Japan Bilingual Publishing Co.

Urban Planning and Construction

https://ojs.bilpub.com/index.php/upc

REVIEW ARTICLE

When the Bear Comes to Town: How the City Could Create Nature

Rob Roggema[1*], Diego Rodriguez[1], Nico Tillie[2]

1. School of Architecture, Arts and Design, Tecnológico de Monterrey, Monterrey, 64849, Mexico
2. Faculty of Architecture, Delft University of Technology, Delft, 2628, The Netherlands

ARTICLE INFO

Article history
Received: 26 January 2024
Revised: 29 February 2024
Accepted: 15 March 2024
Published Online: 29 March 2024

Keywords:
Urban ecology
Nature-based solutions
Human-nature relationship
Monterrey
Urban design
Symbiocene

ABSTRACT

The relationship between humans and nature is in permanent change. Where the city and nature used to be seen as enemies that needed to be kept away from each other, the current paradigm looks at a more symbiotic relationship. In this, man is seen as part of nature, and the city is seen as a determining factor in providing conditions for a rich urban ecology. In this study, urban conditions are seen as the starting point for urban design, enabling biodiversity to thrive. The aim of the research is to distill design strategies that enhance nature in an urban context. These strategies are derived from existing theories, the typical relationship between the city and nature, and the understanding of the natural landscape, and are applied in the heated, dry, and rocky conditions in the metropolitan region of Monterrey, Mexico. The main finding is that the city contains ecologies with their own characteristics, often distinct from rural or natural ecologies. These specific conditions can be amplified using adequate design strategies, which may lead to a greater biodiversity. For improving urban biodiversity, the perspective on the city shall be transformed from seeing it as an enemy of nature towards a symbiotic relationship between the two. At the same time, this perspective requires additional research into two main aspects: the way the city is able to create its own climatic conditions, and how landscape-based design can enhance the urban conditions in a way nature occupies these novel ecological niches.

1. Introduction

During COVID-19 the streets in many cities emptied, and wildlife made use of the lacuna and human absence by reoccupying public spaces and gardens [1–3]. An illustrative story is recorded about a bear encounter in August 2021.

"I started my usual morning walk towards the neighboring gated community immersed in a valley inside the majestic Sierra Madre Oriental. I was walking our dog Aika, when suddenly, she bristled her hair and immediately ran backwards as if she had seen a ghost. Then I also saw it… a huge black bear about 5 meters from where we were standing.

*Corresponding Author:
Rob Roggema,
School of Architecture, Arts and Design, Tecnológico de Monterrey, Monterrey, 64849, Mexico;
Email: rob.roggema@tec.mx

DOI: https://doi.org/10.55121/upc.v2i2.147

Luckily, he was at the other side of a new fence. As soon as Aika discovered the bear she started to pull the leash and forced me to take her back home. It was a close encounter with nature and a true reminder of how close we live to it. It really felt the boundaries from the built and the natural environments started to blur."

Diego Rodríguez, August 2021, Cerro del Mirador

When COVID-19 restrictions were lifted it was expected these kinds of encounters would vanish. However, anecdotally, this seems to be contradicted, at least partially, as illustrated by two recently recorded eyewitnesses of bear encounters in the Monterrey urban area.

"At 5.30 a.m. we heard a loud sound in front of our house and woke up. We heard police voices, flashing lights and sirens in front of our door. We stood up and asked what was going on. There was a bear in an empty lot between our house and that of our neighbors. Our dog remained calm, until we went to the garden. Then she started barking. The bear hid in a very high space between the houses and disappeared. We don't know where she went."

Diego Rodríguez, September 2023, Cerro del Mirador

"I didn't want my son to get anxious. He is afraid of animals even if it is a cat or a dog. Therefore, I covered his face so he wouldn't see the bear, scream or run away. I was afraid that if he got frightened the bear would be scared and attack us."

Mother, September 2023, Parque Chipinque

By no means this is proof of wildlife intruding into the urban environment on a regular basis. Moreover, a bear in the city is not representative of ecological diversity in a broader sense. On the other hand, it illustrates the mingling of the human and natural realms. The romantic idea of a natural and biodiverse landscape that only appears outside the city, is increasingly challenged. At the global level biodiversity hotspots [4,5] are under increased threat of climate change [6]. Locally biodiversity in rural landscapes has declined due to land use change (30%), overexploitation (20%) and climate change (14%) [7]. At the same time, urban inhabitants create conditions for a richer and more diverse nature. As a result of increased temperatures and the urban heat island effect, pollution, globalized consumption and travel of the urban dweller, a cocktail of ingredients come together in the city that enhance biodiversity [8]. Moreover, the lockdown during the COVID-19 pandemic proved that a decrease in urban mobility and the absence of humans generates new conditions for wildlife in the built environment, such as wild boars, jackals, flamingos, and bears roaming freely through public spaces [9].

Given the current pace of biodiversity loss [10] a change of perspective is needed: from seeing "nature as a resource" towards a view that nature and humans are part of one symbiotic system. The regeneration of nature becomes more important than protecting it. The biodiversity in the city is already higher and, compared to many rural areas, increasing [8]. research in Germany has shown that more than 80% of the animal species in the region are found in cities [11]. Four urban conditions give reason for this:

1) In cities a constant arrival of "foreign inhabitants" takes place. The influx of exotic species through travel and trade [12] to and from urban areas have led to the fact that these external guests make up a significant part of urban nature.

2) People have chosen areas with the best opportunities to provide food and materials to create their settlements, the places with the highest biodiversity value. Many urban centers are therefore found in pre-existing biodiversity hotspots [13]. This biodiverse underground layer, though often invisible, is still there.

3) Outside cities many habitats have declined in ecological quality. Instead, urban centers increasingly become ecological oases [14], especially when compared to sterile arable landscapes with maximized agricultural production.

4) In cities a sheer diversity of habitat patches can be found. Scattered bits of habitat form a varied landscape with a multitude of niches, jointly forming a rich, though fragmented, biodiversity. Private gardens cause an enormous diversity, because of the personal preferences of residents [15–19].

In addition to this, cities create their own climate [20–23]. The typical processes and conditions, such as heat, particles, etc. that occur only or more intensely in urban areas, change the climatic conditions, which subsequently impact the type of ecosystems that occur. As an example, urban rain is created because the urban heat island effect accumulates hot air and forces it to move upward. At higher altitudes, the air cools down, condensates and attaches itself to fine air particles that are readily available in the city due to the lower air quality and pollution. As a result of this process, it starts to rain in the city. This urban climate provides specific conditions that attract niche species and builds an urban ecosystem that would not have been there with the conditions that the city provides [8].

So, if urban conditions provoke a certain climate, and this environmental context enhances specific ecologies, what are the design principles urban designers and planners can use to evoke those enriching urban conditions? Based on expert insights, current literature and the relationship between city and nature, these design principles are derived, and applied in the city of Monterrey, Mexico.

2. Materials and Methods

2.1 Case Study Area

The case study area is in the northeast of Mexico, in the city of Monterrey, the second largest city in the country. Approximately 5.5 million people live in the metropolitan area. The region's climate is complex and consists of four of the climates classified in Köppen-Geiger system. The desert arid hot climate (BWh) from the northwest, the arid steppe hot climate (BSh) coming in from the east, a temperate dry winter and hot summer climate (Cwa), and a temperate climate without dry season with hot summer (Cfa) come together (Figure 1). This explains the climate variability, and its unpredictability. Moreover, the urbanized valley is encapsulated in a series of mountain ranges that are not only outside the city, but also at the urban fringe and within the urban boundaries, such as the famous hill located to the north called Topo Chico, the area in which the design principles have been applied.

The city regularly suffers from heat, droughts, bad air quality, and occasionally torrential rains. For humans, these conditions may be experienced as inconvenient, they also generate an urban climate suitable for ecologies that thrive in hot and dry circumstances.

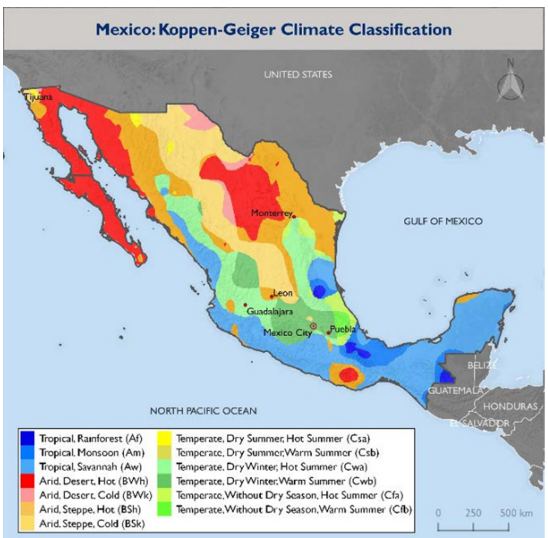

Figure 1. Climate classification in Mexico.

Ecologically, the Monterrey Metropolitan region is located at the boundary of two ecoregions. The Tamaulipan Mesquital [24] is the area at the bottom of the slopes of the Sierra Madre Oriental, and Tamaulipan Matorral [25] is the vast plain to the east up to the Gulf of Mexico (Figure 2).

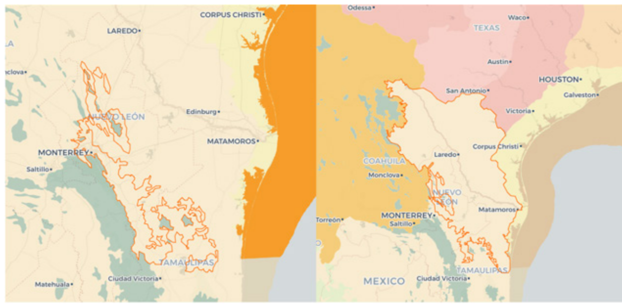

Figure 2. The ecoregions of Tamaulipan Mesquital and Matorral.

Source: [26,27].

The Tamaulipan Mezquital is at the ecological crossroads of east-west and subtropical-tropical. This has resulted in a high biodiversity. It has a semiarid subtropical climate, although the area is also quite humid due to the winds from the Gulf of Mexico. The defining plant community is mesquite grassland with honey mesquite and curly mesquite grass are the defining plant community, including also chaparro and jazmincillo. In open woodlands of mesquite, a grassy understory of taller (e.g., hooded finger grass) and shorter (e.g., grama grass) species appears. Spiny shrubs and trees over grasses, forbs, and succulents dominate thornscrub, while blackbrush, guajillo, cenizo, and a.o. are found in the higher, rocky sites with shallow soils. In lower and flatter areas mesquite is accompanied by granjeno, lotebush, prickly-pear, and brasil. The ocelot, jaguarundi, Texas indigo snake, and birds such as the hook-billed kite, white-tailed kite, gray hawk, white-winged dove, white-tipped dove, green parakeet, greater roadrunner, groove-billed ani, golden-fronted woodpecker, northern beardless-tyrannulet, vermillion flycatcher, scissor-tailed flycatcher, great kiskadee, rose-throated becard, Tamaulipas crow, Chihuahuan raven, green jay, black-crested titmouse, cactus wren, long-billed thrasher, hooded oriole, and olive sparrow, are characteristic for the ecoregion [28].

The ecoregion of Tamaulipan Matorral, between the Nearctic and Neotropic, consists of low valleys and plateaus stretching from the Sierra Madre Oriental to the Gulf Coastal Plain. It is mainly a desert scrub with an arid to semiarid subtropical climate. The desert Christmas cactus, Texas prickly pear cactus, mesquite, smooth mesquite, Spanish dagger, shrubby blue sage, leatherstem, cenizo, *Mammalaria* cacti, tepeguaje (great leadtree), and catclaw mimosa are the most common plant species. The Piedmont scrub on shallow soils below 2,000 m with low rainfall (490–900 mm annually), consists of 3–5 m tall scrubs with baretta, palo estaca, and acacia. Oak accompanied by madrone, yuccas, mountain mahogany, and *Bauhinia*, with legumes and a species-rich herbaceous layer form the montane chaparral at elevations above 1,700 m. The mint family has evolved in this ecoregion with four endemic genera of woody plants and endemic agaves, such as the Queen Victoria agave, are also abundant. Furthermore, characteristic mammals, such as the yellow-faced pocket gopher, Saussure's shrew, the narrow endemic Allen's squirrel, collared peccary, coyote, and the endangered Mexican prairie dog, as well as birds such as the burrowing owl, rose-throated becard, Tamaulipas crow, Chihuahuan raven, green jay, brown jay, long-billed thrasher, black-crested titmouse, hooded oriole, eastern meadowlark, Altamira yellowthroat, hooded yellowthroat, blue bunting, and olive sparrow, inhabit the region [29].

2.2 Methodologies Used

The investigation applies mixed methods which in parallel aim to derive design principles that can be used in cities to enhance biodiversity, using the current urban conditions and climate as the point of departure. The methodology consists of four parts: a literature review, expert interviews, joint roundtables, and a design studio (Figure 3).

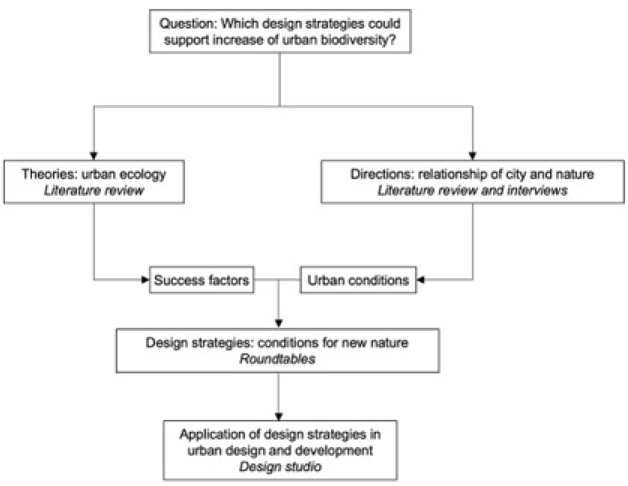

Figure 3. Mix of methods (italic) used in two parallel lines of investigation: success factors and urban conditions.

Literature

The goal of the literature review is to identify potentially successful design principles that can increase biodiversity in the urban context. A search in *SCOPUS, Web of Science and Science Direct* has been carried out, using search terms urban ecology, urban design, urban climate, and biodiversity. In total, 123 articles have been selected and analyzed. The relevant design principles (that were used in an urban condition, with an urban climate and increasing biodiversity) were collected and categorized into eight groups (see section 4.1).

Expert Interviews

The grouped design principles have been tested and validated by conducting six expert interviews with renowned urban ecologists, urban designers, and architects (G.K., W.T., W.M., L.M., I.M., S.J.). Of these experts, two of them own their own offices, and four are working as professors in different universities. Five of them have a Ph.D. (in spatial planning, architecture, ecology, governance) and one has obtained a Master degree (landscape architecture and urbanism). These in-depth, semi-structured conversations lasted two hours each, were held in-person or online, and were divided into four parts of 30 minutes each. Each part started with one question, upon which the conversation is built and extended, depending on the expertise of the interviewee, the dynamic of the conversation and the direction the expert would take it. The starting questions of the four components of each interview were:

1) What do you consider as the main typical urban conditions? For example, think about the building density, the urban patterns, open spaces and green, and the green-blue grid.

2) What do you see as the specific climate conditions that appear (only) in the city? Think for instance about the urban heat island, flash floods, air and other pollution, and surface impermeability.

3) What are the ecological opportunities that you recognize as being typical urban? Think for instance about ecological connections, riparian zones, the hydrological system, ecological niches, and disturbance tolerant species.

4) Which of the eight design principles do you believe offer the most impactful when it comes to increasing biodiversity? What are the required spatial features of the city, the spatial connectivity, the size of public spaces, the width of streets, the space for ecological gradients, the need for humidity, the natural slopes, the soil fertility, and nutrient levels?

Joint Roundtables

The third component of the research consisted of (virtual) joint roundtables. For these roundtables, 20 experts (including the interviewed experts) from different parts of the world were invited to discuss the draft design principles (see section 4.1) in different contexts. In each of the roundtables, lasting 2.5 hours, policymakers, urban designers, landscape architects, planners and urban ecologists took part. Of the 20 people involved eight obtained a doctoral degree (in architecture, planning, urbanism, ecology, landscape architecture and governance), seven held a Master degree (in governance and administration, ecology, botany, urban design, and landscape ecology), and five had a bachelor degree (public administration, ecology, urbanism and architecture). The respective countries represented were the Netherlands (6), the UK (3), Canada (2), Mexico (3), Japan (1), Australia (4), and the US (1).

The first roundtable focused on understanding the urban context and was mainly analytical. The urban condition, the local climate and the regional ecology of Monterrey were introduced. After this, the participants were divided into the three groups to analyze the local conditions, climatic stresses, and the potential urban ecology. These conditions form the basis for confronting the draft design principles.

In the second roundtable, the eight categorized design principles were discussed. The main question here was if the design principles would be applicable in different contexts. The same three groups as in roundtable 1 tested and judged the design principles on their applicability in the given urban context. Adjustments to the principles were suggested and in a final plenary debate, the final design principles were agreed.

Design Studio

The urban design and architecture studio in the Masters-program in the School of Architecture, Art and Design at Tecnológico de Monterrey in the first semester of 2023 formulated as a major objective to investigate how the biodiversity in the San Bernabé area, located at the edge of the Topo Chico natural reserve, can be increased by means of urban design interventions. During the 13-week program, the students studied, amongst other aspects, the regional ecology, the urban fabric, and the formulated design principles. The final results of the studio incorporated the design principles in urban designs for different urban typologies, ensuring that the relation to water, the urban density and the existing ecology was different. Some of these design proposals illustrate the use of the design principles in a practical urban context (see section 4.2).

3. Background

3.1 Nature and the City

Urban nature is a well-established academic field of research. In this paragraph theories of urban ecology and rewilding are used to identify the success factors that could improve biodiversity in the city.

Urban Ecology

Urban ecosystems have been less studied by ecologists in the past because they were seen as inferior compared to a less disturbed rural ecology [30]. Urban ecology [31,32] was approached as the ecology (e.g., the nature) in the city, which is seen as a threat to nature because it damages natural habitat. Later, the field evolved to view the city itself as an ecosystem, and as an urban landscape [33]. It turned the study of urban ecology into a multidisciplinary discipline that aims to understand the high dynamics of ecosystems in an urban context [34]. Here, well-known ecological “rules” such as emergence, succession and symbiosis differ significantly from areas with less human influence [35,36]. However, human influence is varied, and provides a richness of habitat types that support very diverse species.

Several aspects can be directly translated into urban patterns useful for depicting design principles (in bold):

1) Higher rates at which plant biomass accumulates in an ecosystem (the Net Primary Production/NPP) implies higher densities in the eco-population, though not necessarily a higher diversity. This productivity is highest in urban areas that are **moderately dense** and contain a relatively high resource input from humans in green spaces [37]. **Parks, gardens, and golf courses** show therefore higher productivity levels than the surrounding wildlands [38]. **Urban lawns** can have an aboveground productivity that is four to five times higher than native grasslands [39].

2) The human influence on temperature in cities may lead to a buffering effect against colder periods [40] and extend the growing season [38]. It changed local urban climate, and the buffering effect supports invasions of novel species in the city. In cities, a **‘pseudo-tropical bubble’** creates a reduced variability over time which allows some native species to thrive and raise the density of urban eco-populations [37]. Tropical birds have become common in cities in temperate climates [41,42], and do not spread out over the countryside. This implies that essential conditions are available in these cities for their persistence.

3) With an increase in urban development, the richness of plant species increases, the richness of bird species increases moderately or stays constant, and the diversity and abundance of soil fungi and microbes decreases [43–47]. The diversity of colonization and potential extinction due to the **isolation of patches urban habitat**, in combination with the **disturbances in the urban environment** that keep green areas in the early or mid-successional ecological stage, is supporting the species richness in urban landscapes. Species richness in intermediate disturbed areas is higher than in heavily or undisturbed sites, the so-called “intermediate disturbance hypothesis” [48].

4) Higher bird species richness is found in larger, **more heterogeneous cities** [49] and the richness of mammals depends on the **proportion of green space** [50] and **housing density** [51]. A larger number of green spaces, such as **patch areas** and **corridors** have a positive effect on urban biodiversity [52].

4) A recent analysis of hypotheses related to urban ecology shows a list of 62 hypotheses [53]. If the spatially relevant elements (e.g., the ones that can be used in the process of urban design) are extracted from this list, the following aspects are related to a potential increase in urban biodiversity: **higher social-economic areas** [54], **connected patches of remnant native habitat** [55], **green roofs** [56,57], **habitat diversity** [58], **intermediate disturbance levels** [48,59], **higher population density** [60], **larger habitat size** [61], **suburban areas** [62], and **fragmentation of habitats** [63].

Regarding the relationship between socio-economic status and urban biodiversity, recent research in Brazil [64] shows that environmental injustice is a problem [65]. The richer the communities, the more urban green areas and tree-lined streets are present, while poor communities have much less of these spaces [66–68]. The research therefore focuses more on already biodiverse sites, and disregard marginalized communities, a form of environmental racism [69]. This suggests there is a novel, more balanced view needed, to move from an ecology *in*, *of* and *for* cities, towards an ecology *with* cities (see below).

Recently, the perspective of urban ecology has been differentiated and distinguished into three perspectives [70]: ecology *in*, *of* [71] and *for* cities [32,72–76]. The latter transforms ecological research into action-based practice [72] thus establishing stronger connections between urban ecology and urban planning [77]. It is suggested that this move brings us to a new ecological paradigm in urban planning, that of ecological wisdom [78]. However, this may end in an idealized version of large-scale participatory projects, which are not accessible for everyone. Urban ecology needs to benefit from a broader range of approaches, including also small scale, informal ones. By including these an expanded view for fostering interactions and collaboration to achieve stewardship and sustainability goals a more holistic and transdisciplinary ecology *with* cities [79] emerges. "With" suggests an extended form of collaboration beyond the design-planning-governance emphasis, including non-human urban organisms as partners to conserve and restore urban ecosystems. In subsequent steps, the field of urban ecology has enriched itself [80]. It has become a well-established and important discipline for future cities [31,33,81]. Ecology *in* cities is represented by a booming amount of studies in urban biodiversity [82,83], ecology *of* cities in a timely integration of biodiversity in urban land use [84–86], the ecology for cities illustrates the intersection of urban planning and biodiversity through for instance the growth of applications of nature-based solutions [87], green infrastructure [88,89], blue-green grids [90,91] and ecological corridors [92,93] and the afforestation thereof [94] in urban planning and design, and ultimately ecology with cities is increasingly integrating humans in urban ecology [32,34,95].

Finally, a recent approach to regenerative urban design is to use the understanding of ecosystem level biomimicry as a model [96,97] by integrating local ecological structures, processes, and functions into every phase of urban design. To design the city regeneratively, it is therefore necessary to use all components of an ecosystem, its biological structure, physical abiotic structures, and material and energy flows [98] to concurrently improve society's wellbeing and the integrity of ecological systems [99]. This holistic approach on the role of ecosystems in the urban planning process, starting with a comprehensive socio-ecological diagnosis before planning or designing the city, fits with the Contingent view on the relationship of urban-nature (see section 3.2).

Urban Rewilding

In recent decades, ecosystem restoration through "rewilding" has been seen as innovative and hopeful [100–102]. Rewilding is "an ambitious and optimistic agenda for conservation, centered on the (re)establishment of ecological processes with a less controlling or coercive management approach by humans" [101]. Most studies about rewilding have focused on what rewilded non-human species, the so-called keystone, flagship, indicator, or umbrella species [103–105], contribute to ecosystem functions and -services [106]. Their ecological engineering capabilities aim to benefit humans, species, or landscapes [107]. In Europe, urban wildlife has gained greater interest [108], but most attention is oriented at rural and peri-urban areas. Urban rewilding is often linked to urban greening, including landscape connectivity, ecological succession, and environmental justice [66,109,110]. Moreover, the benefits of a rewilded city for human health and wellbeing puts emphasis on the benefits it has for the urban society [111–114].

However, recently, rewilding is increasingly seen as an added value for cities, as "novel urban wildernesses" which are defined "by a high level of self-regulation in ecosystem processes, including population dynamics of native and non-native species with open-ended community assembly, where direct human impacts are negligible." [115].

Moreover, there has been little interest in species that intently react to their own circumstances and auto-rewilded as beings 'with their own familial, social, and ecological networks, their own lookouts, agendas, and needs' [116]. Wild animals have taken advantage of urban land-use changes in (postindustrial) cities [117] by urban greening of waterways, parklands, backyards, urban farms, community gardens or rain gardens [118,119]. Therefore, urban rewilding is an urban process that is occurring [120,121] as a 'spontaneous, autonomous occupation of [urban] space by nonhuman animals' [122]. Autonomous 'activities of animals themselves' [123] to move and relocate where they previously didn't occur, being 'out of place' or 'invasive' [106] is defined as auto-rewilding. The mobility of various animal, bird, and plant species responding to human activities is more complex and fluid than a simple in/out of place stigma [124]. By accepting, even stimulating this mobility in rewilding strategies in urban design and regeneration projects, the resilience of the city can be improved [125].

Urban rewilding can provide the spaces for autonomous emergence of wildlife in the city. Wild animals are occupying urban green spaces of different kinds and do so in a complex and fluid way. When, where and which animals will find their fitting condition is difficult to predict, hence the best spatial strategy to follow is to enhance the opportunities for rewilding animals, to allow them to auto-rewild. Developing a **dispersed and differentiated system of green spaces** throughout the city, that are **slightly connected**, will present a selective environment for a range of new ecological residents. The idea of sharing spaces with other species such as racoons, deer, flamingos, kites, opossums, etc. could play a profound role in increasing biodiversity in cities.

3.2 Urban and Nature

Despite there are many ecological interventions that have been proposed recently, such as Green Infrastructure (GI) [88,89], green belts [126], blue-green grids [90,91], nature-based solutions (NBS) [87] or connective ecological corridors [92,93] the view on how the urban and nature are related (Table 1) determines the spatial planning and design approaches hence the impact of nature on the urban form. Where green belts establish a Contrast (see Table 1), green infrastructure brings the urban and nature in Contact, and blue green grids and corridors provide a Contract, nature-based solutions interlink with the concept of nature as being Contingent for the city. Therefore, each view on the relationship between the city and nature (Table 1) has fundamentally different implications for if and how nature is integrated in urban planning. It determines the potential for non-human species to occupy a space hence the ecological quality and biodiversity of the city.

Table 1. Different types of relationships between nature and the city.

	Contrast	Contact	Contract	Contingent
Image of nature	Wilderness	Accessible nature	Ecosystem services	Indistinguishable
Formal interaction	City and nature have sharp boundaries, protected areas	City and nature intertwine	City and nature take each other's form	Nature directs urban form
Landscape first	Landscape is separate	Landscape as basic layer	Landscape is city	Landscape and ecology first, second and last
Spatial ratio	Bring the city to nature: 'satellites' and 'garden cities'	Insert nature into the city 'green wedges' and 'parks'	Go for a complete mix, 'reweaving the urban tapestry' and 'broadacre city'	Landscape and ecology guide the design of the city
Equilibrium	The city takes, landscape gives	Exchange	City gives, landscape receives	Live and work within natural boundaries
City second	City is independent	Green infrastructure in the city	City is landscape	City as representation of its hyperlocal Bioregion
Functional interaction	City and nature are each other's jungle	City and nature come to each other's rescue	City and nature take on each other's form	City utilizing and mimicking natural processes
Human uses	Places to get lost	Regulated leisure in nature	Produce food on your own garden lot	Live and work within natural boundaries
Physical interaction	City and nature keep their distance	City and nature exchange information	City and nature take on each other's construction	City connecting to its hyperlocal Bioregion
Reciprocity	Urban-land distinction: green belts	Urban-land integration: green-blue infrastructure	Urban-land symbiosis: city as a system, metabolic city	Landscape-driven city
Expression	Natural expression of the city: 'non-human' outside	Natural expression of the city: 'well-tempered' environment outside	Expression of city and agriculture: 'new hybrids' in – and outside the city	Ecological expression: natural processes and rewilding of urban space
Vision of the city	From 'Cabanes' to 'Metropolis'	From Green-Blue infrastructure to Lobe city'	From 'Subtopia' to 'Metabolic City'	From 'Nature-Based City' to the City as 'Garden of Eden'

Source: Elaborated on and adapted from [127,128].

Contrast

The first view on how the urban and nature are related is one of contrast. The boundaries between what is urban and what is nature are very sharp, separating the surrounding landscape from the city. There is 'non-human' wilderness outside the urban boundaries, of which people should be afraid, refrain from entering and withdraw behind their physical and cultural walls. Where people hardly enter nature outside their home, the same is happening for nature, not entering inside urban boundaries. Both would get lost. The landscape provides its natural resources to the city for it to be independent and function on its own. In regional urban planning, the city is 'brought to' nature in the form of satellite cities [129], garden cities [130] or growth nuclei [131]. In between the city and these urban centers at a distance, green belts emerged [126]. Nature is seen as everything that is not human.

Contact

When nature and the city intertwine, contact is established. Nature becomes accessible for people. The urban-nature contact is literally designed by bringing green [132] or green-blue infrastructure [133] into the city, in the form of urban parks [134], or green wedges [135], forming a lobe city [136] The landscape forms the basis for locating the blue and green. The connection between urban and nature makes an exchange of humans and non-humans possible. They come to each other's rescue, increasing the ecological capacity in the city, and making the green spaces accessible for recreation and regulated leisure. Nature is tempered within the urban context, accommodating the natural experience for humans.

Contract

When the city is landscape and the landscape is city, they are in a long-lasting contract, as if it were a marriage. Eventually they take on each other's form and have become interdependent. The once boundaries diminish, as city and nature operate as one system, benefitting from each other. Nature provides ecosystem services [137], and the city provides the spaces and resources to make that possible, as a symbiotic relationship. Therefore, the urban planning model is one of a complete mix, a broadacre city [138] that is reweaving the urban tapestry [139]. The city transforms from subtopia [140] to a metabolic city [141] and is seen as an organically functioning system [142], open to the forming of new hybrids such as the growth of food in one's own garden or allotment.

Contingent

Where the contract, contact and contract viewpoints are well-known and for each of these many examples can be witnessed in practice, the contingent perspective is novel and an upcoming concept. With this addition to the spectrum of human-nature relationships, the role of nature and biodiversity in human dominated contexts (e.g., urban) is reoriented, proposing urban ecology as a main driver for urban growth and development. When the city and nature become indistinguishable the shape of the urban form is directed by the intrinsic qualities of nature. Nature and landscape are taken as the point of departure for urban development but also play a guiding role during the process of urbanization and urban use. The ecology is the first, second and last consideration when designing the city. In the nature-driven city [143,144] ecological processes and rewilding determine urban form and use. This urban-nature relationship goes beyond a 'Nature-Based City' [145] as the city connects to the hyperlocal Bioregion [145], aiming to create a 'Garden of Eden' [146]. In this context, people live and work within natural boundaries, whilst the city utilizes and mimics natural processes [147].

The different perspectives, from contrast to contingent, can be seen as a transition, each of the views overlapping in time. It moves from a pure human-centric viewpoint to a perspective that is driven by ecology, within which human activities are embedded. The relationship between urban and nature is key in guiding urban development and design. Firstly, the understanding of the landscape 'beneath' the city provides information on elevation, the natural water system, and the local ecosystem. This 'landscape-first' approach, such as applied in Western Sydney [148,149] and the Zernike project in Groningen, the Netherlands [144,150] and landscape-based urbanism [151,152] can determine areas of largest interest from an ecological point of view, such as where gradients of humid-dry, warm-cold, or nutrient-rich and -poor occur. Secondly, the climate emerging in the urban context can be understood as the starting condition for unique ecological processes such as the settling of organisms, succession, and evolution. Urban heat islands, dry and rocky substrates, or the disruptive urban environment are all attracting a potential ecology that doesn't exist outside the city.

3.3 Symbiocene

It is widely recognized that humankind has entered the Anthropocene, defined as follows: 'considering major and still growing impacts of human activities on earth and atmosphere, and at all, including global, scales, it is more than appropriate to emphasize the central role of mankind in geology and ecology by using the term "Anthropocene" for the current geological epoch' [153]. The impact of these human influences on people because their direct environment has changed causes pessimism and distress makes them homesick at home [154]. This emotion is dubbed solastalgia [155]. This finds its roots in the dichotomy of culture vs. nature, and humans changing the natural landscape so much that these negative emotions occur. It asks for a transition into a new geological time, in which the nature-culture contrast is replaced by a symbiotic relationship, the Symbiocene [156]: 'a period in the history of humanity on this Earth, [which] will be characterized by human intelligence and praxis that replicate the symbiotic and mutually reinforcing life-reproducing forms and processes found in living systems. This period of human existence will be a positive affirmation of life, and it offers the possibility of the complete re-integration of the human body, psyche, and culture with the rest of life' [157]. In this new epoch of mutualism [158] humans would value 'collaboration and interdependence...change the way we relate to each other in an ecosystem dominated by mutually advantageous relationships rather than mutually destructive relationships...the body should be considered part of the properly functioning whole of the external environments: its biodiversity, its social policies, and its practices: We must see ourselves as part of the ecosystem. Eventually, we'll realize that if we destroy the ecosystem, we destroy ourselves' [159].

Current cities are set up as a status quo of opposites and separated spheres, human vs. nature. If ecological processes such as symbiosis, emergence and evolution could work both for human and non-human organisms, the urban planning of the city would be approached as a unified cosmological concept [160]. In this sumbiopolis, sumbiofacts are fabricated by human-nature interactions, as opposed to artefacts, that are artificially made by humans [157].

The design of the sumbiopolis is based on three main elements:

- Orientation on the long term, emphasizing environmental quality and biodiversity, as well as limiting climate change and social justice, as the basis of urban life.
- Allowing social and environmental changes to influence urban planning permanently and determining the shape and use of the city by continuous eco-interventions and adaptations.
- Making inclusive plans for the city, in which the spatial directions and decisions are determined by underprivileged, future (not yet born) generations, or artistic communities, and non-human organisms, such as rivers, mountains, trees, plant and animal species or the land in general.

4. Results

4.1 Retrieval of Design Principles

The turning of urban biodiversity ambitions into urban design and planning demands the bridging of both fields. Traditional ecologists have moved considerably to applying a landscape approach [161–168]. Simultaneously, urban planners and designers have also adopted a landscape approach to dealing with the city, consisting of patches, corridors, and the patch-corridor matrix [162,169,170], which to ecologists is a relatively new context. Benefits of the urban landscape [162,170,167] as the platform of collaboration of urbanists and ecologists to 'mold the land so nature and people both thrive long term' [170].

The literature review, the interviews and roundtables have surfaced a set of eight design principles, which can be used and applied in the concrete urban design process:

1) Develop diverse, relatively isolated, green spaces which may be relatively disturbed by urban/human activity.

2) Create bird habitats that fit the local urban substrates.

3) Create a range of urban heat environments for thermophilic species.

4) Offer a dispersed and differentiated system of green spaces throughout the city to allow the settling of rewilding animals.

5) Make use of the pre-urban landscape-ecology conditions in the city (elevation, water, ecology) to establish humid-dry, warm-cold, or nutrient-rich and -poor gradients.

6) Encapsulate urban climates such as urban heat islands, dry and rocky substrates, and the disruptive urban environment for long term biodiversity.

7) Embed eco-interventions that 'go with the flow' of changed environmental conditions.

8) Make use of the mindsets of formerly excluded human and non-human actors in the urban development process.

4.2 Application of Design Principles

When these design principles are used in a concrete location the specific context will determine the outcomes.

Design of Urban-driven Nature

The typical climatic and urban conditions of San Bernabé (Figure 4), located in the center of the Monterrey metropolis, form the context in which the design principles have been applied. San Bernabé is a densely populated area where about 80,000 people live, many of whom are in disadvantaged conditions. The urban grid consists of a myriad of small street, low-rise buildings, and isolated patches of green. The water system (both natural as the sewage) is for a large part hidden underground. The water and ecological quality are low. The precinct is bound by the Topo Chico hill in the northeast, a State ecological reserve and main source of water and biodiversity. The hill is covered by Submontane shrub with rocky places where Crasas (Succulents) and Agaváceas (Agave family) are present. The abundance of flora attracts pollinators such as butterflies. The area contains over 1000 species of flora and fauna (Table 2).

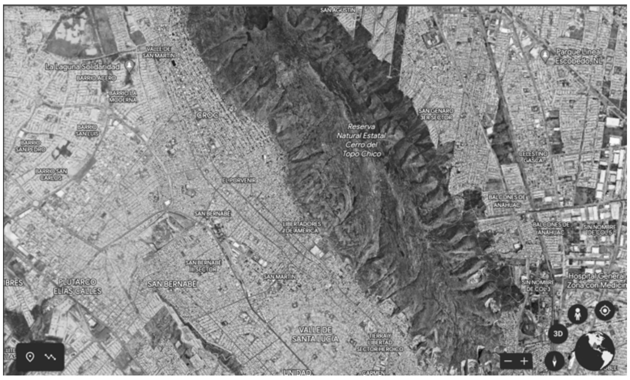

Figure 4. The case study area of San Bernabé.

Table 2. Key Flora and Fauna in the Topo Chico eco-reserve.

Topo Chico eco-reserve	
Flora	**Fauna**
Anacahuita Cordia Boissieri (Mexican olive)	*Lynx Rufus* (Red Lynx)
Vachellia Rigidula / Chaparro Prieto (Blackbrush Acacia)	*Armadillo Dasypus Novemcinctus* (Nine-banded Long-nosed Armadillo)
Agave Lechuguilla (Shin Dagger or Tampico Fiber)	*Parabuteo Unicinctus* (Bay-winged Hawk)
Sotol Dasylirion Texanum (Texas Sotol)	*Crotalus Atrox* (Western Diamond-back Rattlesnake)
Ocotillo Fouquieria Splendens (Devil's Walking Stick or Candle-wood)	*Coleonyx Brevis* (Texas Banded Gecko)
Laredo Coryphantha Nicklesiae (Nickle's Cactus)	*Danaus Plexippus* (Monarch butterfly)
Cochlospermum Wrightii (Wright's yellowshow)	*Gopherus Berlandieri* (Berlandier's Tortoise)
Retama Parkinsonia Aculeata (Mexican palo verde or Jelly bean tree)	*Bassariscus Astutus* (Raccoon-fox, or ring-tailed cat)
Huizache Vachellia Farnesiana (sweet acacia)	*Micrurus Tener* (Arlequin coral snake)

Source: [171].

This precinct is used to apply the design principles at two different scales: Ecological corridors structuring the masterplan, and the transitional linear park from mountain to precinct.

Master Plan

The Master Plan (Figure 5) is based on a combination of all eight design principles. The pre-urban landscape (principle 5) of the Topo Chico Mountain and the river plains surrounding the mountain have been taken as the basis for the ecological urban design of the Master Plan. The underlying system of elevation, hydrology and ecological remnants determine the localization of the green patches, and the main structure of the connecting historic river system and offer a range of native and local species belonging to the Tamaulipan Matorral and Tamaulipan Mesquital eco-regions (Table 3) to colonize these regenerated green spaces. These rivers are predominantly dry, and carry only occasionally water, which attracts species that can survive during long dry periods and simultaneously cope with extreme flooding conditions. Biotopes of floodplains, riparian zones, and grasslands with sparsely scattered trees and shrubs, will emerge in and along the riverbed, hosting species of the lower plains (Tamaulipan Mesquital), especially riparian forests, featuring species such as Carya Palmeri [172] mixed with tall grasses. The canopy in the upper parts of the riverbed can be dense and reach 15 meters high.

The Master Plan features an interconnected network of dispersed and different green spaces (principle 4). Some of these are connected through ecological corridors such as the riparian zones along historic rivers and along the major road, but others are more isolated to provide specific ecological conditions (grasslands, open public spaces with low shrubs and vegetation). In the Master Plan, no final and detailed designs for these green spaces are proposed, but rather the basic conditions are created to host a diverse range of ecologies where auto-rewilding species can settle. In the plan four colonias, or communities, each establish an ecology that differs from the others. The conditions in the Topo Chico area provide spaces for water storage, connecting the streams to discharge the water from the mountain, while in the Lago-sector the Aztlán canal is regenerated as a permeable corridor. The Panteón (cemetery) sector is an arid area that suffers from occasional heavy flood risk. In this area, the conditions are created to absorb the water in extended green spaces, while in the CCAI sector a new community center offers the possibility to connect the ecological corridors with a large new park.

In the precinct the disturbed (major roads and avenues), isolated (patches of grasslands, shrubs, and urban forests) and diverse (wet and dry, 'foresty', meadows, bare, and diversity of larger and smaller) green spaces (principle 1) are dispersed over the area, sometimes interlinked, but more often kept separate.

Which species will land in which area depends on the conditions, the possibility of occupying the area and coincidence. In the design, the objective to plan for a certain ecotype or species is consciously excluded because nature is invited to occupy places and substrates as it wants, and only the general conditions (humid, water intense and ecological corridors, green niche patches and dry and rocky substrates formed by dwellings and impermeable pavements) are proposed. This allows for transgressing animals (small mammals, birds, reptiles, amphibians, and insects) that come from the Topo Chico Mountain and use the riparian zones along the historic river system and smaller streams. Their preferential habitats and demands are used to create the network (principle 8). Birds are invited to find habitats by providing nesting opportunities in the drier, rocky areas in public spaces and on roofs (principle 2). The warmer places in the precinct are not denied but instead used to create habitats for heat-loving species along streets, in public spaces and parks with fewer trees (principle 3). These warmer places, the major avenues, and dry squares, although capitalize their warm and disturbed conditions, are also encapsulated by the broader green network of riparian riverine zones and larger parks (principle 6).

Finally, the opportunities that changes in the urban realm offer, such as relocation of residential dwellings (1800 in the Lago sector and 1244 in the Panteón sector) and a new community center (CCIA) open opportunities for eco-interventions (principle 7). The spaces that are left behind can be occupied by novel ecologies, such as pioneer species that make use of the former urban conditions and substrates. Moreover, the new residential and commercial areas offer new spaces, such as roofs, gardens, and public spaces that are attractive to native species of the local ecoregions.

Figure 5. Masterplan "Reconectando San Bernabé".

Source: Carlos F. Fonseca, Pricila Dávila, Daniela Lozano, Daniela Morales, Melissa A. Cortés, Diana Carolina Robles, Rubén Ram Guajardo, Nesin Inayeh; 2023.

Table 3. Key species that are found or can be expected in the ecological corridor biotopes.

	Riparian zones and floodplains	Grasslands
General	Granjeno (*Celtis Ehrenbergiana*) Sugar hackberry (*Celtis Laevigata*) Texas ebony (*Ebenopsis Ebano*) anacua (*Ehretia Anucua*) Mexican ash (*Fraxinus Berlandierana*) Tepeguaje (*Leucaena Pulverulenta*) Cedar elm (*Ulmus Crassifolia*)	Texas grama (*Bouteloua Rigidiseta*) Little bluestem (*Schizachyrium Scoparium*) Sand dropseed (*Sporobolus Cryptandrus*) Bull-nettle (*Cnidoscolus Texanus*) Shrubby blue sage (*Salvia Ballotiflora*) Hairy tubetongue (*Justicia Pilosella*) Texas palafoxia (*Palofoxia Texana*) Hairy zexmania (*Wedelia Texana*)
Riverbanks	Black mimosa (*Mimosa Asperata*) Black willow (*Salix Nigra*) Giant reed (*Arundo Donax*)	
Common	Spanish moss (*Tillandsia Usneoides*) Bailey's ballmoss (*Tillandsia Baileyi*) Pecan (*Carva Illinoinensis*) Plateau live oak (*Quercus Fusiformis*) Sierra Madre torchwood (*Amyris Madrensis*) Texas torchwood (*Amyris Texana*) Barbados cherry (*Malpighia Glabra*) Catclaw acacia (*Senegalia Wrightii*) Brushholly (*Xylosma Flexuosa*)	
Rare	Montezuma cypresses (*Taxodium Mucronatum*) Mexican sabal palm (*Sabal Mexicana*)	
Herbaceous layer	Bunch cutgrass (*Leersia Monandra*) Tropical sage (*Salvia Coccinea*) Blue boneset (*Tamaulipa Azurea*) [173–176]	

Linear Park

The linear park (Figure 6) forms the transition zone of the steep slopes of Topo Chico Mountain and the flat floodplain that is the ground layer of San Bernabé. The valuable resource of the ecological reserve on Topo Chico Mountain is reconnected with the urban precinct by introducing this new green patch between the two. The park uses the pre-urban landscape (principle 5) as the point of departure of the design. Where the slope transits to the plain water stagnates and this space can potentially be used to store runoff water in a series of ponds. This prevents flooding downstream, in the San Bernabé precinct and offers an ecological value by keeping a higher humidity than both in the dryer mountain slopes and the urban precinct. The transition from slope to plain is a small replication of the larger landscape of the Tamaulipan Matorral and Tamaulipan Mesquital eco-regions. This offers native species from the region (Table 4) the eco-condition to find their habitat in the linear park. The needs of these species are used to design the different green spaces (principle 8) and create the habitats that provide shelter, the space to forage, rest and replicate within the linear park. It allows the animals from the mountainous zone to migrate into the green urban network of rivers and streams. Within the lengthy park, the green spaces are dispersed and very different (principle 4), with a range of forest types, smaller interconnected ponds that store rainwater, wetlands, and open green spaces with shrubs and grasses. The diversity of these green spaces (principle 1) ranges from riparian zones in the floodplains, smaller and open grasslands, rocky uplands and shrubs on the steeper parts, and arid areas closer to the urban precinct with cacti and agaves (Table 4). The newly designed urban edge with residential dwellings is encapsulated by the linear park (principle 6), marking the transition between the urban and mountain by creating a gradient of wet (foothill) to dry (residential) zone. The relocation of housing from this zone to the urban edge and further inside the urban fabric opens the opportunity for pioneer species to make use of the substrate that is left behind and forms a part of the ground conditions in the linear park (principle 7). This can be rocky and disturbed terrain (principle 1), in which the flora can settle and attract insects, and other animals. Especially the creation of bird habitats of shrubs and urban forest patches at the foot of the mountain use the former substrate of the urbanity that was here before, waiting to be occupied by mountain birds and other animals (principle 2). Also at this scale, the design provides the ecological conditions (humidity, gradients, fertility, and differentiated green patches and habitats) to offer an environment to the species from the ecoregions that flora and fauna can occupy as they see fit (principle 8).

Figure 6. Linear park. Masterplan "Reconectando San Bernabé".

Source: Carlos F. Fonseca, Pricila Dávila, Daniela Lozano, Daniela Morales, Melissa A. Cortés, Diana Carolina Robles, Rubén Ram Guajardo, Nesin Inayeh; 2023.

5. Discussion and Conclusions

Many, older, ecological studies tend to focus on areas outside cities [183], discuss the urban-rural gradient [184,185] or aim to integrate ecology with socio-economic and planning perspectives in the urban-rural cultural landscape [186]. Few studies take the urban environment as the point of departure. This has led to an underestimation of potential ecological qualities in cities. The mismatch between the spatiality and temporality of ecological processes, and human dimensions of decision making and planning have not only limited the understanding of the value of urban ecology but also its integration into urban planning [187].

Though it is widely recognized that ecological knowledge is important to urban planning [188–192], key questions are raised about the integration of that knowledge in urban planning [188,189,192], possible adjustments to the planning process [192] and the way this knowledge can be best obtained [192]. Often this starts from the urban habitat, with the objective to maintain existing biodiversity and develop a management strategy to do so [189,191]. Here, the main concern is how to limit the impacts of urbanization on (native) ecology [188], for which urbanization is seen as a threat for the overall biodiversity [193]. In attempts to create an ecology *of* the city (and not *in* the city) concepts are developed that intervene in the urban system to conserve and maintain existing biodiversity [190] but refrain from looking at the city and how it could provide the conditions for creating a unique urban ecology. It is rather using ecological science to react from an ecological perspective on

Table 4. Key species that are found or can be expected in the biotopes of the Linear park.

Riparian zones and floodplains	Grasslands	Xeric rocky uplands/shrublands	Cacti, Agave
Granjeno (*Celtis Ehrenbergiana*) Sugar hackberry (*Celtis Laevigata*) Texas ebony (*Ebenopsis Ebano)* anacua (*Ehretia Anucua)* Mexican ash (*Fraxinus Berlandierana*) Tepeguaje (*Leucaena Pulverulenta*) Cedar elm (*Ulmus Crassifolia*)	Texas grama (*Bouteloua Rigidiseta*) Little bluestem (*Schizachyrium Scoparium*) Sand dropseed (*Sporobolus Cryptandrus*) Bull-nettle (*Cnidoscolus Texanus*) Shrubby blue sage (*Salvia Ballotiflora*) Hairy tubetongue (*Justicia Pilosella*) Texas palafoxia (*Palofoxia Texana*) Hairy zexmania (*Wedelia Texana*)	Cenizo (*Leucophyllum Frutescens)* Guajillo (*Acacia Berlandieri)* Texas kidneywood (*Eysenhardtia Texana)* Twisted acacia (*Vachellia Schaffneri)* Spanish dagger (*Yucca Treculeana*) Baretta (*Helietta Parvifolia*) Creosote bush (*Larrea Tridentata*)	Lace cactus (*Echinocactus Reichenbachii*) Horse-crippler cactus (*Echinocactus Texensis)* Root cactus (*Acanthocereus scheeri*) Barbed wire cactus (*Acanthocereus Tetragonus)* Star cactus (*Astrophytum Asterias*) Runyon's beehive cactus (*Coryphantha Macromeris var. Runyonii*) Berlandier's hedgehog (*Echinocereus Berlandieri)* Pitaya (*Echinocereus enneacanthus var. brevispinus*) Allicoche hedgehog cactus (*Echinocereus papillosus)* Ladyfinger hedgehog (*Echinocereus Pentalophus)* Dahlia cactus (*Echinocereus Poselgeri*) Junior Tom Thumb cactus (*Escobaria emskoetteraana*) Turk's head barrel cactus (*Ferocactus Hamatacanthus var. sinuatus*) Peyote (*Lophophora Williamsii*) Heyder's pincushion cactus (*Mammillaria Heyderi)* Hair-covered cactus (*Mammillairia Prolifera var. texana*) pale mammillaria (Mammillaria Spharrica) Twisted rib cactus (*Thelocactus Setispinus)* [177] *Astrophytum Caput-medusae* [178]
Black mimosa (*Mimosa Asperata*) Black willow (*Salix Nigra*) Giant reed (*Arundo Donax*)		Narrowleaf thryallis (*Galphimia Angustifolia*) Peonia (*Acourtia Runcinata*) Gregg's senna (*Chamaecrista Greggii*) Plateau rocktrumpet (*Macrosiphonia Macrosiphon*) Hairy zexmania (*Wedelia Hispida*) [179,180]	
Spanish moss (*Tillandsia Usneoides*) Bailey's ballmoss (*Tillandsia Baileyi*) Pecan (*Carva Illinoinensis*) Plateau live oak (*Quercus Fusiformis*) Sierra Madre torchwood (*Amyris Madrensis*) Texas torchwood (*Amyris Texana*) Barbados cherry (*Malpighia Glabra*) Catclaw acacia (*Senegalia Wrightii*) Brushholly (*Xylosma Flexuosa*)		*Opuntia leptocaulis, Opunia lindheimeri* *Prosopis juliflora, Prosopis laevigata* *Yucca treculeana* *Salvia ballotaeflora* *Jatropha dioica, Leucophyllum texanum (cenizo)* *Mammillaria hemisphaerica, Leucaena pulverulenta (Tepeguaje)* *Mimosa biuncifera* *Acacia spp.* *Helietta parvifolia, Neopringlea integrifolia*	
Montezuma cypresses (*Taxodium Mucronatum*) [181] Mexican sabal palm (*Sabal Mexicana*)		Shadowrich places: *Quercus, Arbutus, Yucca, Cercocarpus, Bauhinia* [182]	
Bunch cutgrass (*Leersia Monandra*) Tropical sage (*Salvia Coccinea*) Blue boneset (*Tamaulipa Azurea*) [173-176]		*Agave victoria-reginae, Clappia, Nephropetalum, Pterocaulon, Runyonia*	

how to deal with the urban area [190] than building on the urban climate and environmental conditions, to guide the city to novel ecological landscapes.

An attempt to integrate ecological knowledge in the planning process is proposed by applying 'interdisciplinary research' [189], which aims to integrate ecological and social systems. This presupposes a balance between the ecological and social systems. Either urban systems destroy valuable (native) ecology, or the urban climate differs from the rural surroundings hence it creates a different condition for nature. This, apart from most current research, requires a new ecological science that understands the ecology that emerges from the urban context and creates ecology *with* the city.

The integration of ecology in urban design can be supported by the knowledge generated through an ecological analysis [191], informing biodiverse sensitive urban designs that create habitats, promote dispersal of species, and foster community stewardship. This, however, focuses, again, on protection and persistence [188], and not so much on the development and creation of habitats that fit the urban climate.

In this article, the city is seen as a specific ecosystem, which is formed by its own urban climate, which distinguishes itself from ecosystems outside cities. This offers opportunities to enhance urban biodiversity. In this study, urban ecology and the urban-nature relationship have been used to develop design principles that can be applied in urban design projects to increase urban biodiversity. In summary, the eight design principles focus:

- Making use of the pre-urban landscape-ecology.
- The creation of isolated, dispersed, and disturbed green spaces throughout the city.
- To make use of urban substrates.
- Establish environments that suit thermophilic species.
- Embrace extreme urban climates (such as heat islands).
- Embed eco-interventions to accommodate rapid changes in the city.
- Include non-human actors in the design process.

These design principles can be used to plan for a diversity of heated, dry, and rocky urban conditions. The urban designs are a spatial response to the question how conditions for enhanced urban biodiversity can be created. The examples in Monterrey are in the design stage and have not yet been implemented. As such, it is difficult to measure the ecological gains resulting from the designs. This would require additional research and longitudinal monitoring of species.

Further study is also needed to understand how cities create urban climates, the potential ecological impact, and how the design of urban landscapes enhances the processes of nature occupying these novel ecological niches. The role of auto-rewilding nature shows, however, that human-induced design must move into a symbiotic relationship with nature to co-evolve in a mutual urban ecology.

Author Contributions

Conceptualization, R.R.; methodology, R.R.; software, n/a; validation, N.T.; formal analysis, R.R.; investigation, R.R.; resources, D.R.; data curation, D.R.; writing—original draft preparation, R.R.; writing—review and editing, D.R. and N.T.; visualization, D.R.; supervision, R.R.; project administration, D.R.; funding acquisition, n/a. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Ethics

For the presented project, an ethical approval was not required, since specific consent procedures were not required for this study. The development of this research was based on the ethical principles and code of conduct proposed by the American Psychological Association (APA), guided by the principles of beneficence, fidelity and responsibility for one's own conduct, integrity, justice and respect for the rights and dignity of persons.

Data Availability Statement

No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Acknowledgments

The authors would like to sincerely thank the students from the Master of Architecture and Urban Design Program of Tecnológico de Monterrey for their contributions to apply the design principles in their projects and herewith enhance this research during the Master design studio (Spring 2023): Carlos F. Fonseca, Pricila Dávila, Daniela Lozano, Daniela Morales, Melissa A. Cortés, Diana Carolina Robles, Rubén Ram Guajardo, Nesin Inayeh.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Coman, I.A., Cooper-Norris, C.E., Longing, S.,

et al., 2022. It is a wild world in the city: Urban wildlife conservation and communication in the age of COVID-19. Diversity. 14(7), 539.
DOI: https://doi.org/10.3390/d14070539

[2] Silva-Rodríguez, E.A., Gálvez, N., Swan, G.J., et al., 2021. Urban wildlife in times of COVID-19: What can we infer from novel carnivore records in urban areas?. Science of the Total Environment. 765, 142713.
DOI: https://doi.org/10.1016/j.scitotenv.2020.142713

[3] Zellmer, A.J., Wood, E.M., Surasinghe, T., et al., 2020. What can we learn from wildlife sightings during the COVID-19 global shutdown?. Ecosphere. 11(8), e03215.
DOI: https://doi.org/10.1002/ecs2.3215

[4] Mittermeier, R.A., Turner, W.R., Larsen, F.W., et al., 2011. Global biodiversity conservation: The critical role of hotspots. Biodiversity hotspots: Distribution and protection of conservation priority areas. Springer-Verlag: Berlin. pp. 3–22.

[5] Reid, W.V., 1998. Biodiversity hotspots. Trends in Ecology & Evolution. 13(7), 275–280.
DOI:https://doi.org/10.1016/S0169-5347(98)01363-9

[6] Trew, B.T., Maclean, I.M., 2021. Vulnerability of global biodiversity hotspots to climate change. Global Ecology and Biogeography. 30(4), 768–783.
DOI: https://doi.org/10.1111/geb.13272

[7] How do Humans Affect Biodiversity? [Internet]. The Royal Society. [cited 2023 Mar 26]. Available from: https://royalsociety.org/topics-policy/projects/biodiversity/human-impact-on-biodiversity/

[8] Schilthuizen, M., 2018. Darwin comes to town. How the urban jungle drives evolution. Quercus: London.

[9] Tucker, M.A., Schipper, A.M., Adams, T.S., et al., 2023. Behavioral responses of terrestrial mammals to COVID-19 lockdowns. Science. 380(6649), 1059–1064.
DOI: https://doi.org/10.1126/science.abo6499

[10] Almond, R.E.A., Grooten, M., Juffe Bignoli, D., et al., 2022. Living Planet Report 2022—Building a nature positive society. WWF: Gland.

[11] Sweet, F.S.T., Apfelbeck, B., Hanusch, M., et al., 2022. Data from public and governmental databases show that a large proportion of the regional animal species pool occur in cities in Germany. Journal of Urban Ecology. 8(1).
DOI: https://doi.org/10.1093/jue/juac002

[12] Sukopp, H., 2008. On the early history of urban ecology in Europe. Urban ecology: An international perspective on the interactions between humans and nature. Springer: Berlin. pp. 79–97.

[13] Secretariat of the Convention on Biological Diversity, 2012. Cities and biodiversity outlook. CBD: Montreal.

[14] Chocholoušková, Z., Pyšek, P., 2003. Changes in composition and structure of urban flora over 120 years: A case study of the city of Plzeň. Flora-Morphology, Distribution, Functional Ecology of Plants. 198(5), 366–376.
DOI: https://doi.org/10.1078/0367-2530-00109

[15] Gaston, K.J., Warren, P.H., Thompson, K., et al., 2005. Urban domestic gardens (IV): The extent of the resource and its associated features. Biodiversity & Conservation. 14, 3327–3349.
DOI: https://doi.org/10.1007/s10531-004-9513-9

[16] Jaganmohan, M., Vailshery, L.S., Nagendra, H., 2013. Patterns of insect abundance and distribution in urban domestic gardens in Bangalore, India. Diversity. 5(4), 767–778.
DOI: https://doi.org/10.3390/d5040767

[17] Smith, R.M., Thompson, K., Hodgson, J.G., et al., 2006. Urban domestic gardens (IX): Composition and richness of the vascular plant flora, and implications for native biodiversity. Biological Conservation. 129(3), 312–322.
DOI: https://doi.org/10.1016/j.biocon.2005.10.045

[18] Smith, R.M., Warren, P.H., Thompson, K., et al., 2006. Urban domestic gardens (VI): Environmental correlates of invertebrate species richness. Biodiversity & Conservation. 15, 2415–2438.
DOI: https://doi.org/10.1007/s10531-004-5014-0

[19] Zerbe, S., Maurer, U., Schmitz, S., et al., 2003. Biodiversity in Berlin and its potential for nature conservation. Landscape and Urban Planning. 62(3), 139–148.
DOI: https://doi.org/10.1016/S0169-2046(02)00145-7

[20] Freitag, B.M., Nair, U.S., Niyogi, D., 2018. Urban

modification of convection and rainfall in complex terrain. Geophysical Research Letters. 45(5), 2507–2515.
DOI: https://doi.org/10.1002/2017GL076834

[21] Ginzburg, A.S., Dokukin, S.A., 2021. Influence of thermal air pollution on the urban climate (estimates using the COSMO-CLM model). Izvestiya, Atmospheric and Oceanic Physics. 57, 47–59.
DOI: https://doi.org/10.1134/S0001433821010059

[22] Paul, S., Ghosh, S., Mathew, M., et al., 2018. Increased spatial variability and intensification of extreme monsoon rainfall due to urbanization. Scientific Reports. 8, 3918.
DOI: https://doi.org/10.1038/s41598-018-22322-9

[23] Sobstyl, J.M., Emig, T., Qomi, M.A., et al., 2018. Role of city texture in urban heat islands at nighttime. Physical Review Letters. 120(10), 108701.
DOI: https://doi.org/10.1103/PhysRevLett.120.108701

[24] Lombardi, J.V., Stasey, W.C., Caso, A., et al., 2022. Ocelot density and habitat use in Tamaulipan thornshrub and tropical deciduous forests in Northeastern México. Journal of Mammalogy. 103(1), 57–67.
DOI: https://doi.org/10.1093/jmammal/gyab134

[25] Domínguez Gómez, T.G., González Rodríguez, H., Ramírez Lozano, R.G., et al., 2013. Structural diversity of the tamaulipan thornscrub during dry and wet seasons. Forestales. 4(17), 106–123. (in Spanish).

[26] Digital Observatory for Protected Areas (DOPA) Explorer, Tamaulipan Matorral [Internet]. European Commission. [cited 2023 Apr 6]. Available from: https://dopa-explorer.jrc.ec.europa.eu/ecoregion/51311

[27] Digital Observatory for Protected Areas (DOPA) Explorer, Tamaulipan Mesquital [Internet]. European Commission. [cited 2023 Apr 6]. Available from: https://dopa-explorer.jrc.ec.europa.eu/ecoregion/51312

[28] Tamaulipan Matorral [Internet]. OneEarth. [cited 2023 Apr 5]. Available from: https://www.oneearth.org/ecoregions/tamaulipan-matorral/

[29] Tamaulipan Mezquital [Internet]. OneEarth. [cited 2023 Apr 5]. Available from: https://www.oneearth.org/ecoregions/tamaulipan-mezquital/

[30] Gilbert, O.L., 1989. The ecology of urban habitats. Chapman and Hall: London.

[31] McPhearson, T., Pickett, S.T., Grimm, N.B., et al., 2016. Advancing urban ecology toward a science of cities. BioScience. 66(3), 198–212.
DOI: https://doi.org/10.1093/biosci/biw002

[32] Pickett, S.T., Cadenasso, M.L., Childers, D.L., et al., 2016. Evolution and future of urban ecological science: Ecology in, of, and for the city. Ecosystem Health and Sustainability. 2(7), e01229.
DOI: https://doi.org/10.1002/ehs2.1229

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

[34] Alberti, M., Marzluff, J.M., Shulenberger, E., et al., 2003. Integrating humans into ecology: Opportunities and challenges for studying urban ecosystems. BioScience. 53(12), 1169–1179.
DOI: https://doi.org/10.1641/0006-3568(2003)053[1169:IHIEOA]2.0.CO;2

[35] Shochat, E., 2004. Credit or debit? Resource input changes population dynamics of city-slicker birds. Oikos. 106(3), 622–626.
DOI: https://doi.org/10.1111/j.0030-1299.2004.13159.x

[36] Wandeler, P., Funk, S.M., Largiader, C.R., et al., 2003. The city-fox phenomenon: genetic consequences of a recent colonization of urban habitat. Molecular Ecology. 12(3), 647–656.
DOI: https://doi.org/10.1046/j.1365-294X.2003.01768.x

[37] Shochat, E., Lerman, S.B., Katti, M., et al., 2004. Linking optimal foraging behavior to bird community structure in an urban-desert landscape: Field experiments with artificial food patches. The American Naturalist. 164(2), 232–243.
DOI: https://doi.org/10.1086/422222

[38] Imhoff, M.L., Tucker, C.J., Lawrence, W.T., et al., 2000. The use of multisource satellite and geospatial data to study the effect of urbanization on primary productivity in the United States. IEEE Transactions on Geoscience and Remote Sensing. 38(6), 2549–2556.
DOI: https://doi.org/10.1109/36.885202

[39] Kaye, J.P., McCulley, R.L., Burke, I.C., 2005. Car-

bon fluxes, nitrogen cycling, and soil microbial communities in adjacent urban, native and agricultural ecosystems. Global Change Biology. 11(4), 575–587.
DOI: https://doi.org/10.1111/j.1365-2486.2005.00921.x

[40] Parris, K.M., Hazell, D.L., 2005. Biotic effects of climate change in urban environments: The case of the grey-headed flying-fox (*Pteropus poliocephalus*) in Melbourne, Australia. Biological Conservation. 124(2), 267–276.
DOI: https://doi.org/10.1016/j.biocon.2005.01.035

[41] Hatzofe, O., Yom-Tov, Y., 2002. Global warming and recent changes in Israel's avifauna note. Israel Journal of Zoology. 48(4), 351–357.

[42] Murgui, E., Valentin, A., 2003. Relationships between the characteristics of the urban landscape and the introduced bird community in the city of Valencia (Spain). ARDEOLA. 50(2), 201–214.

[43] Marzluff, J.M., 2008. Island biogeography for an urbanizing world: How extinction and colonization may determine biological diversity in human-dominated landscapes. Urban ecology. Springer: Boston. pp. 355–371.

[44] McIntyre, N.E., 2011. Urban ecology: Definitions and goals. The Routledge handbook of urban ecology. Routledge: Abingdon. pp. 7–16.

[45] McKinney, M.L., 2008. Effects of urbanization on species richness: A review of plants and animals. Urban Ecosystems. 11, 161–176.
DOI: https://doi.org/10.1007/s11252-007-0045-4

[46] Pouyat, R.V., Yesilonis, I.D., Szlavecz, K., et al., 2008. Response of forest soil properties to urbanization gradients in three metropolitan areas. Landscape Ecology. 23, 1187–1203.
DOI: https://doi.org/10.1007/s10980-008-9288-6

[47] Wu, J.G., Buyantuyev, A., Jenerette, G.D., et al., 2011. Quantifying spatiotemporal patterns and ecological effects of urbanization: A multiscale landscape approach. Applied urban ecology: A global framework. Blackwell: Oxford. pp. 35–53.

[48] Connell, J.H., 1978. Diversity in tropical rain forests and coral reefs: High diversity of trees and corals is maintained only in a nonequilibrium state. Science. 199(4335), 1302–1310.
DOI: https://doi.org/10.1126/science.199.4335.1302

[49] Callaghan, C.T., Poore, A.G., Major, R.E., et al., 2021. How to build a biodiverse city: Environmental determinants of bird diversity within and among 1581 cities. Biodiversity and Conservation. 30, 217–234.
DOI: https://doi.org/10.1007/s10531-020-02088-1

[50] de Carvalho, C.A., Raposo, M., Pinto-Gomes, C., et al., 2022. Native or exotic: A bibliographical review of the debate on ecological science methodologies: Valuable lessons for urban green space design. Land. 11(8), 1201.
DOI: https://doi.org/10.3390/land11081201

[51] Fidino, M., Gallo, T., Lehrer, E.W., et al., 2021. Landscape-scale differences among cities alter common species' responses to urbanization. Ecological Applications. 31(2), e02253.
DOI: https://doi.org/10.1002/eap.2253

[52] Beninde, J., Veith, M., Hochkirch, A., 2015. Biodiversity in cities needs space: A meta-analysis of factors determining intra-urban biodiversity variation. Ecology Letters. 18(6), 581–592.
DOI: https://doi.org/10.1111/ele.12427

[53] Lokatis, S., Jeschke, J.M., Bernard-Verdier, M., et al., 2023. Hypotheses in urban ecology: Building a common knowledge base. Biological Reviews. 98(5), 1530–1547.
DOI: https://doi.org/10.1111/brv.12964

[54] Kinzig, A.P., Warren, P., Martin, C., et al., 2005. The effects of human socioeconomic status and cultural characteristics on urban patterns of biodiversity. Ecology and Society. 10(1).

[55] Catterall, C.P., Cousin, J.A., Piper, S., et al., 2010. Long-term dynamics of bird diversity in forest and suburb: decay, turnover or homogenization?. Diversity and Distributions. 16(4), 559–570.
DOI: https://doi.org/10.1111/j.1472-4642.2010.00665.x

[56] Oberndorfer, E., Lundholm, J., Bass, B., et al., 2007. Green roofs as urban ecosystems: Ecological structures, functions, and services. BioScience. 57(10), 823–833.
DOI: https://doi.org/10.1641/B571005

[57] Williams, N.S., Lundholm, J., Scott MacIvor, J., 2014. Do green roofs help urban biodiversity

conservation?. Journal of Applied Ecology. 51(6), 1643–1649.
DOI: https://doi.org/10.1111/1365-2664.12333

[58] Pysek, P., 1989. On the richness of Central European urban flora. Preslia. 61, 329–334.

[59] Grime, J.P., 1973. Competitive exclusion in herbaceous vegetation. Nature. 242, 344–347.
DOI: https://doi.org/10.1038/242344a0

[60] Luck, G.W., 2007. A review of the relationships between human population density and biodiversity. Biological Reviews. 82(4), 607–645.
DOI: https://doi.org/10.1111/j.1469-185X.2007.00028.x

[61] MacArthur, R.H., Wilson, E.O., 1967. The theory of island biogeography. Princeton University Press: Princeton.

[62] Blair, R.B., 2001. Birds and butterflies along urban gradients in two ecoregions of the United States: Is urbanization creating a homogeneous fauna? Biotic homogenization. Kluwer Academic/Plenum Publishers: New York. pp. 33–56.

[63] Miles, L.S., Rivkin, L.R., Johnson, M.T., et al., 2019. Gene flow and genetic drift in urban environments. Molecular Ecology. 28(18), 4138–4151.
DOI: https://doi.org/10.1111/mec.15221

[64] Sartori, R.A., Gomes, A., Narcizo, A., et al., 2023. Urban ecology and biological studies in Brazilian cities: A systematic review. Urban Ecosystems. 26, 547–558.
DOI: https://doi.org/10.1007/s11252-022-01324-6

[65] Costa, S., 2018. Entangled inequalities, state, and social policies in contemporary Brazil. The social life of economic inequalities in contemporary Latin America. Palgrave Macmillan: Cham. pp. 59–80.

[66] Gould, K.A., Lewis, T.L., 2017. Green gentrification: Urban sustainability and the struggle for environmental justice. Routledge: Abingdon.

[67] Rigolon, A., Browning, M.H., Lee, K., et al., 2018. Access to urban green space in cities of the Global South: A systematic literature review. Urban Science. 2(3), 67.
DOI: https://doi.org/10.3390/urbansci2030067

[68] Schwarz, K., Fragkias, M., Boone, C.G., et al., 2015. Trees grow on money: Urban tree canopy cover and environmental justice. PloS One. 10(4), e0122051.
DOI: https://doi.org/10.1371/journal.pone.0122051

[69] Schell, C.J., Dyson, K., Fuentes, T.L., et al., 2020. The ecological and evolutionary consequences of systemic racism in urban environments. Science. 369(6510), eaay4497.
DOI: https://doi.org/10.1126/science.aay4497

[70] van Zyl, B., Cilliers, E.J., Lategan, L.G., et al., 2021. Closing the gap between urban planning and urban ecology: A South African perspective. Urban Planning. 6(4), 122–134.
DOI: https://doi.org/10.17645/up.v6i4.4456

[71] Pickett, S.T.A., Burch, W.R., Dalton, S.E., et al., 1997. Integrated urban ecosystem research. Urban Ecosystems. 1, 183–184.
DOI: https://doi.org/10.1023/A:1018579628818

[72] Childers, D.L., Cadenasso, M.L., Grove, J.M., et al., 2015. An ecology for cities: A transformational nexus of design and ecology to advance climate change resilience and urban sustainability. Sustainability. 7(4), 3774–3791.
DOI: https://doi.org/10.3390/su7043774

[73] Grove, J.M., Childers, D.L., Galvin, M., et al., 2016. Linking science and decision making to promote an ecology for the city: Practices and opportunities. Ecosystem Health and Sustainability. 2(9), e01239.
DOI: https://doi.org/10.1002/ehs2.1239

[74] Schwarz, K., Herrmann, D.L., 2016. The subtle, yet radical, shift to ecology for cities. Frontiers in Ecology and the Environment. 14(6), 296–297.
DOI: https://doi.org/10.1002/fee.1288

[75] McDonnell, M.J., MacGregor-Fors, I., 2016. The ecological future of cities. Science. 352(6288), 936–938.
DOI: https://doi.org/10.1126/science.aaf3630

[76] Osmond, P., Pelleri, N., 2017. Urban ecology as an interdisciplinary area. Encyclopedia of sustainable technologies. Elsevier: Amsterdam. pp. 31–42.

[77] Tan, P.Y., 2017. Perspectives on greening of cities through an ecological lens. Greening cities. Springer: Cham. pp. 15–39.

[78] Heymans, A., Breadsell, J., Morrison, G.M., et al., 2019. Ecological urban planning and design: A

systematic literature review. Sustainability. 11(13), 3723.
DOI: https://doi.org/10.3390/su11133723

[79] Byrne, L.B., 2022. Ecology with cities. Urban Ecosystems. 25, 835–837.
DOI: https://doi.org/10.1007/s11252-021-01185-5

[80] Kowarik, I., 2023. Urban biodiversity, ecosystems and the city. Insights from 50 years of the Berlin School of urban ecology. Landscape and Urban Planning. 240, 104877.
DOI: https://doi.org/10.1016/j.landurbplan.2023.104877

[81] McDonnell, M.J., Hahs, A.K., 2013. The future of urban biodiversity research: moving beyond the 'low-hanging fruit'. Urban Ecosystems. 16, 397–409.
DOI: https://doi.org/10.1007/s11252-013-0315-2

[82] Knapp, S., von der Lippe, M., Kowarik, I., 2022. Interactions of functional traits with native status and ecosystem novelty explain the establishment of plant species within urban ecosystems: Evidence from Berlin, Germany. Frontiers in Ecology and Evolution. 10, 790340.
DOI: https://doi.org/10.3389/fevo.2022.790340

[83] Rega-Brodsky, C.C., Aronson, M.F., Piana, M.R., et al., 2022. Urban biodiversity: State of the science and future directions. Urban Ecosystems. 25, 1083–1096.
DOI: https://doi.org/10.1007/s11252-022-01207-w

[84] Aronson, M.F., Lepczyk, C.A., Evans, K.L., et al., 2017. Biodiversity in the city: Key challenges for urban green space management. Frontiers in Ecology and the Environment. 15(4), 189–196.
DOI: https://doi.org/10.1002/fee.1480

[85] Nilon, C.H., Aronson, M.F., Cilliers, S.S., et al., 2017. Planning for the future of urban biodiversity: A global review of city-scale initiatives. BioScience. 67(4), 332–342.
DOI: https://doi.org/10.1093/biosci/bix012

[86] Parris, K.M., Amati, M., Bekessy, S.A., et al., 2018. The seven lamps of planning for biodiversity in the city. Cities. 83, 44–53.
DOI: https://doi.org/10.1016/j.cities.2018.06.007

[87] Puskás, N., Abunnasr, Y., Naalbandian, S., 2021. Assessing deeper levels of participation in nature-based solutions in urban landscapes—A literature review of real-world cases. Landscape and Urban Planning. 210, 104065.
DOI: https://doi.org/10.1016/j.landurbplan.2021.104065

[88] Parker, J., Zingoni de Baro, M.E., 2019. Green infrastructure in the urban environment: A systematic quantitative review. Sustainability. 11(11), 3182.
DOI: https://doi.org/10.3390/su11113182

[89] Pauleit, S., Ambrose-Oji, B., Andersson, E., et al., 2019. Advancing urban green infrastructure in Europe: Outcomes and reflections from the GREEN SURGE project. Urban Forestry & Urban Greening. 40, 4–16.
DOI: https://doi.org/10.1016/j.ufug.2018.10.006

[90] Donati, G.F., Bolliger, J., Psomas, A., et al., 2022. Reconciling cities with nature: Identifying local Blue-Green Infrastructure interventions for regional biodiversity enhancement. Journal of Environmental Management. 316, 115254.
DOI: https://doi.org/10.1016/j.jenvman.2022.115254

[91] Molné, F., Donati, G.F., Bolliger, J., et al., 2023. Supporting the planning of urban blue-green infrastructure for biodiversity: A multi-scale prioritisation framework. Journal of Environmental Management. 342, 118069.
DOI: https://doi.org/10.1016/j.jenvman.2023.118069

[92] Ding, G., Yi, D., Yi, J., et al., 2023. Protecting and constructing ecological corridors for biodiversity conservation: A framework that integrates landscape similarity assessment. Applied Geography. 160, 103098.
DOI: https://doi.org/10.1016/j.apgeog.2023.103098

[93] Shen, J., Wang, Y., 2023. An improved method for the identification and setting of ecological corridors in urbanized areas. Urban Ecosystems. 26, 141–160.
DOI: https://doi.org/10.1007/s11252-022-01298-5

[94] de Freitas, W.K., Magalhães, L.M.S., de Santana, C.A.A., et al., 2020. Tree composition of urban public squares located in the Atlantic Forest of Brazil: A systematic review. Urban Forestry & Urban Greening. 48, 126555.
DOI: https://doi.org/10.1016/j.ufug.2019.126555

[95] Avolio, M.L., Swan, C., Pataki, D.E., et al., 2021. Incorporating human behaviors into theories of ur-

ban community assembly and species coexistence. Oikos. 130(11), 1849–1864.
DOI: https://doi.org/10.1111/oik.08400

[96] Hayes, S., Desha, C., Gibbs, M., 2019. Findings of case-study analysis: System-Level biomimicry in built-environment design. Biomimetics. 4(4), 73.
DOI: https://doi.org/10.3390/biomimetics4040073

[97] Pedersen Zari, M., 2018. Regenerative urban design and ecosystem biomimicry. Routledge: London.

[98] Odum, E.P., 1969. The strategy of ecosystem development: An understanding of ecological succession provides a basis for resolving man's conflict with nature. Science. 164(3877), 262–270.
DOI: https://doi.org/10.1126/science.164.3877.262

[99] Blanco, E., Pedersen Zari, M., Raskin, K., et al., 2021. Urban ecosystem-level biomimicry and regenerative design: Linking ecosystem functioning and urban built environments. Sustainability. 13(1), 404.
DOI: https://doi.org/10.3390/su13010404

[100] Jepson, P., 2019. Recoverable Earth: A twenty-first century environmental narrative. Ambio. 48, 123–130.
DOI: https://doi.org/10.1007/s13280-018-1065-4

[101] Lorimer, J., Sandom, C., Jepson, P., et al., 2015. Rewilding: Science, practice, and politics. Annual Review of Environment and Resources. 40, 39–62.
DOI: https://doi.org/10.1146/annurev-environ-102014-021406

[102] Svenning, J.C., Pedersen, P.B., Donlan, C.J., et al., 2016. Science for a wilder Anthropocene: Synthesis and future directions for trophic rewilding research. Proceedings of the National Academy of Sciences. 113(4), 898–906.
DOI: https://doi.org/10.1073/pnas.1502556112

[103] Barua, M., 2011. Mobilizing metaphors: The popular use of keystone, flagship and umbrella species concepts. Biodiversity and Conservation. 20, 1427–1440.
DOI: https://doi.org/10.1007/s10531-011-0035-y

[104] Jepson, P., Barua, M., 2015. A theory of flagship species action. Conservation and Society. 13(1), 95–104.
DOI: https://doi.org/10.4103/0972-4923.161228

[105] Lorimer, J., 2007. Nonhuman charisma. Environment and Planning D: Society and Space. 25(5), 911–932.
DOI: https://doi.org/10.1068/d71j

[106] Clancy, C., Ward, K., 2020. Auto-rewilding in post-industrial cities: The case of inland cormorants in urban Britain. Conservation and Society. 18(2), 126–136.
DOI: https://doi.org/10.4103/cs.cs_19_71

[107] Overend, D., Lorimer, J., 2018. Wild performatives: Experiments in rewilding at the Knepp Wildland Project. GeoHumanities. 4(2), 527–542.
DOI: https://doi.org/10.1080/2373566X.2018.1478742

[108] Buller, H., 2014. Reconfiguring wild spaces: The porous boundaries of wild animal geographies. Routledge handbook of human-animal studies. Routledge: Abingdon. pp. 233–245.

[109] Bunce, S., 2018. Sustainability policy, planning, and gentrification in cities. Earthscan/Routledge: Abingdon.

[110] Rutt, R.L., Gulsrud, N.M., 2016. Green justice in the city: A new agenda for urban green space research in Europe. Urban Forestry & Urban Greening. 19, 123–127.
DOI: https://doi.org/10.1016/j.ufug.2016.07.004

[111] Danford, R.S., Strohbach, M.W., Warren, P.S., et al., 2018. Active Greening or rewilding the city: How does the intention behind small pockets of urban green affect use?. Urban Forestry & Urban Greening. 29, 377–383.
DOI: https://doi.org/10.1016/j.ufug.2017.11.014

[112] Farahani, L.M., Maller, C., 2019. Investigating the benefits of 'leftover' places: Residents' use and perceptions of an informal greenspace in Melbourne. Urban Forestry & Urban Greening. 41, 292–302.
DOI: https://doi.org/10.1016/j.ufug.2019.04.017

[113] Mills, J.G., Weinstein, P., Gellie, N.J., et al., 2017. Urban habitat restoration provides a human health benefit through microbiome rewilding: The Microbiome Rewilding Hypothesis. Restoration Ecology. 25(6), 866–872.
DOI: https://doi.org/10.1111/rec.12610

[114] Threlfall, C.G., Kendal, D., 2018. The distinct ecological and social roles that wild spaces play in ur-

ban ecosystems. Urban Forestry & Urban Greening. 29, 348–356.
DOI: https://doi.org/10.1016/j.ufug.2017.05.012

[115] Kowarik, I., 2018. Urban wilderness: Supply, demand, and access. Urban Forestry & Urban Greening. 29, 336–347.
DOI: https://doi.org/10.1016/j.ufug.2017.05.017

[116] Collard, R.C., Dempsey, J., Sundberg, J., 2015. A manifesto for abundant futures. Annals of the Association of American Geographers. 105(2), 322–330.
DOI: https://doi.org/10.1080/00045608.2014.973007

[117] Hunold, C., 2019. Green infrastructure and urban wildlife: Toward a politics of sight. Humanimalia. 11(1), 89–108.
DOI: https://doi.org/10.52537/humanimalia.9479

[118] Aronson, M.F., La Sorte, F.A., Nilon, C.H., et al., 2014. A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. Proceedings of the Royal Society B: Biological Sciences. 281(1780).
DOI: https://doi.org/10.1098/rspb.2013.3330

[119] Ives, C.D., Lentini, P.E., Threlfall, C.G., et al., 2016. Cities are hotspots for threatened species. Global Ecology and Biogeography. 25(1), 117–126.
DOI: https://doi.org/10.1111/geb.12404

[120] Evans, M., 2021. Rewilding European urban spaces. European Journal of Public Health. 31(Supplement_3), ckab165.217.
DOI: https://doi.org/10.1093/eurpub/ckab165.217

[121] Owens, M., Wolch, J., 2019. Rewilding cities. Cambridge University Press: Cambridge.

[122] Mathey, J., Rink, D., 2010. Urban wastelands: A chance for biodiversity in cities? Ecological aspects, social perceptions, and acceptance of wilderness by residents. Urban biodiversity and design. Wiley-Blackwell: Hoboken. pp. 406–424.

[123] Tsing, A., 2017. The buck, the bull, and the dream of the stag: Some unexpected weeds of the Anthropocene. Suomen Antropologi: Journal of the Finnish Anthropological Society. 42(1), 3–21.
DOI: http://orcid.org/0000-0002-0411-959X

[124] Pettorelli, N., Durant, S., Du Toit, J., 2019. Rewilding. Cambridge University Press: Cambridge.

[125] Lehmann, S., 2021. Growing biodiverse urban futures: Renaturalization and rewilding as strategies to strengthen urban resilience. Sustainability. 13(5), 2932.
DOI: https://doi.org/10.3390/su13052932

[126] Bishop, P., Martinez Perez, A., Roggema, R., et al., 2020. Repurposing the green belt in the 21st century. UCL Press: London.
DOI: http://dx.doi.org/10.14324/111.9781787358843

[127] Roggema, R., Keeffe, G., 2022. Design for emergencies. Future talks. Inholland University of Applied Sciences: Alkmaar. pp. 145–159.

[128] Sijmons, D., 2019. Contrast, contact, contract; Pathways to pacify urbanization and natural processes. Nature driven urbanism. Springer: Dordrecht. pp. 9–42.

[129] Taylor, G.R., 1915. Satellite cities: A study of industrial suburbs. D. Appleton and Company: New York/London.

[130] Howard, E., 1902. Garden cities of tomorrow. S. Sonnenschein & Co., Ltd.: London.

[131] Faludi, A., Van der Valk, A.J., 1990. The growth centers as the cornerstones of the Dutch planning dopctrine. Van Gorcum: Assen. (in Dutch).

[132] Grabowski, Z.J., McPhearson, T., Matsler, A.M., et al., 2022. What is green infrastructure? A study of definitions in US city planning. Frontiers in Ecology and the Environment. 20(3), 152–160.
DOI: https://doi.org/10.1002/fee.2445

[133] Berg, P.G., Ignatieva, M., Granvik, M., et al., 2014. Green-blue infrastructure in urban-rural landscapes-introducing resilient citylands. Nordic Journal of Architectural Research. 25(2).

[134] Chiesura, A., 2004. The role of urban parks for the sustainable city. Landscape and Urban Planning. 68(1), 129–138.
DOI: https://doi.org/10.1016/j.landurbplan.2003.08.003

[135] Hautamäki, R., 2021. Constructing the green wedge in the planning discourse-a case study of Central Park in Helsinki, Finland. Landscape Research. 46(6), 878–893.
DOI: https://doi.org/10.1080/01426397.2021.1918653

[136] Rombaut, E.P. (editor), 2008. Urban planning and biodiversity: Thoughts about an ecopolis, plea for a lobe-city. Casestudy of the Belgian cities Sint-

Niklaas and Aalst. Commemorative International Conference of the Occasion of the 4th Cycle Anniversary of KMUTT Sustainable Development to Save the Earth: Technologies and Strategies Vision 2050; 2009 Apr 7–9; Bangkok, Thailand.

[137] Bolund, P., Hunhammar, S., 1999. Ecosystem services in urban areas. Ecological Economics. 29(2), 293–301.
DOI: https://doi.org/10.1016/S0921-8009(99)00013-0

[138] Dehaene, M., 2002. Broadacre City: The city in the eye of the beholder. Journal of Architectural and Planning Research. 19(2), 91–109.

[139] Haas, T., Locke, R., 2018. Reflections on the ReUrbanism paradigm: Re-weaving the urban fabric for urban regeneration and renewal. Quaestiones Geographicae. 37(4), 5–21.
DOI: https://doi.org/10.2478/quageo-2018-0037

[140] McCann, A., 1998. Introduction: Subtopia, or the problem of suburbia. Australian Literary Studies.

[141] Zaffi, L., D'Ostuni, M., 2020. Metabolic cities of the future. Between agriculture and architecture. Agathón| International Journal of Architecture, Art and Design. 8, 82–93.
DOI: https://doi.org/10.19229/2464-9309/882020

[142] Gardner, G., 2016. The city: A system of systems. State of the world. Island Press: Washington DC. pp. 27–44.

[143] Roggema, R., 2020. Nature-driven urbanism. Springer: Dordrecht.

[144] Roggema, R., 2021. From nature-based to nature-driven: Landscape first for the design of Moeder Zernike in Groningen. Sustainability. 13(4), 2368.
DOI: https://doi.org/10.3390/su13042368

[145] Scott, M., Lennon, M., Haase, D., et al., 2016. Nature-based solutions for the contemporary city/Re-naturing the city/Reflections on urban landscapes, ecosystems services and nature-based solutions in cities/Multifunctional green infrastructure and climate change adaptation: Brownfield greening as an adaptation strategy for vulnerable communities?/Delivering green infrastructure through planning: Insights from practice in Fingal, Ireland/Planning for biophilic cities: From theory to practice. Planning Theory & Practice. 17(2), 267–300.
DOI: https://doi.org/10.1080/14649357.2016.1158907

[146] Delumeau, J., O'Connell, M., 2000. History of paradise: The Garden of Eden in myth and tradition. University of Illinois Press: Champaign IL.

[147] Taylor Buck, N., 2017. The art of imitating life: The potential contribution of biomimicry in shaping the future of our cities. Environment and Planning B: Urban Analytics and City Science. 44(1), 120–140.
DOI: https://doi.org/10.1177/0265813515611417

[148] Roggema, R., Monti, S., 2021. Nature driven planning for the FEW-Nexus in Western Sydney. TransFEWmation: Towards design-led food-energy-water systems for future urbanization. Springer: Cham. pp. 59–94.

[149] Roggema, R., Tillie, N., Keeffe, G., 2021. Nature-based urbanization: Scan opportunities, determine directions and create inspiring ecologies. Land. 10(6), 651.
DOI: https://doi.org/10.3390/land10060651

[150] Roggema, R., Tillie, N., Hollanders, M., 2021. Designing the adaptive landscape: Leapfrogging stacked vulnerabilities. Land. 10(2), 158.
DOI: https://doi.org/10.3390/land10020158

[151] Nijhuis, S., 2022. Landscape-based urbanism: Cultivating urban landscapes through design. Design for regenerative cities and landscapes: Rebalancing human impact and natural environment. Springer: Dordrecht. pp. 249–277.

[152] Nijhuis, S., Xiong, L., Cannatella, D., 2020. Towards a landscape-based regional design approach for adaptive transformation in urbanizing deltas. Research in Urbanism Series. 6, 55–80.
DOI: https://doi.org/10.7480/rius.6.94

[153] Crutzen, P.J., Stoermer, E.F., Steffen, W., 2000. The "Anthropocene". The future of nature. Yale University Press: London.

[154] Albrecht, G., Sartore, G.M., Connor, L., et al., 2007. Solastalgia: The distress caused by environmental change. Australasian Psychiatry. 15(1_suppl), S95–S98.
DOI: https://doi.org/10.1080/10398560701701288

[155] Albrecht, G.A., 2020. Negating solastalgia: An emotional revolution from the Anthropocene to the

Symbiocene. American Imago. 77(1), 9–30.
DOI: https://doi.org/10.1353/aim.2020.0001

[156] Albrecht, G., 2014. Ecopsychology in the symbiocene. Ecopsychology. 6(1), 58–59.

[157] Albrecht, G.A., 2019. Earth emotions: New words for a new world. Cornell University Press: Ithaka.

[158] Prescott, S.L., Logan, A.C., 2017. Down to earth: Planetary health and biophilosophy in the symbiocene epoch. Challenges. 8(2), 19.
DOI: https://doi.org/10.3390/challe8020019

[159] Weintraub, P., 1984. The new epoch: Jonas Salk. The Omni interviews. Ticknor and Fields: Boston MA. pp. 94–115.

[160] Latour, B., 2015. Facing Gaia. Eight conferences on the New Climate Regime. Éditions La Découverte: Paris. (in French).

[161] Ahern, J., 2013. Urban landscape sustainability and resilience: The promise and challenges of integrating ecology with urban planning and design. Landscape Ecology. 28, 1203–1212.
DOI: https://doi.org/10.1007/s10980-012-9799-z

[162] Forman, R.T.T., 2008. Urban regions: Ecology and planning beyond the city. Cambridge University Press: Cambridge.

[163] Jones, K.B., Zurlini, G., Kienast, F., et al., 2013. Informing landscape planning and design for sustaining ecosystem services from existing spatial patterns and knowledge. Landscape Ecology. 28, 1175–1192.
DOI: https://doi.org/10.1007/s10980-012-9794-4

[164] Lee, Y.C., Yeh, C.T., Huang, S.L., 2013. Energy hierarchy and landscape sustainability. Landscape Ecology. 28, 1151–1159.
DOI: https://doi.org/10.1007/s10980-012-9706-7

[165] Musacchio, L.R., 2009. The scientific basis for the design of landscape sustainability: A conceptual framework for translational landscape research and practice of designed landscapes and the six Es of landscape sustainability. Landscape Ecology. 24, 993–1013.
DOI: https://doi.org/10.1007/s10980-009-9396-y

[166] Musacchio, L.R., 2011. The grand challenge to operationalize landscape sustainability and the design-in-science paradigm. Landscape Ecology. 26, 1–5.
DOI: https://doi.org/10.1007/s10980-010-9562-2

[167] Wu, J., 2008. Making the case for landscape ecology: An effective approach to urban sustainability. Landscape Journal. 27(1), 41–50.
DOI: https://doi.org/10.3368/lj.27.1.41

[168] Wu, J., 2010. Landscape of culture and culture of landscape: Does landscape ecology need culture?. Landscape Ecology. 25, 1147–1150.
DOI: https://doi.org/10.1007/s10980-010-9524-8

[169] Forman, R.T.T., 1995. Land mosaics: The ecology of landscapes and regions. Cambridge University Press: Cambridge.

[170] Forman, R.T.T., 2008. The urban region: Natural systems in our place, our nourishment, our home range, our future. Landscape Ecology. 23, 251–253.
DOI: https://doi.org/10.1007/s10980-008-9209-8

[171] Cerro El Topochko, NL, MX [Internet]. Available from: https://www.naturalista.mx/places/cerro-el-topochico#/places/cerro-el-topochico= (in Spanish).

[172] Martínez, M., 1998. Floristic inventory of the Sierra de San Carlos, Tamps. Autonomous University of Tamaulipas. Institute of Applied Ecology. Final report SNIB-CONABIO Project No. P024, México, D.F., México. (in Spanish).

[173] Tamaulipan Floodplain [Internet]. [cited 2023 Apr 29]. Available from: https://tpwd.texas.gov/landwater/land/programs/landscape-ecology/ems/emst/woody-wetlands-and-riparian/tamaulipan-floodplain

[174] Rio Grande Delta Thorn Woodland and Shrubland [Internet]. [cited 2023 Apr 29]. Available from: https://tpwd.texas.gov/landwater/land/programs/landscape-ecology/ems/emst/woody-wetlands-and-riparian/rio-grande-delta-thorn-woodland-and-shrubland

[175] Tamaulipan Palm Grove Riparian Forest [Internet]. [cited 2023 Apr 29]. Available from: https://tpwd.texas.gov/landwater/land/programs/landscape-ecology/ems/emst/woody-wetlands-and-riparian/tamaulipan-palm-grove-riparian-forest

[176] Southern North America: Southern United States into Northeastern Mexico [Internet]. [cited 2023 Apr 29]. Available from: https://www.worldwildlife.org/ecoregions/na1312

[177] Loflin, B., Loflin, S., 2009. Texas cacti. Texas A&M University Press: College Station TX.

[178] Hernández, H.M., Gómez-Hinostrosa, C., 2011. Mapping the cacti of Mexico: Their geographical distribution based on referenced records. Dh Books: Milborne Port.

[179] Tamaulipan Calcareous Thornscrub [Internet]. [cited 2023 Apr 29]. Available from: https://tpwd.texas.gov/landwater/land/programs/landscape-ecology/ems/emst/shrublands/tamaulipan-calcareous-thornscrub

[180] Tamaulipan Mixed Deciduous Thornscrub [Internet]. [cited 2023 Apr 29]. Available from: https://tpwd.texas.gov/landwater/land/programs/landscape-ecology/ems/emst/shrublands/tamaulipan-mixed-deciduous-thornscrub

[181] Elsabina National Park [Internet]. Available from: https://www.gob.mx/semarnat/articulos/parque-nacional-el-sabinal (in Spanish).

[182] Marroquín, J.S., Borja, G., Velázquez, R., et al., 1981. Ecological and forestry study of the arid zones of northern Mexico, Special Publication 2. Mexico City: Instituto Nacional de Investigaciones Forestales, SARH: Mexico. (in Spanish).

[183] Theobald, D.M., Spies, T., Kline, J., et al., 2005. Ecological support for rural land-use planning. Ecological Applications. 15(6), 1906–1914.
DOI: https://doi.org/10.1890/03-5331

[184] McDonnell, M.J., Pickett, S.T., 1990. Ecosystem structure and function along urban-rural gradients: An unexploited opportunity for ecology. Ecology. 71(4), 1232–1237.
DOI: https://doi.org/10.2307/1938259

[185] McDonnell, M.J., Pickett, S.T., Groffman, P., et al., 2008. Urban ecology: An international perspective on the interaction between humans and nature. Springer: New York.
DOI: https://doi.org/10.1007/978-0-387-73412-5

[186] Pauleit, S., Breuste, J., Qureshi, S., et al., 2010. Transformation of rural-urban cultural landscapes in Europe: Integrating approaches from ecological, socio-economic and planning perspectives. Landscape Online. 20.
DOI: https://doi.org/10.3097/LO.201020

[187] Haase, D., Frantzeskaki, N., Elmqvist, T., 2014. Ecosystem services in urban landscapes: Practical applications and governance implications. AMBIO. 43, 407–412.
DOI: https://doi.org/10.1007/s13280-014-0503-1

[188] Garrard, G.E., Williams, N.S., Mata, L., et al., 2018. Biodiversity sensitive urban design. Conservation Letters. 11(2), e12411.
DOI: https://doi.org/10.1111/conl.12411

[189] Niemelä, J., 1999. Ecology and urban planning. Biodiversity & Conservation. 8, 119–131.
DOI: https://doi.org/10.1023/A:1008817325994

[190] Pickett, S.T.A., Cadenasso, M.L., McGrath, B., 2013. Ecology of the city as a bridge to urban design. Resilience in ecology and urban design. Springer: Dordrecht.
DOI: https://doi.org/10.1007/978-94-007-5341-9_1

[191] Steiner, F., 2016. The application of ecological knowledge requires a pursuit of wisdom. Landscape and Urban Planning. 155, 108–110.
DOI: https://doi.org/10.1016/j.landurbplan.2016.07.015

[192] Yli-Pelkonen, V., Kohl, J., 2005. The role of local ecological knowledge in sustainable urban planning: perspectives from Finland. Sustainability: Science, Practice and Policy. 1(1), 3–14.
DOI: https://doi.org/10.1080/15487733.2005.11907960

[193] Yli-Pelkonen, V., Niemelä, J., 2005. Linking ecological and social systems in cities: Urban planning in Finland as a case. Biodiversity & Conservation. 14, 1947–1967.
DOI: https://doi.org/10.1007/s10531-004-2124-7