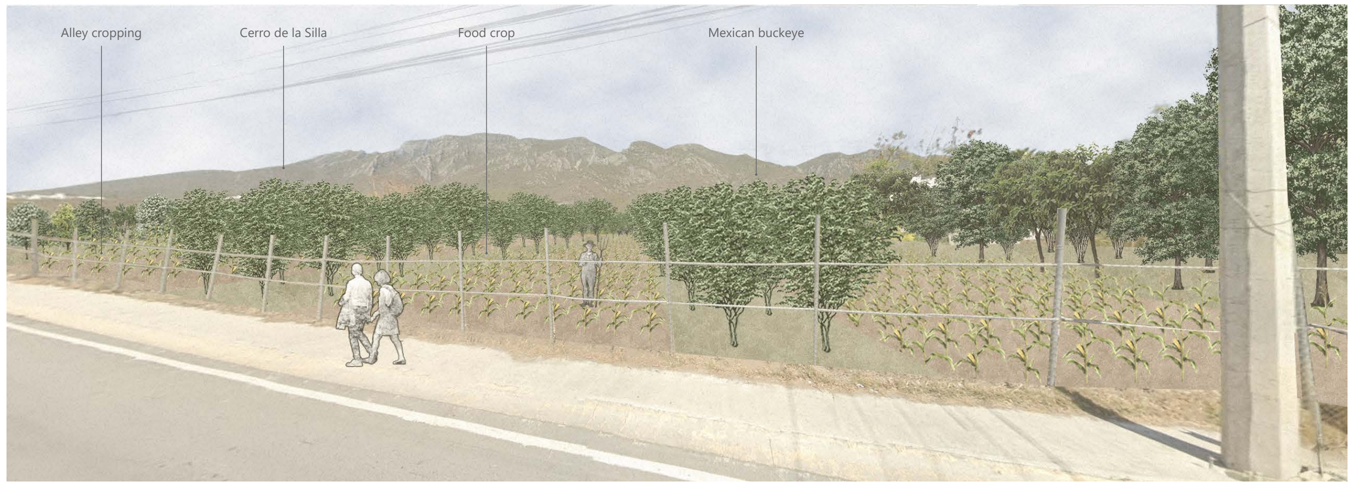


Existing situation

Forestry vision

Agroforestry with alley cropping and food production

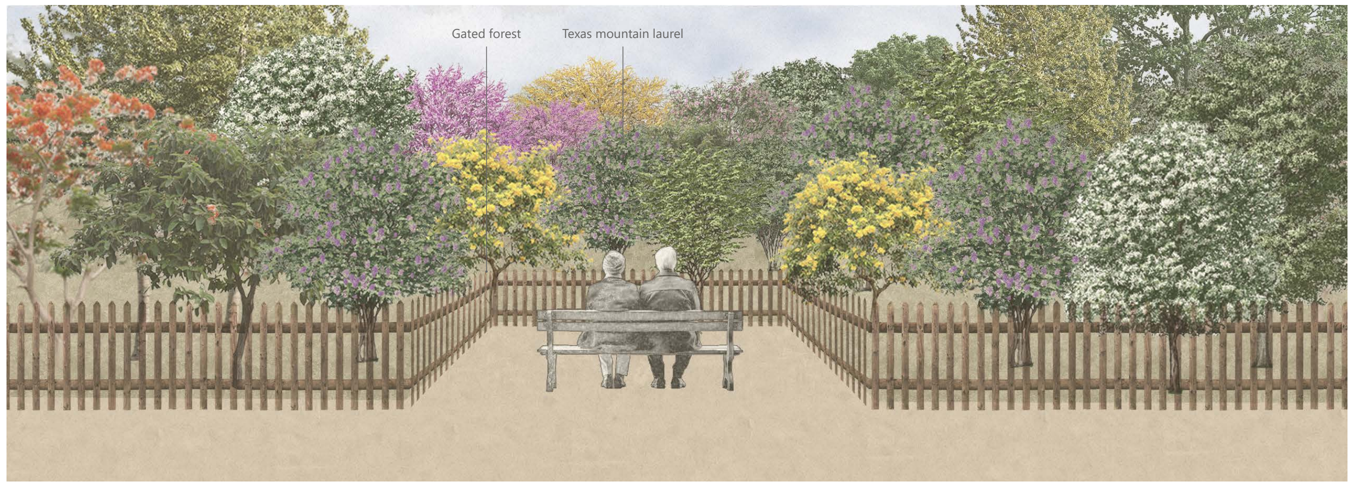




Google Maps. (2023, March). *Eje Metropolitano 31* [Street view]. Google Maps. https://maps.app.goo.gl/c3A3VQRRQMhtNxjq7

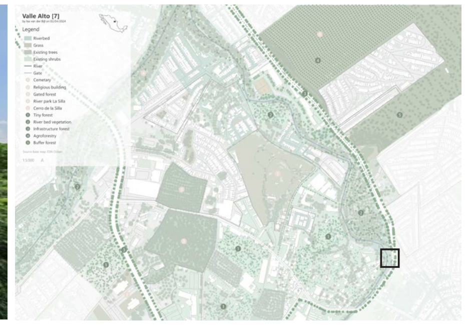
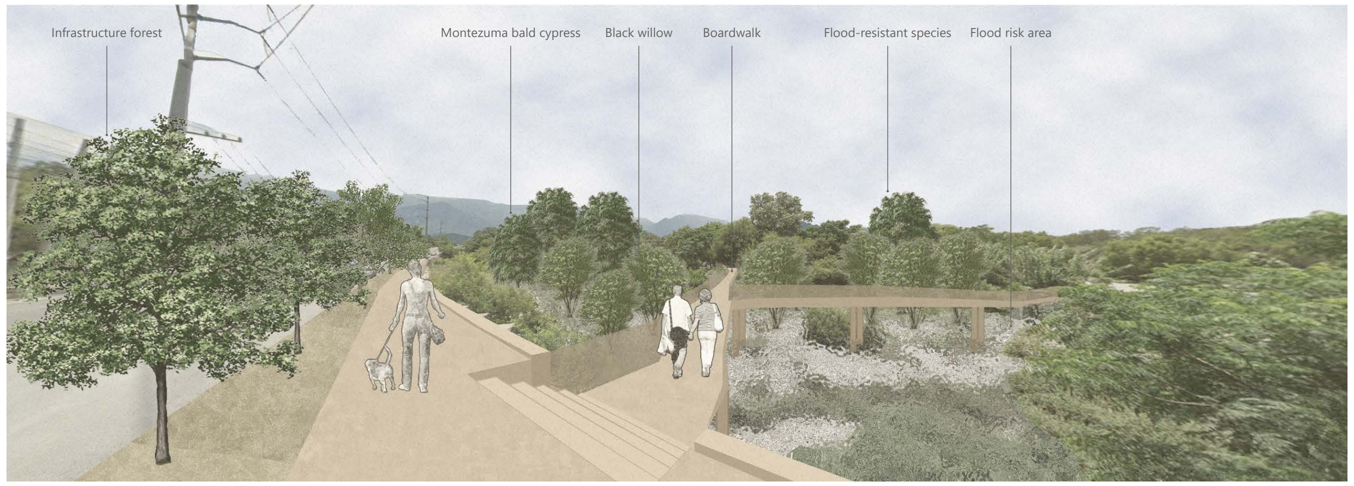
Tiny forest with high biodiversity and benches to educate about nature





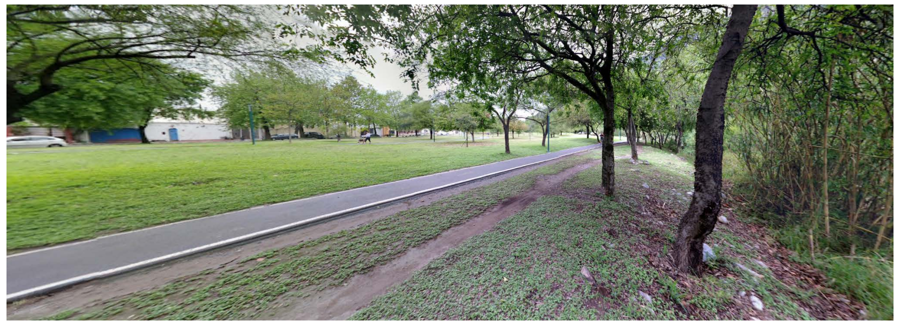
Google Maps. (2017, August). *Monterrey, Nuevo Leon* [Street view]. Google Maps. https://maps.app.goo.gl/esaCGL98YgbcXZRg6

Sponge forest with boardwalk and flood resistant species

Google Maps. (2023, June). *Eje Metropolitano 31* [Street view]. Google Maps. https://maps.app.goo.gl/7fzTHahihe38YGRs7

Sport forest to strengthen the existing park

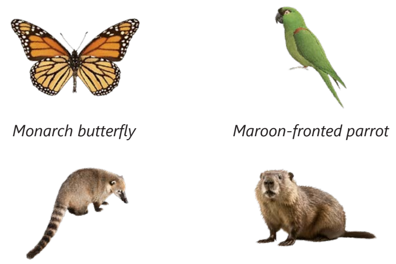


Dávila, A. (2017, March). *Río la Silla natural park* [Street view]. Google Maps. https://maps.app.goo.gl/wErpp9CLRjPR9TpCA

Design interventions

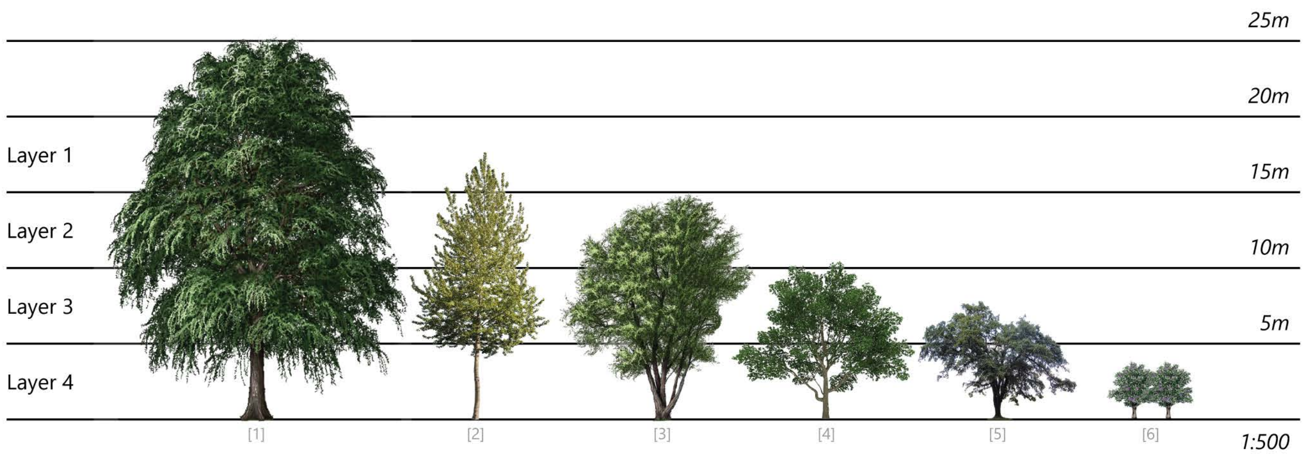
The design interventions in Valle Alto include flood-resistant tree species like Montezuma bald cypress *(Taxodium mucronatum [1])* and Black willow *(Salix nigra [3])*. The key animal species in the Valle Alto area are the Monarch butterfly, Maroon-fronted parrot, White-nosed coati, and the North American beaver. In the cross-section, the transformation from industry lots to tiny forests can be seen, and in the detailed section, the recreational boardwalk in the sponge forest is shown.

[1] Key fauna species



Monarch butterfly · *Maroon-fronted parrot*
White-nosed coati · *North American beaver*

Valle Alto species



Layer 1

Taxodium mucronatum [1]
Platanus occidentalis mexicana
Populus tremuloides [2]

Layer 2

Junglas mollis
Salix nigra [3]
Quercus polymorpha

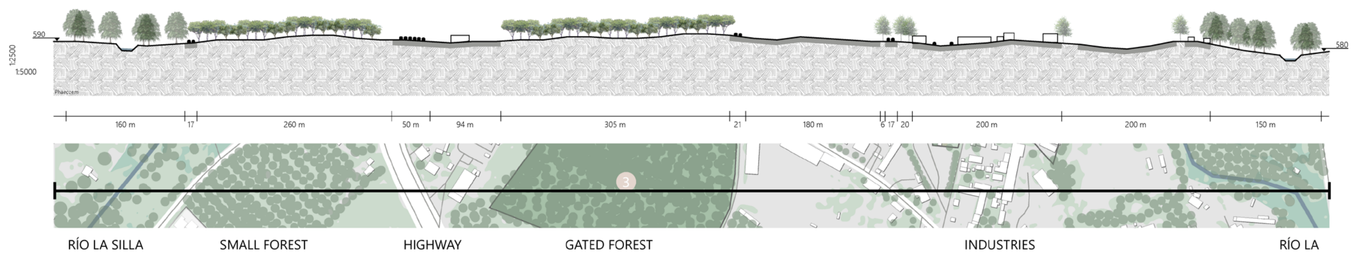
Layer 3

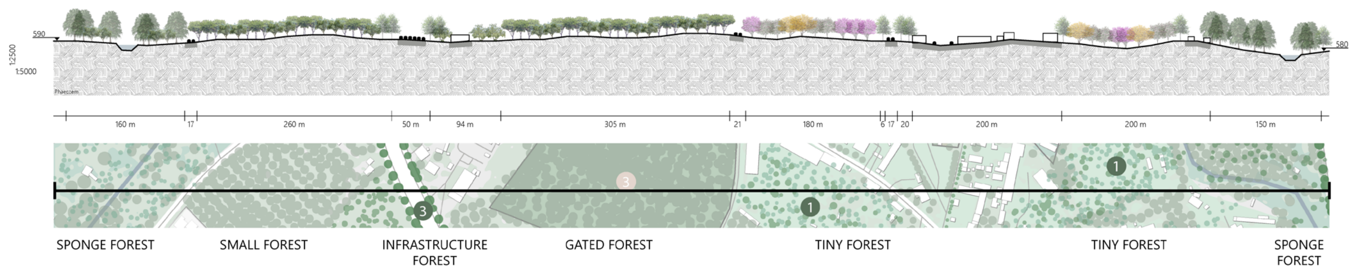
Quercus virginiana [4]
Quercus canbyi
Quercus laceyi
Quercus graciliformis
Quercus fusiformis
Ulmus crassifolia [5]
Ehretia anacua
Sapindus saponaria
Sargentia greggii

Layer 4

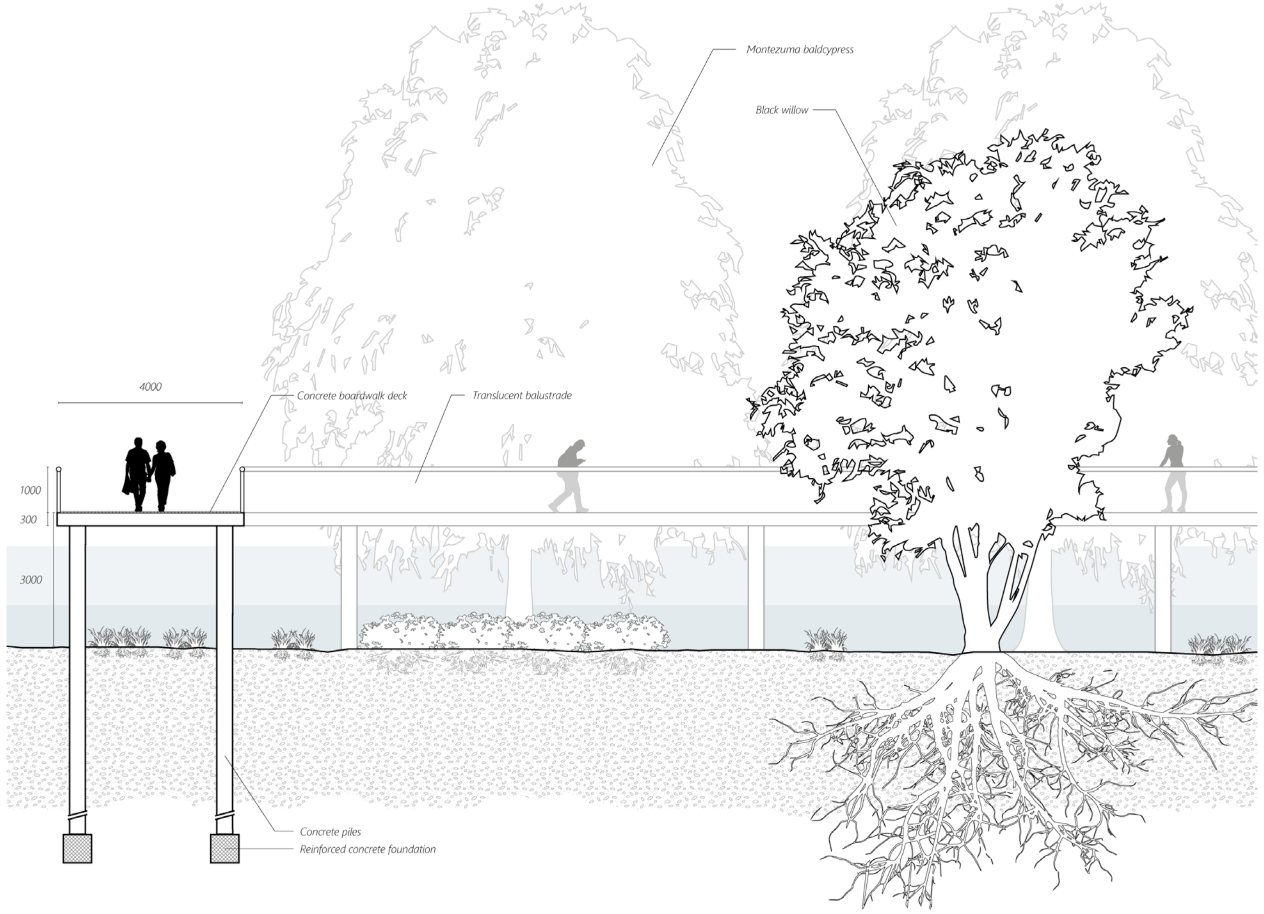
Cordia boissieri
Diospyros texana
Ungnadia speciosa
Sophora secundiflora [7]

Valle Alto tiny forest section





Sponge forest boardwalk section



6.2 Riveras del Río

Riveras del Río, in the north-western part of Monterrey, is a densely built neighbourhood with a high degree of social disadvantage. The area is built next to state nature reserve “Cerro del Topo”, or “Topo Chico”. Río Pesquería, one of the most polluted rivers in the region, flows through the area and also hosts informal settlements on the borders of the river. The neighbourhood is close to San Bernabé, one of the poorest areas in the city.

Riveras del Río is chosen because it is indicative of the steppe climate requiring additional resources for natural forest growth. This location will demonstrate how a forest can be established in regions needing more effort, showcasing what it entails, its possible appearance, and its potential benefits.

Existing situation

Main urban and landscape typologies

[1]
Formal community

[2]
Informal community

[4]
Infrastructure

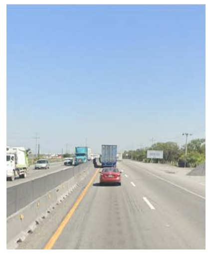
[6]
Isolated urban sprawl

[G]
Urban vegetation

[H]
Natural protected area

Parque del Prado 1

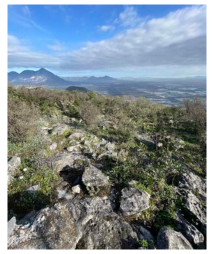
Colonia Croc



México 40 highway

Agropecuaria del Norte Lázaro Cárdenas

Plain field



Topo Chico

Google Maps. (2022, August). *314 Llanura Blanca* [Street view]. Retrieved April, 3, 2024. Google Maps. https://maps.app.goo.gl/SgZALPJVXotzg6Gr6

Google Maps (2022, August). *1069 C. Artículo 123* [Street view]. Retrieved April, 3, 2024. Google Maps. https://maps.app.goo.gl/bQSZUXzVRYyS4Y3u8

Google Maps (2022, October). *México 40* [Street view]. Retrieved April, 3, 2024. Google Maps. https://maps.app.goo.gl/zHFifevEQUqZSjFNA

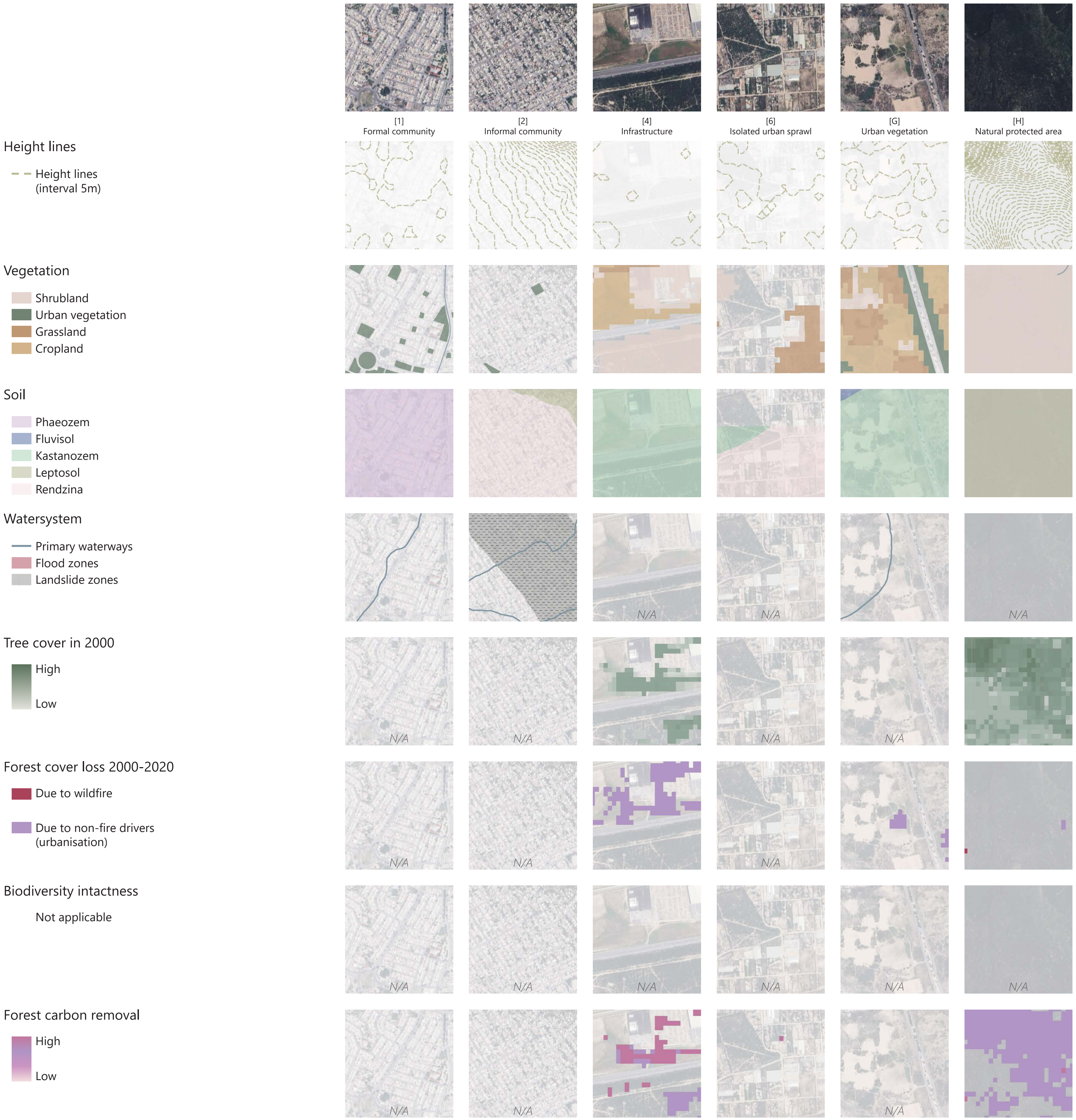
Google Maps. (2019, July). *Chinameca* [Street view]. Retrieved April, 3, 2024. Google Maps. https://maps.app.goo.gl/xnNyfN329DHgL7LBA

Google Maps. (2022, September). *Av. Luis Donaldo Colosio Murrieta 2765* [Street view]. Retrieved April, 3, 2024. Google Maps. https://maps.app.goo.gl/oxKniK7FXArm7ShU8

Cheke 58. (2024, February). *Topochico subiendo por segundo cañon croc*. Wikiloc: Trails of the World. https://www.wikiloc.com/hiking-trails/topochico-subiendo-por-segundo-canon-croc-162179133/photo-101573459

Site conditions

This matrix illustrates the site conditions of the main typologies of Riveras del Río, providing an overview of the differences in the landscape layers. Compared to Valle Alto, the landscape in Riveras del Río is less intact (marked as N/A) and falls within the red zone on the value map. Only certain parts of this area contain valuable greenery, such as the shrublands in the urban vegetation and the natural protected areas. The majority of the area consists of urban and concrete spaces, some of which are polluted. However, there remains potential to create a new forest network extending from the natural protected area into the city, as there is open space and fertile soil suitable for plant and forest growth.



Soil types

Numerous soil types exist in Riveras del Río, including leptosols, phaeozems, and fluvisols, which are also present in Valle Alto. In addition, there are kastanozems and rendzinas.

[1] Kastanozem

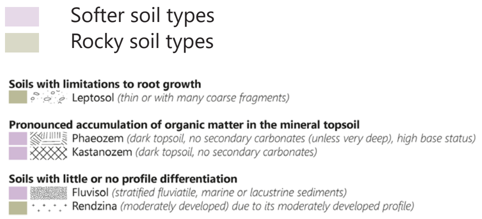
Kastanozem is characterized by a dark, humus-rich surface horizon and accumulation of calcium carbonate in the subsoil. Kastanozems form under relatively dry climates with steppe-like vegetation (Bautista & Aguilera, 2023). Kastanozems are generally fertile soils suitable for agriculture when there is sufficient moisture, but in Monterrey, their distribution is limited, and they are primarily found under natural vegetation (Bautista & Aguilera, 2023).

[2] Rendzina

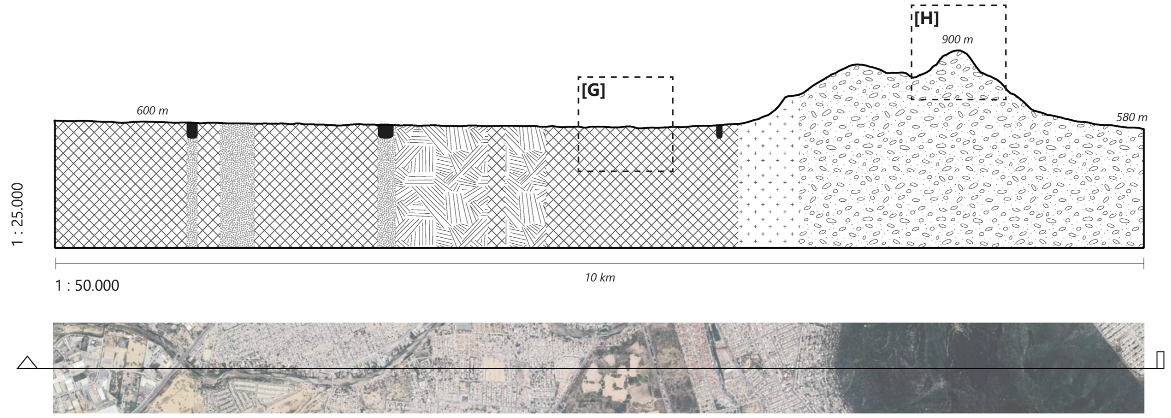
Rendzina soils are found in parts of the Monterrey metropolitan area and surrounding mountains in northeastern Mexico. These shallow, dark-coloured soils form from the weathering of carbonate-rich parent materials like limestone, which is abundant in the Sierra Madre Oriental mountain range near Monterrey (SEMARNAT, 2008). Rendzina soils in the Monterrey area often support natural vegetation rather than crops.

In short, Riveras del Río has leptosols in the Topo Chico mountain and mainly kastanozem in the rest of the neighbourhood.

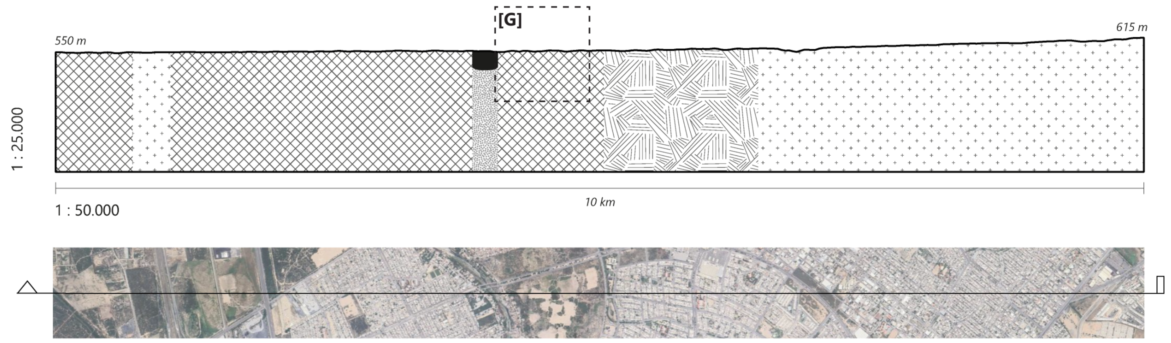
Soil types



Soil sections

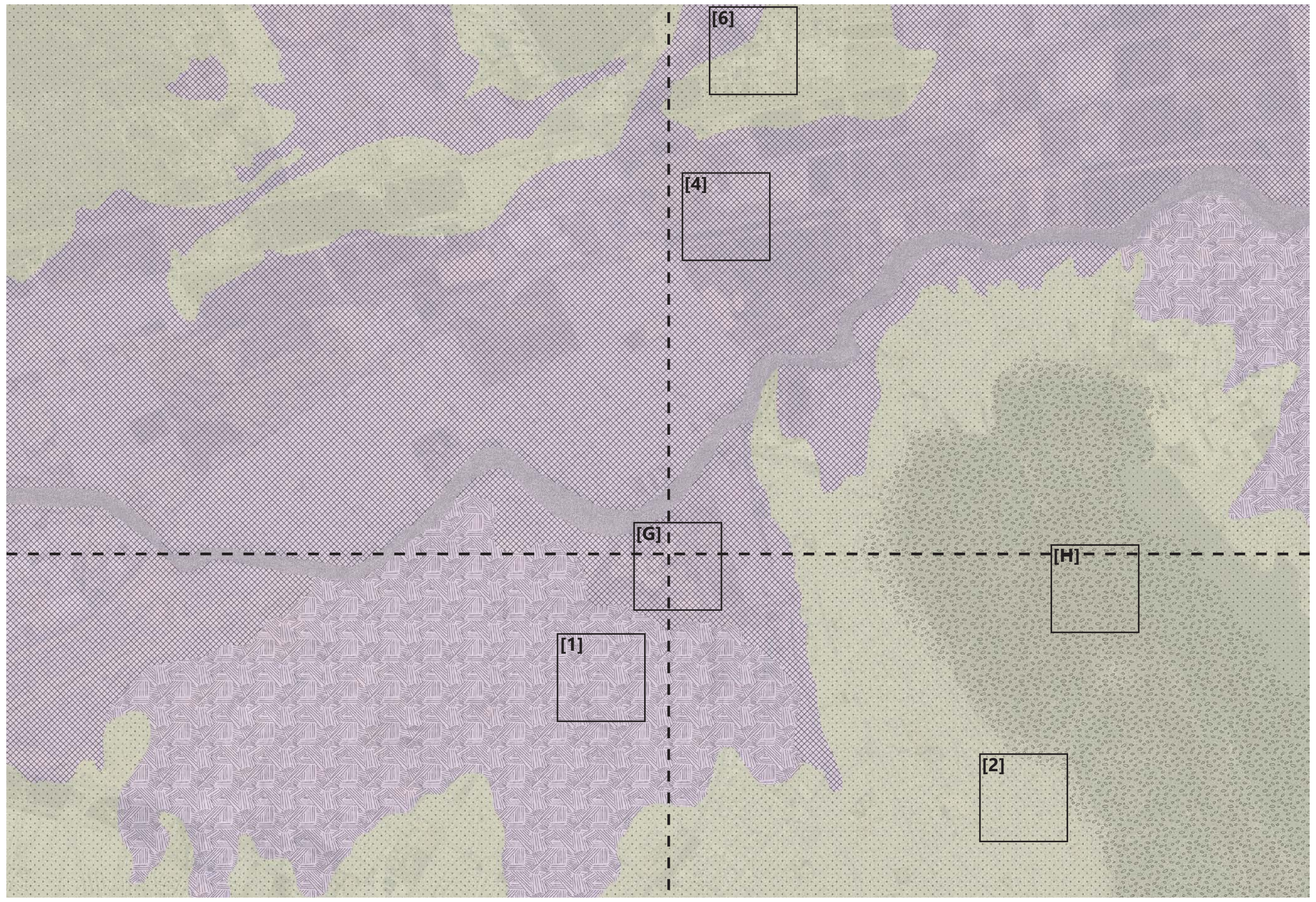


Transverse



Longitudinal

Soil types

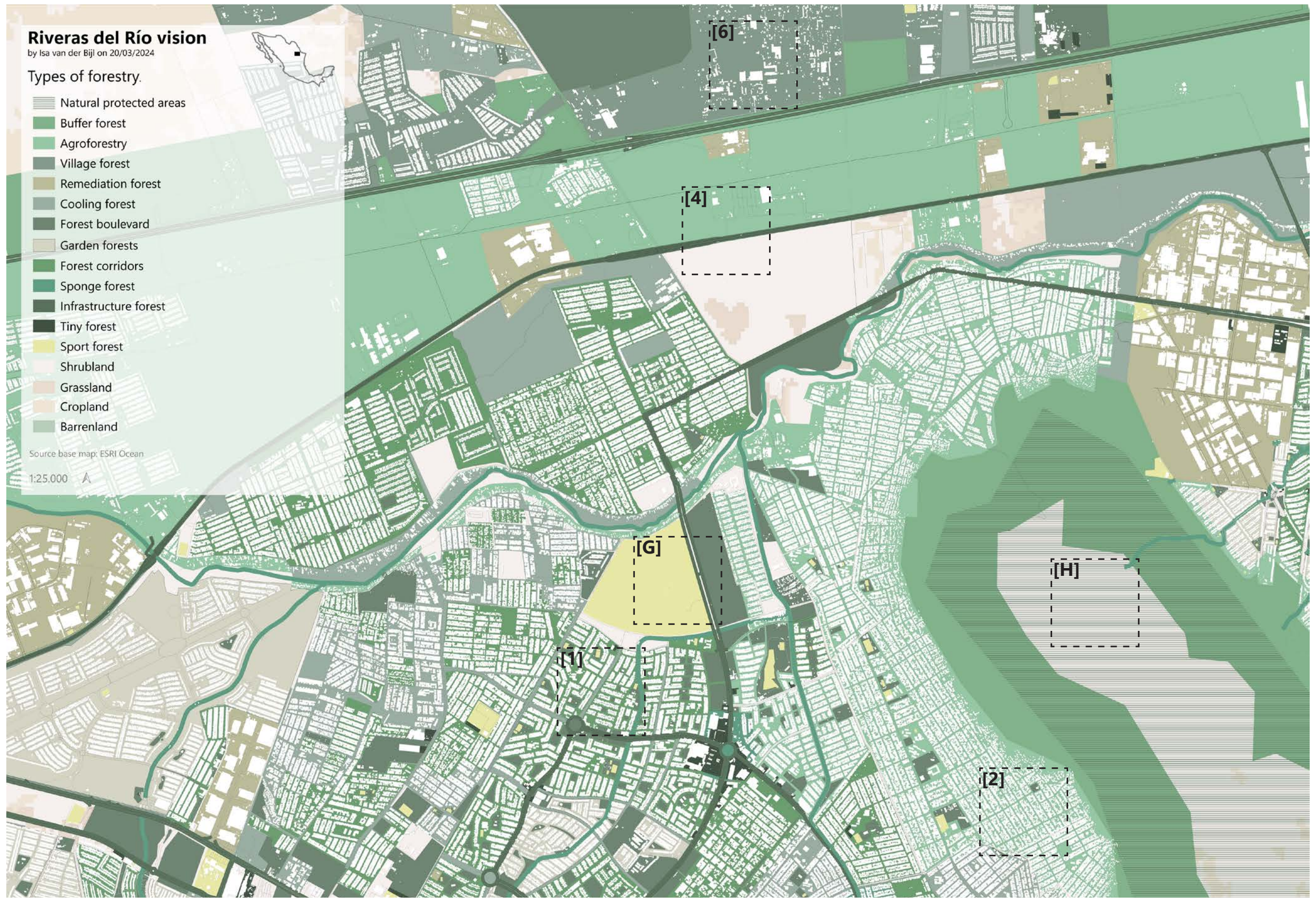


Forestry vision

Forest types were selected based on the existing urban and landscape typologies to propose a forestry vision for Riveras del Río. Informal communities will be introduced to agroforestry, isolated urban sprawl will have village forests, and urban vegetation will be transformed into a forest boulevard. This aims to create an ecological continuum and a sensitive new green network, engaging communities and harmonizing human-nature relationships. For a detailed design, the area that currently has urban vegetation (location G), has been used to show what kind of forest types could be implemented here.

This forestry vision is meant to show the possibilities over time. In order to create a forest network systemically and with care, the miyawaki method is going to be used. Seedlings of native trees that would naturally grow in the area are planted densely, and after three years the trees most adapted to the local conditions will grow rapidly (Urban Forests, 2023). After 15-20 years a mature natural forest will be flourishing in Riveras del Río.

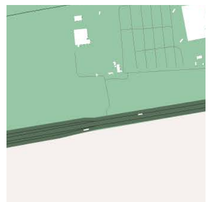
Riveras del Río vision

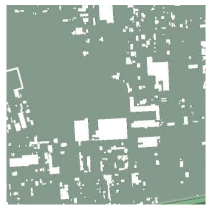


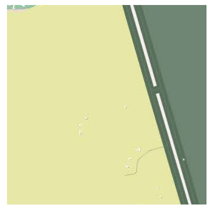
Riveras del Río forest types


[1]
Formal community

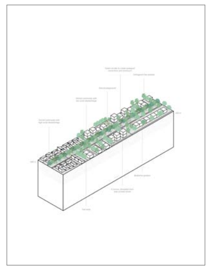

[2]
Informal community

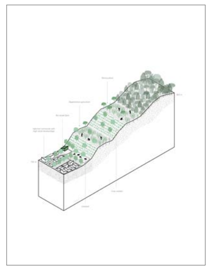

[4]
Infrastructure

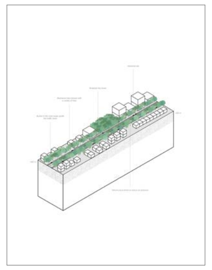

[6]
Isolated urban sprawl

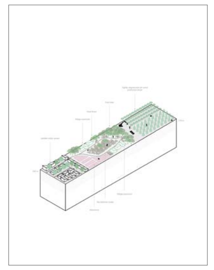

[G]
Urban vegetation

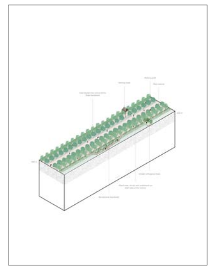

[H]
Natural protected area

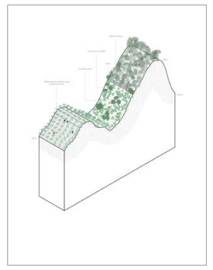

Forest corridor


Agroforestry


Infrastructure forest


Village forest


Forest boulevard


Buffer forest

Forest boulevard

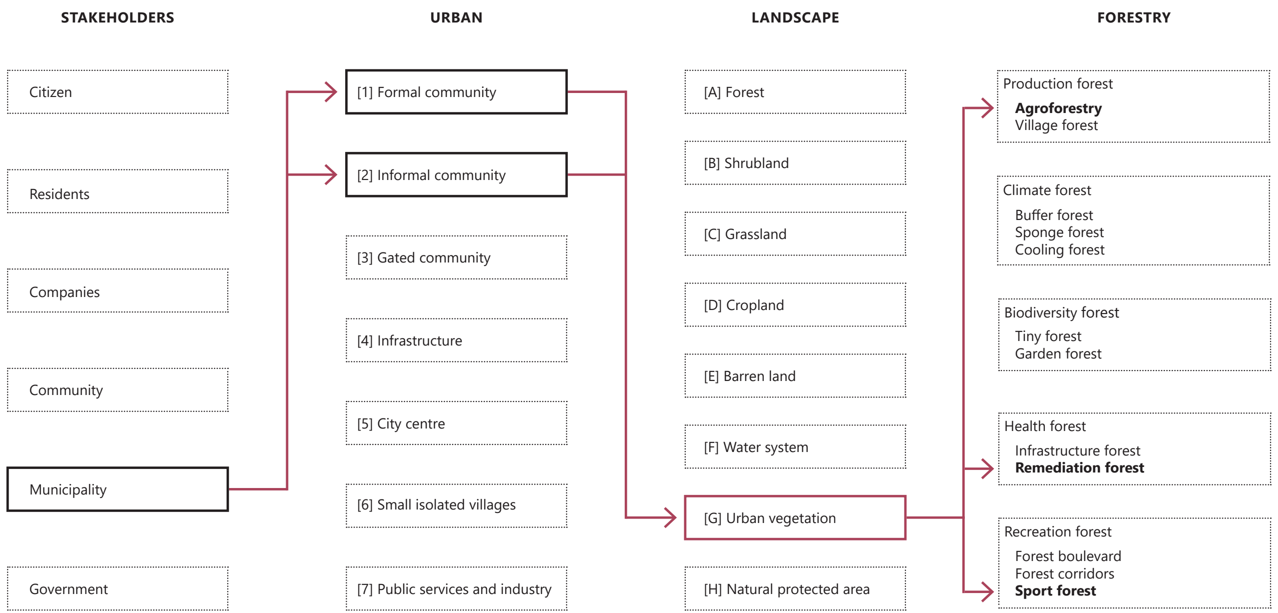
The zoom-in location in Riveras del Río includes three small football fields [1], a former baseball field [2] and slums [3] on the border of Río Pesquería [4].

In order to revive this plain field (image 1), a plan is proposed to add new sports fields [2], playground meadows [3] and desert willows [6] to create a sense of place. In an attempt to clean a part of the water flowing through Río Pesquería, a natural water filter system [1] will be introduced. Moreover, the main roads will become infrastructure forests [5], and the vacant strip on the east side will be transformed into agroforestry [4], including maguey agave. This approach aims to engage communities, create jobs, detoxify river water, and improve the quality of life for residents by creating this new park to be the core of the neighbourhood.

[1] Plain field (location G)

Google Maps. (2022, September). *Av. Luis Donaldo Colosio Murrieta 2765* [Street view]. Retrieved April, 3, 2024. Google Maps. https://maps.app.goo.gl/oxKniK7FXArm7ShU8

Design strategy



Existing situation

Forestry vision

Sport forest with a clear gate to the park

Google Maps. (2022, September). *Av. Luis Donaldo Colosio Murrieta 2765.* [Street view]. Google Maps. https://maps.app.goo.gl/oxKniK7FX-Arm7ShU8

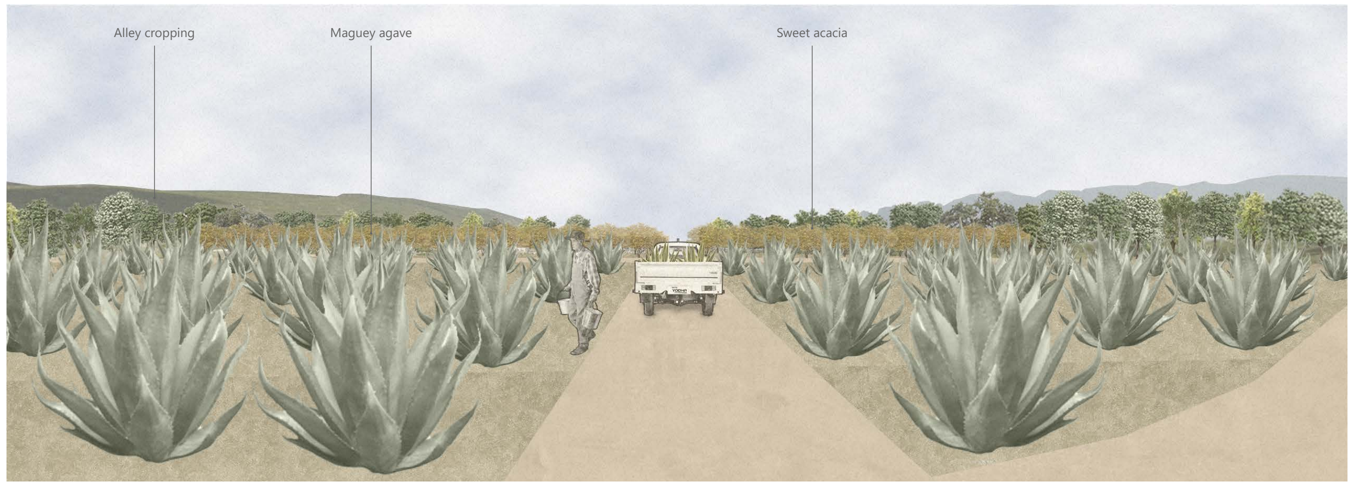
Clear entrance from the neighbourhood

Google Maps. (2022, August). *5350 Av. Camino del Pastizal.* [Street view]. Google Maps. https://maps.app.goo.gl/oGA2yNW83M2fnWws6

Remediation forest with educational boardwalk

Google Maps. (2019, June). *Monterrey, Nuevo Leon.* [Street view]. Google Maps. https://maps.app.goo.gl/Az35iVJwBNTBrDye6

Agroforestry with Maguey agave

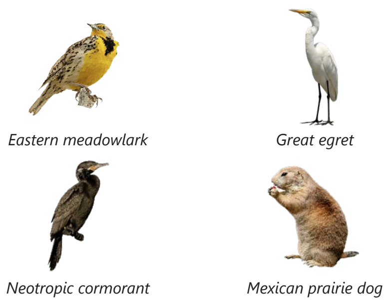


Google Maps. (2019, June). *Antiguo Camino Real.* [Street view]. Google Maps. https://maps.app.goo.gl/FCybqr9dgsmzzBWt6

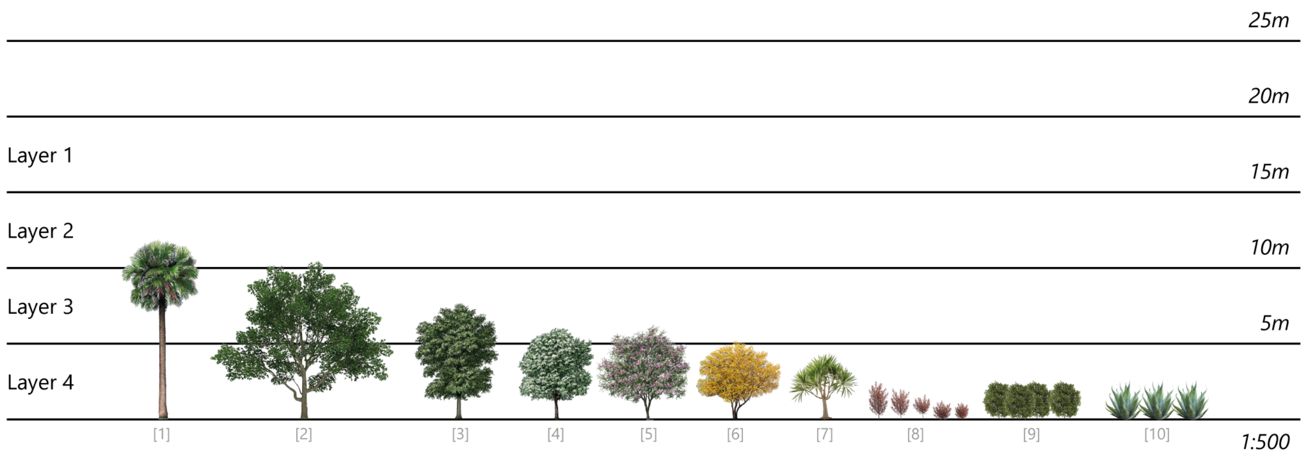
Design interventions

The design interventions in Riveras del Río include plant species that are resistant in the steppe zone, such as Desert willow *(Chilopsis linearis [5])* and Maguey *(Agave americana [10])*. The key animal species are the Eastern meadowlark, Great egret, Neotropic cormorant, and the Mexican prairie dog. In the park section, the transformation of the plain field to the sport forest is shown, and in the detailed section, the educational boardwalk in the remediation forest is drawn. This includes a helophyte filter with reeds to filter a part of the polluted Río Pesquería river.

[1] Key fauna species



Riveras del Río species



Layer 1

Layer 2

Junglas mollis
Quercus polymorpha
Sabal mexicana [1]

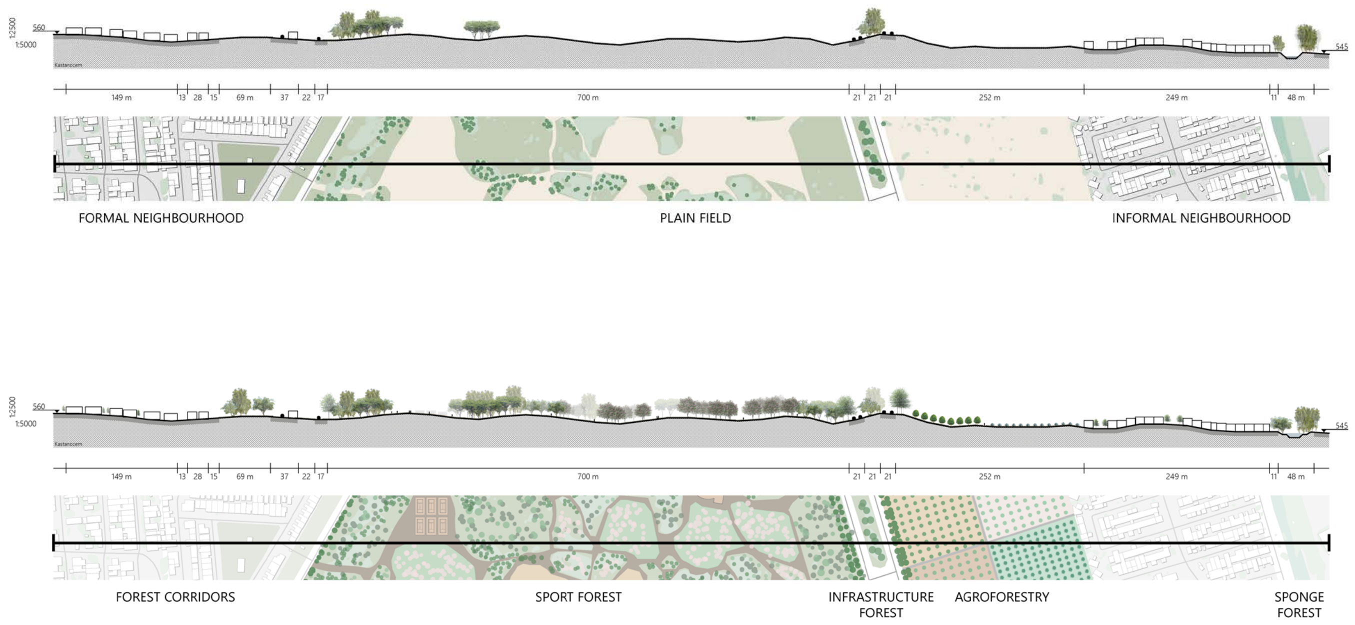
Layer 3

Quercus virginiana [2]
Quercus fusiformis
Ebenopsis ebano
Celtis laevigata [3]
Ehretia anacua [4]
Sapindus saponaria
Prosopis glandulosa
Chilopsis linearis [5]
Parkinsonia aculeata
Sargentia greggii
Caesalpinia mexicana

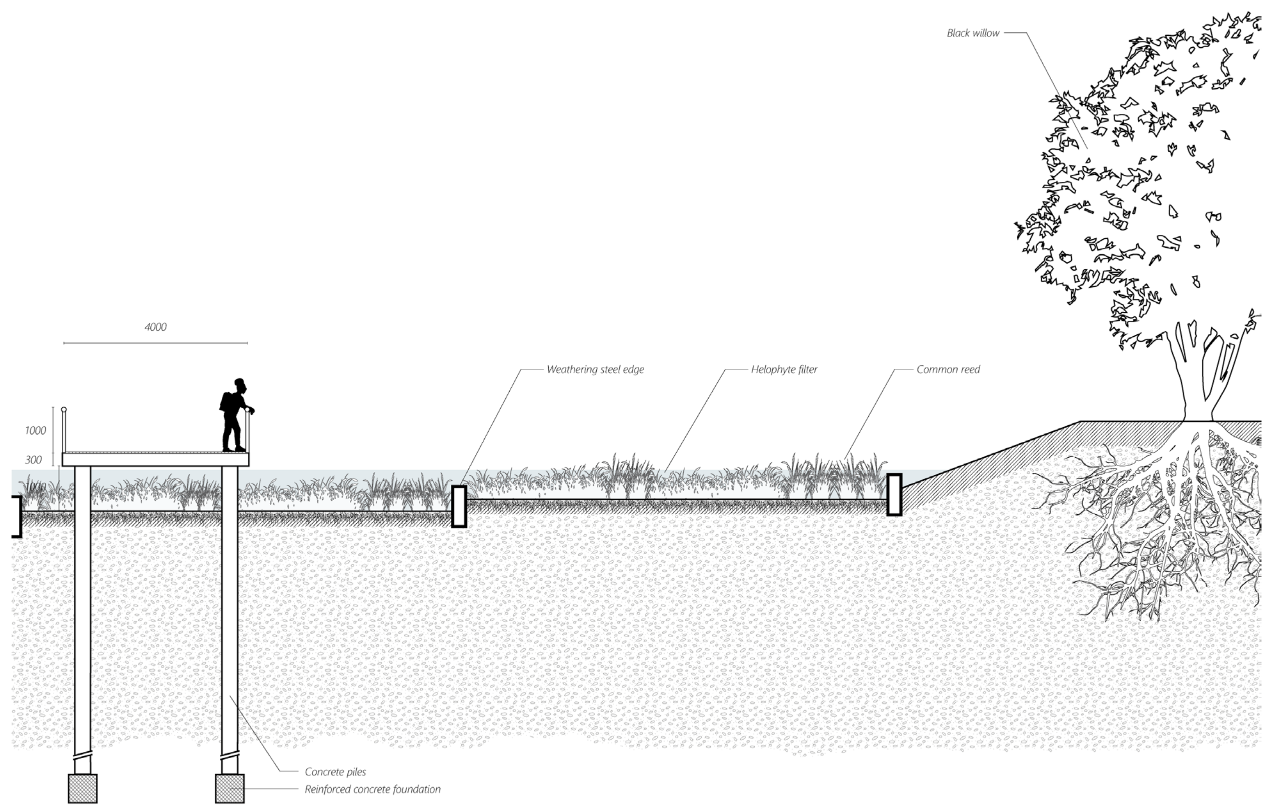
Layer 4

Acacia farnesiana [6]
Cordia boissieri
Diospyros texana
Yucca filifera [7]
Sophora secundiflora
Acacia berlandieri
Dodonaea viscosa [8]
Celtis ehrenbergiana [9]
Leucophyllum frutescens
Larrea tridentata
Agave americana [10]

Riveras del Río park section



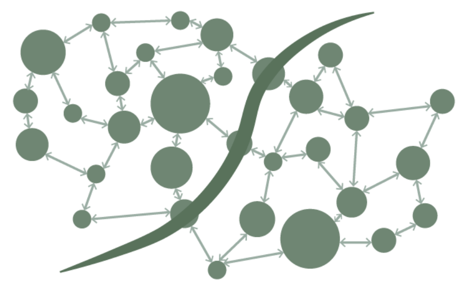
Remediation forest educational boardwalk section



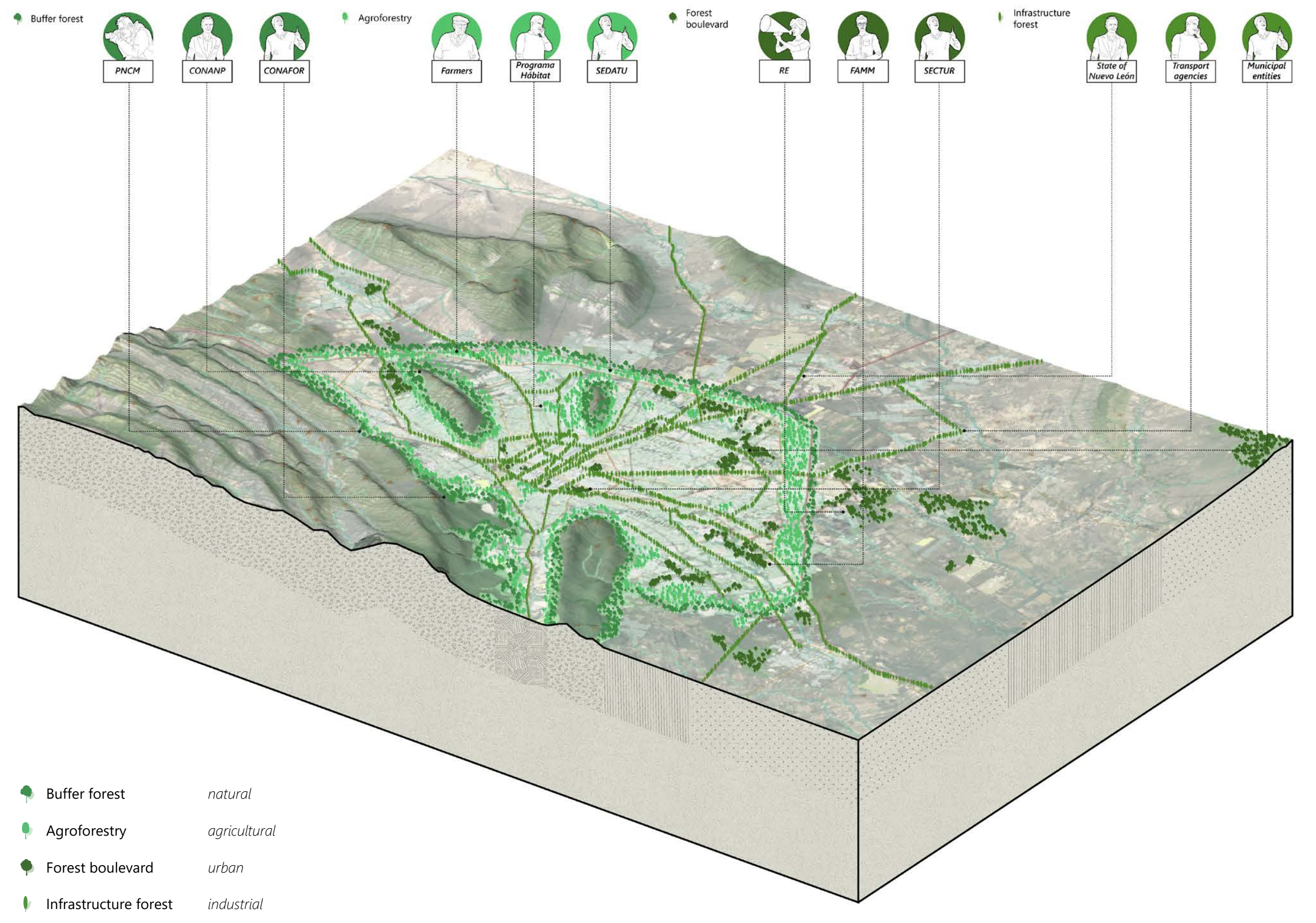
6.3 Systemic design

The forest types are categorized by their scale and scope with the backbone-continuum-patch model. These three components require different types of management, from more Top-Down to more Bottom-Up, that structure the system across the city and region. The large-scale backbone, including protected areas and green boulevards, requires Top-Down government planning focused on conservation and recreation. The medium-scale continuum, featuring connecting elements like sponge forests and wildlife corridors, uses a hybrid approach with collaboration between government, community, and private stakeholders. The small-scale patches, such as village forests and tiny forests, are primarily Bottom-Up efforts driven by local residents and community initiatives to green neighbourhoods and improve quality of life.

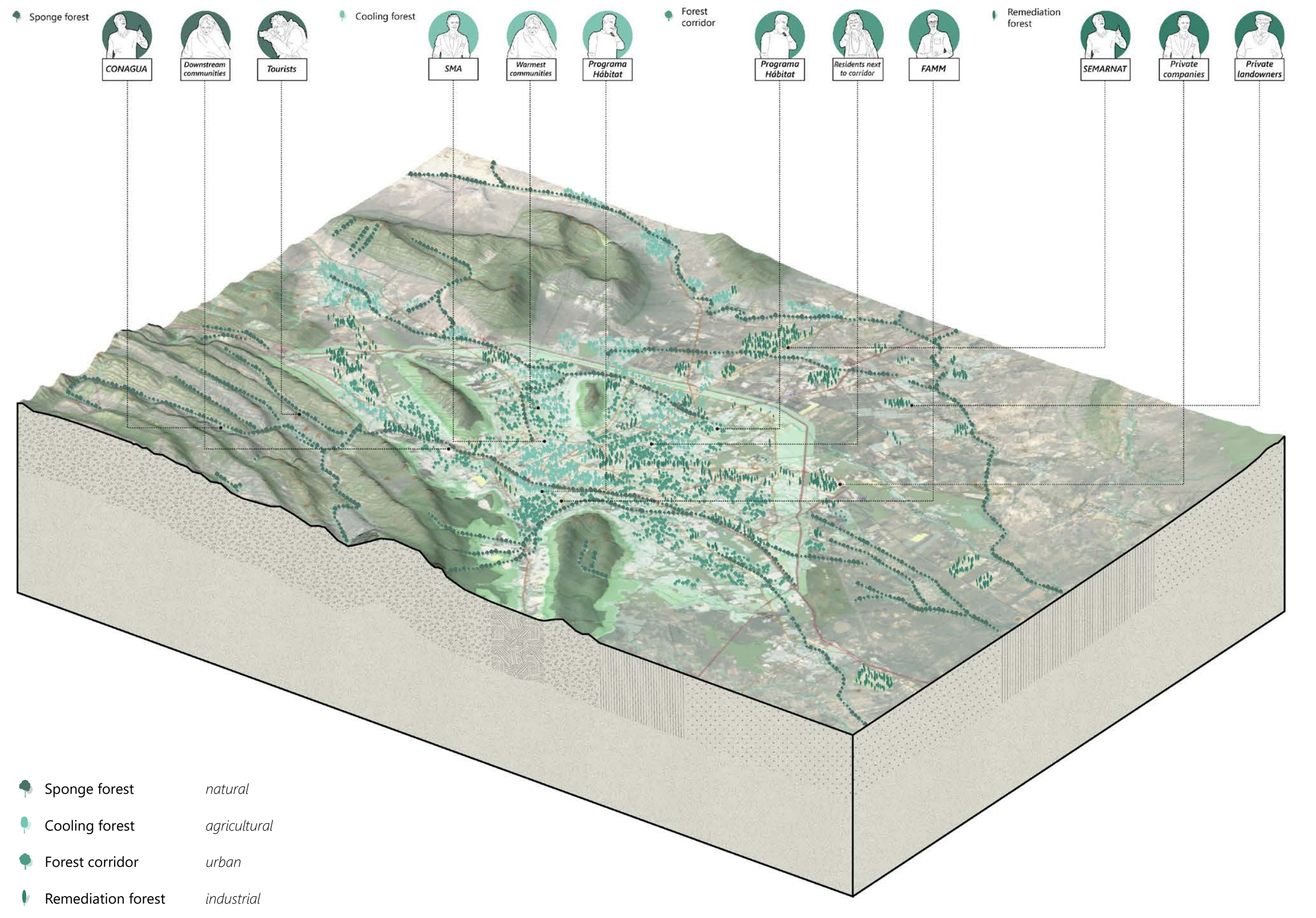
[1] Backbone-continuum-patch model



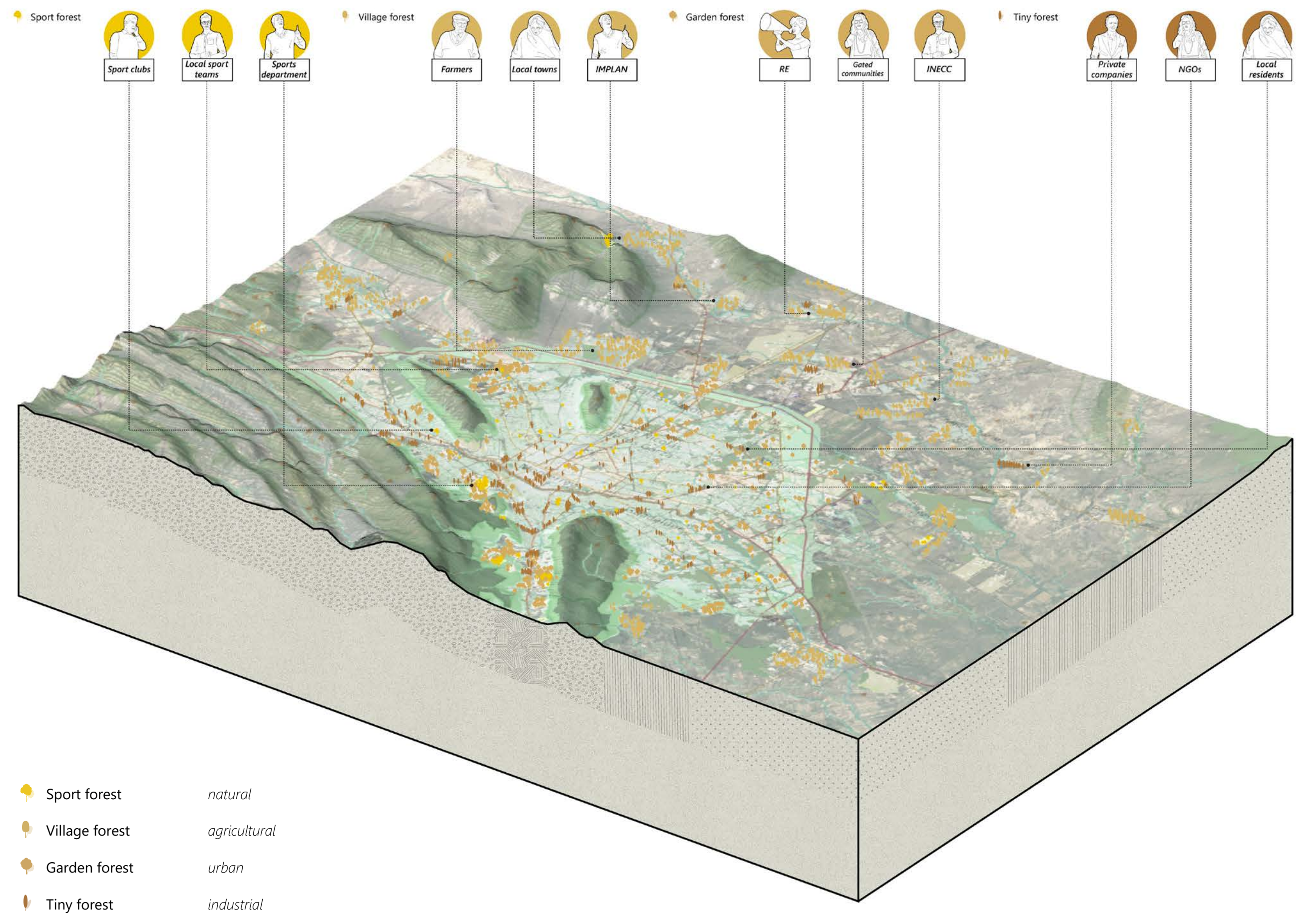
Backbone: Top-Down approach



Continuum: Hybrid approach



Patch: Bottom-Up approach



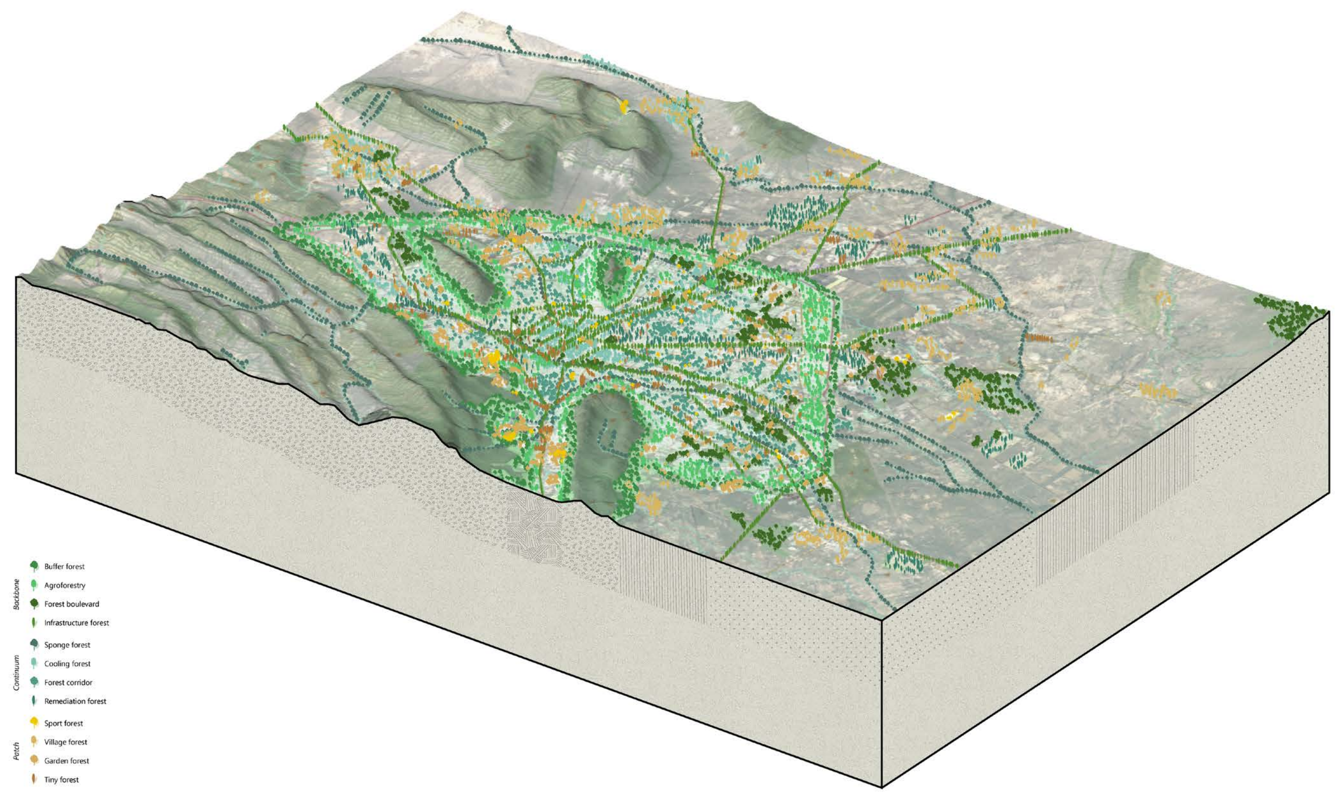
Stakeholders

[1] Top-Down backbone
The backbone of the forest system connects the natural protected areas to the city centre, mainly by creating a forest ring around the urban sprawl. This includes buffer forests, agroforestry, forest boulevards, infrastructure forests, and mainly a Top-Down approach with key stakeholders in government to create long-term policies. For the national park and reserves, this includes federal and state environmental protection and natural resource agencies. The forest boulevards engage public works and tourism departments. Moreover, local communities near the protected areas and users like pedestrians and cyclists are also important stakeholders impacted by these backbone components.

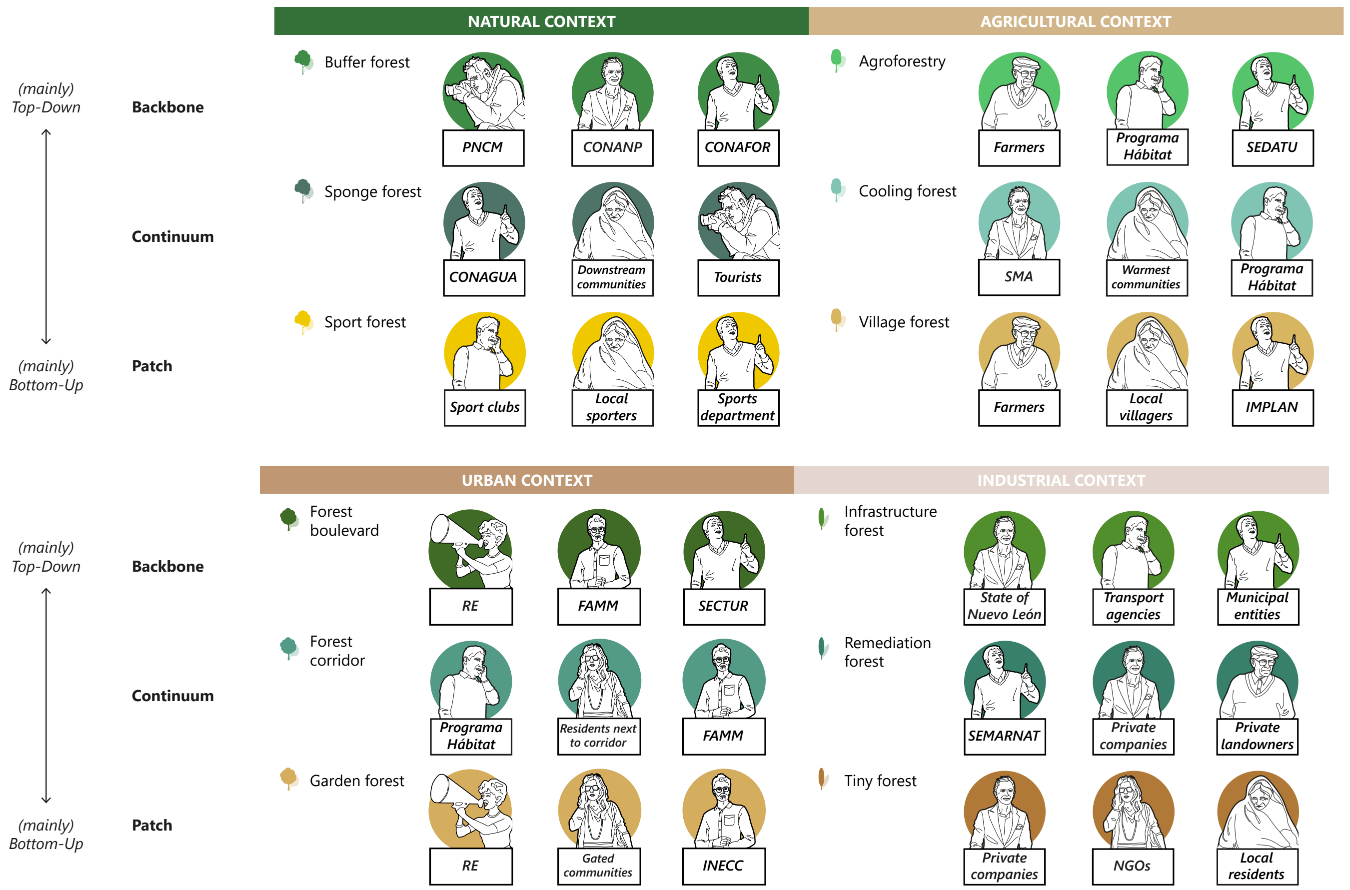
[2] Hybrid continuum
The forest continuum, including sponge forests, cooling forests, forest corridors and remediation forests, requires a hybrid Top-Down and Bottom-Up stakeholder approach. Government agencies focused on water management, urban heat mitigation, habitat conservation and contaminated site clean-up are key Top-Down stakeholders. Bottom-Up stakeholders include local residents benefiting from flood control, heat relief, access to nature, and remediated land. Community organizations, public health groups, schools and companies liable for contaminated sites are also important Bottom-Up stakeholders shaping and benefiting from the forest continuum.

[3] Bottom-Up patch
The forest patches, including sport forests, village forests, garden forests and tiny forests, are driven by mainly Bottom-Up stakeholder engagement. Local residents are the primary stakeholders, because they are the main users of these green spaces. Community-based organizations like sports clubs, farmers, homeowners associations, and schools are essential in designing and guiding patch projects. Municipal government and local councils play a supporting role by providing land and resources. Environmental NGOs are also key catalysts of small-scale patch initiatives.

ArborMetropolis vision

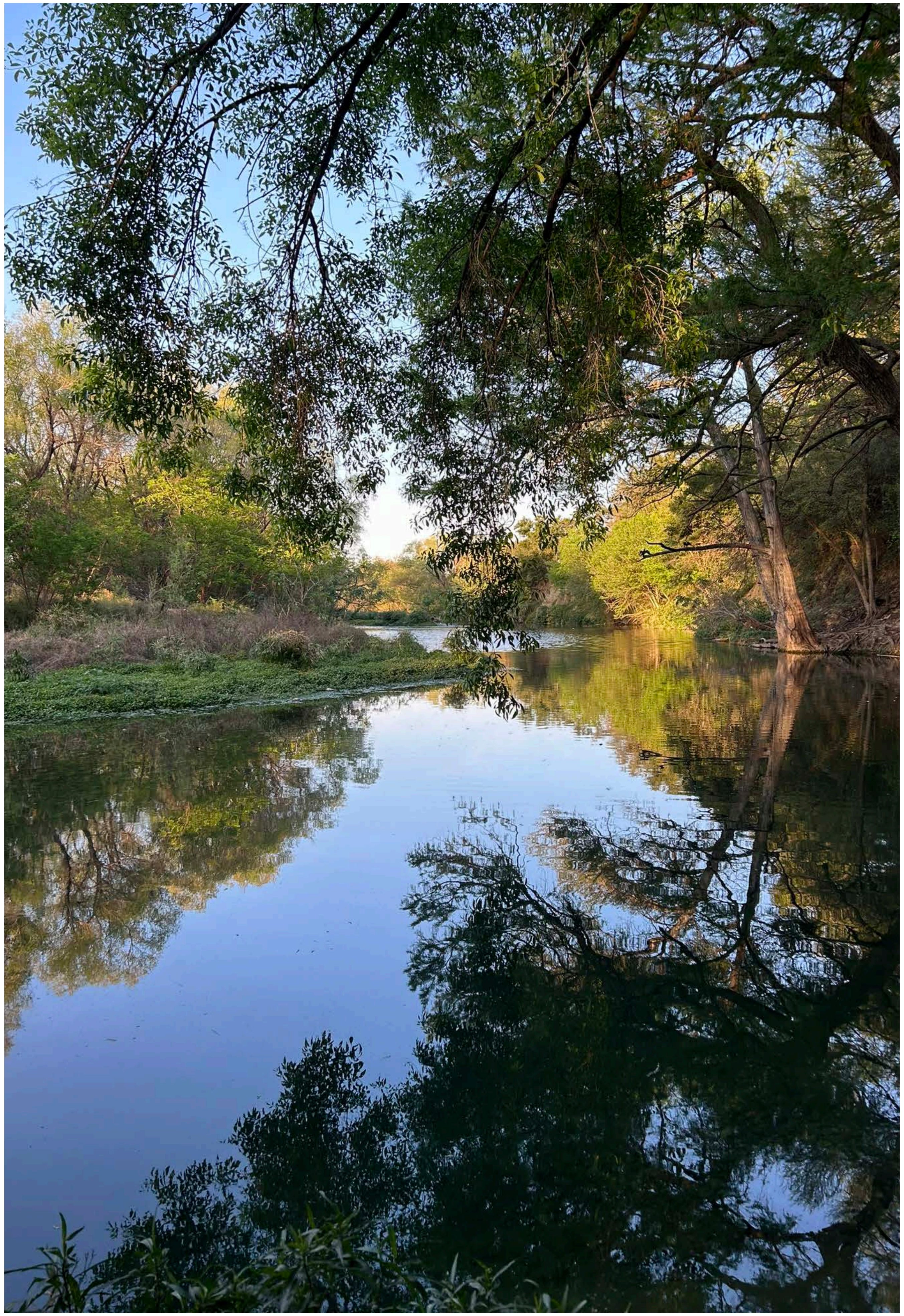


ArborMetropolis stakeholders



ArborMetropolis vision

Over time, the Monterrey Metropolitan Area will have more and more forests. This transformation will be visible through greening projects in the neighbourhoods. More importantly, when viewed from the national park overlooking the entire region, the city's landscape will visibly transition to a more green environment, accompanied by a reduction in air pollution.



Own photograph.

7. Final considerations

Conclusion

This thesis explored the potentialities of upscaling urban forestry and regional afforestation in Monterrey, Mexico, to enhance ecosystem services, defragment the natural landscape, and harmonize the relationship between people and nature. Through a multi-dimensional methodological framework integrating site-specific research, landscape theory, and geological analysis, the project aimed to address the ecological, social, and spatial complexities within Monterrey's urban environment.

The research revealed that Monterrey's urban landscape morphology is shaped by the conflict between powerful natural forces and turbulent human activities, resulting in deforestation and a fragmented, inaccessible natural landscape. In response, the thesis proposed implementing an ecosystem-based adaptation approach by establishing an extensive forestry network consisting of twelve forest types throughout the Monterrey region.

The design process employed a trans-scalar perspective, considering both immediate impacts and long-term evolution of the proposed interventions. Moreover, ecosystem understanding, informed by biophysical and biodiversity analysis, guided the selection of appropriate tree species and forest planting strategies adapted to Monterrey's ecological zones. A suitability analysis based on soil ecology identified areas with the greatest potential for intervention and impact. Furthermore, the forest catalogue principles developed are scalable and applicable to other arid climate zones.

The methodological framework emphasized context sensitivity and fostered an iterative relationship between research and design, resulting in robust and locally relevant proposals. Graphical analysis, cartographic interpretation, and data collection from various sources informed the research process and visualized the findings.

The site visit to Monterrey offered a tangible understanding of the physical conditions, social dynamics, and environmental context, grounding the design proposals in reality.

The integrated empowerment of local communities and their knowledge, adapted to the conditions of the site and forest type, holds significant potential for systemic transformation in Monterrey. However, this requires a collaborative management of local practices and monitoring systems alongside municipal and regional governance. Aligning the ecological goals of the local communities with those of the governmental entities will benefit both of them. Such conditions can only be realized in collaboration through an accepted and shared vision, ultimately facilitating a holistic view and sustainable growth of the metropolitan area of Monterrey.

This thesis bridges various spatial disciplines, contributing to a deeper understanding of urban ecosystems and advocating for new methodologies in landscape architecture, urban ecological design, and sustainable urban development. The social implications are profound, addressing environmental justice, accessibility to nature, and the importance of community engagement in urban planning.

In conclusion, the results of this thesis demonstrate the potential of urban forestry and regional afforestation in arid urban landscapes like Monterrey. It proposes an evolutionary framework to connect landscape patches with natural protected areas, emphasizing the significance of ecosystem-based adaptation. By strategically integrating urban forestry, Monterrey can enhance ecosystem services, defragment its natural landscape, and foster a harmonious relationship between its residents and the natural environment.

Reflection

Discussion

Transferability and scalability
The approach of strategically planting as many forests and trees as possible is a concept that can be used on a much larger scale. While the project focuses on the metropolitan area of Monterrey, the forest catalogue principles apply to all arid climate zones. Moreover, the use of multiple forestry types can be implemented worldwide, as deforestation is a universal problem.

Limitations
During the thesis process, various limitations became apparent. Firstly, there were not enough precise data sets available. They were either incomplete or only available for one of the twelve municipalities in the region. The urban inventory map, as described before, was completely manually traced from Google Street View, to provide an overview of where the different urban typologies, such as gated communities, are located. Moreover, some research and design parts were based on assumptions, knowledge of the landscape, or conclusions drawn from satellite maps and photographs, which may lead to inaccuracies. Due to the scale of the region, large car-dependent infrastructure, and 5.5 million inhabitants, it was not possible to visit every design location, during the site visit, or accurately interpret all social aspects. Most of the time, the site visit was accommodated on the campus of Tec de Monterrey, which is a private institution. This created a social bubble that was difficult to escape. Furthermore, the project focuses on idealistic visions and proposes concepts that may only be feasible in the region with properly accommodating stakeholders.

Site visit
The site visit to Monterrey played a crucial role in the research and design process. It provided an opportunity to experience the scale and proportions of the city first-hand, as well as the natural landscape and extensive mountain systems. During the visit, it was possible to explore multiple ecological zones within the city, including the mountains, desert, and steppe regions. The differences between the northern and southern parts of the region, as well as the eastern and western areas, became apparent. The project was presented at various meetings with different organizations, primarily on campus, but also at an international symposium. This allowed for diverse perspectives and valuable feedback from a range of individuals, which significantly influenced the development of the proposals. Without these interactions, the project would not have taken the same shape.

Future recommendations
If this project were to be implemented, several recommendations should be adopted that were not sufficiently researched in this thesis. As heard multiple times during the site visit, the understanding of the social complexities in Latin America, Mexico, and Monterrey, is challenging for an outsider. To implement any of the proposals, a collaborative process is required, and a more in-depth study on the society as well. Presumably, not all identified stakeholders will be willing to collaborate and understand the forestry vision. To be able to pinpoint what the residents need, is one of the most difficult issues, even if you are a landscape architect or designer born in Monterrey. The existing twelve municipalities do not yet share the same vision for the region. To create a multi-scale vision for the entire region is unprecedented and will likely be seen as controversial.

Reflection on the methods and process

The research process for this project employed a multidimensional methodological framework to comprehensively address the challenges and opportunities in enhancing Monterrey's urban forestry and landscape connectivity. This approach integrated site-specific research, theoretical research, and geological analysis, providing a nuanced understanding of the complex interplay between the urban fabric and the natural environment.

The analytical approach, involving the examination of various layers of the urban landscape, effectively detailed the existing conditions. Furthermore, a comprehensive inventory, compiled through superimposing soil ecology data on green spaces, urban fabric, natural areas, and socio-economic factors, laid a solid foundation for further analysis and decision-making. The metropolitan approach ensured that the proposed solutions were context-sensitive, and addressed broader urban dynamics, emphasizing sustainable maintenance and community engagement as a long-term approach.

Therefore, incorporating socio-cultural values and considering diverse stakeholders fostered a more inclusive and locally relevant approach to urban forestry. The trans-scalar perspective allowed for a comprehensive understanding of the immediate impacts and long-term evolution of the proposed interventions. In addition, ecosystem understanding, informed by biophysical and biodiversity analysis, guided the selection of appropriate tree species and forest planting strategies tailored to Monterrey's ecological zones.

Moreover, the suitability analysis based on soil ecology identified areas with the greatest potential for intervention and impact. Graphical analysis, cartographic interpretation, and data collection from various sources enriched the research process and facilitated effective communication of findings. Precedent studies provided valuable insights into urban forestry and afforestation strategies in other semi-arid cities facing similar challenges.

The site visit to Monterrey was crucial, offering a tangible understanding of the physical conditions, social dynamics, and environmental context, thereby grounding the design proposals in the reality of Monterrey's urban landscape. Additionally, an iterative relationship between research and design allowed for a comprehensive and context-sensitive approach, where design raised new research questions and findings continuously refined design strategies.

In summary, this methodological framework provided a comprehensive approach to addressing urban forestry, regional afforestation, and landscape connectivity challenges in Monterrey, integrating various research methods, emphasizing context sensitivity, and fostering an iterative relationship between research and design, resulting in robust and locally relevant proposals for enhancing Monterrey's urban landscape.

To be complete, the relationship between the graduation topic and master track, as well as the professional, social, and scientific relevance of the project, amongst others, can be found in the methodology chapter.

Own photograph.

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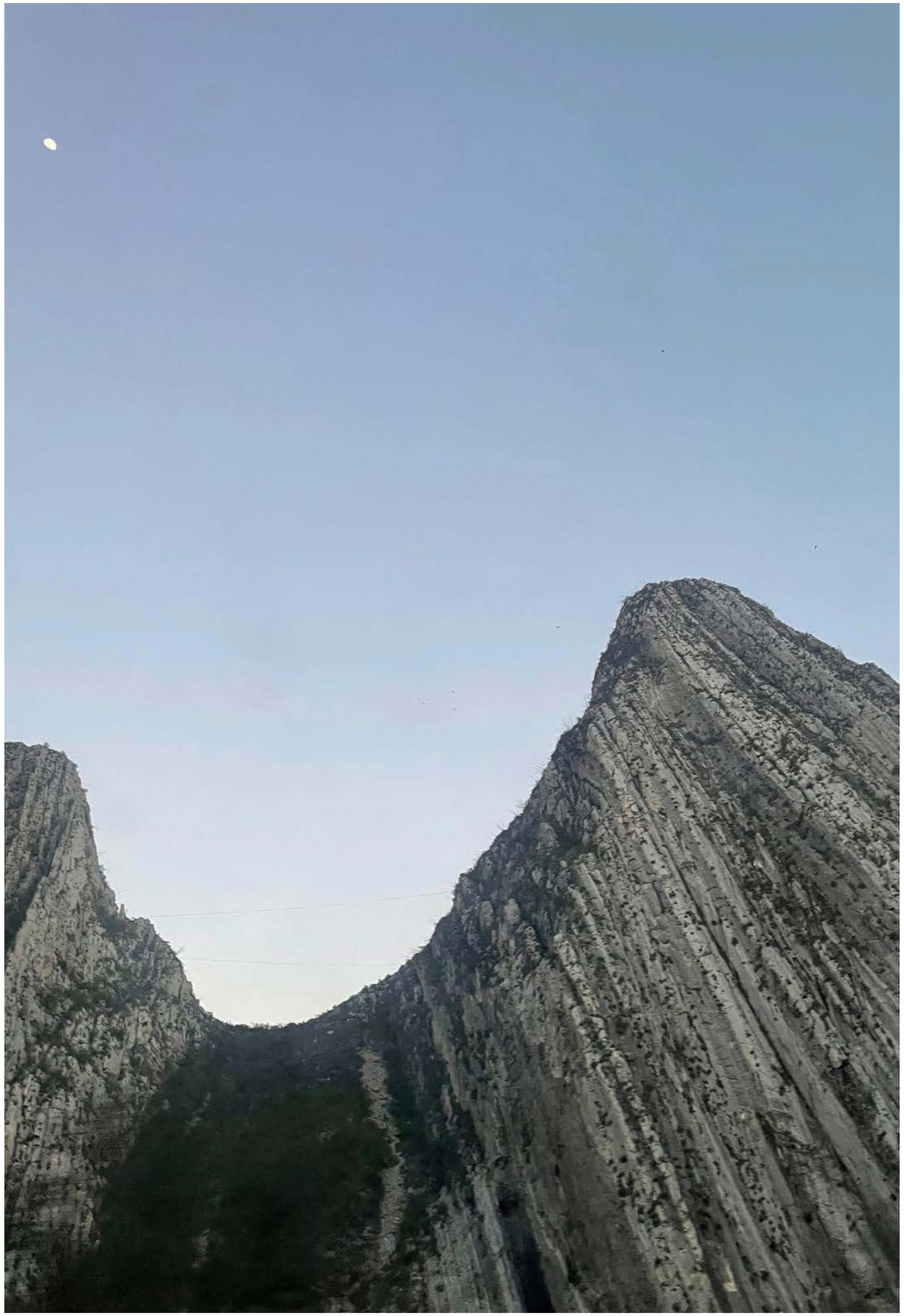

Own photograph.

9. Appendix

Recognition

The site visit was made possible by:

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