MIT ENVIRONMENTAL RESEARCH + ACTION

UTEC UNIVERSIDAD DE INGENIERÍA Y TECNOLOGÍA

STUDENT REPORT

Assessing Biodiversity Stressors: A Literature Review of Global Studies and Amazonian Perspectives

Author: Jiao Zhao, supervised by Marco Herndon, Matteo Stiglich, Marcela Angel, July 2025
Date: July 2025
Supported by: MISTI

Assessing Biodiversity Stressors: A Literature Review of Global Studies and Amazonian Perspectives

By Jiao Zhao, supervised by Matteo Stiglich, Marcela Angel, Marco Herndon, July 2025

Introduction

Cities are economic powerhouses and major environmental players, accounting for 80% of global GDP while producing over 60% of greenhouse gas emissions (United Nations, 2024; World Bank, 2024). As of 2023, 57.25% of the world's population lives in urban areas, and projections suggest this will rise to 68% by 2050, adding another 2.5 billion urban residents (World Bank, 2024; United Nations Department of Economic and Social Affairs, 2018). Cities represent the dominant settlement pattern and have significant environmental impacts. Human activities have dramatically changed 75% of Earth's land surface (IPBES, 2019), and the loss of biodiversity caused by land cover change and habitat destruction from urbanization is undeniable. However, rather than viewing cities as inherently destructive to biodiversity, more nuanced perspectives on the relationship between the two reveal both challenges and opportunities. Cities need biodiversity to enhance ecosystem services shared by humans and other species **(**Nowak et al., 2010)); they also require biodiversity to mitigate increasing irregular climate patterns (Ziter, 2016). Access to biodiversity and green spaces plays an important role in human wellness (Sandifer et al., 2015). Biodiversity conservation increasingly requires recognizing the reality of cities as vital parts of ecosystems with a larger role in social governance.

The promising vision of cities as potential laboratories for sustainable coexistence between humans and other species is based on research evidence showing that biodiverse cities are feasible. However, addressing social, technical, and ecological issues within the complexities of social networks won't be easy and requires new methodologies and synthesis that can foster cross-disciplinary collaboration among biology, ecology, urban planning, and public policy. Pilot initiatives, such as Singapore's 2021 Biodiversity Index, utilized the biodiversity index as a framework to monitor and assess biodiversity in urban contexts. Beyond the biophysical actors, the discussion unfolds in two sections: native biodiversity and ecosystem services, which include the political and social governance aspects of biodiversity. The 2030 Biodiverse Cities report proposes a framework comprising four elements: impact, state, pressure, and drivers, aiming to incorporate the effects of economic activities within cities on biodiversity.

Urbanization in the Amazonian region was stimulated by resource extraction within tropical rainforest in the last century (Richards & VanWey, 2015). The Amazon region has urbanized rapidly, with its population increasing sevenfold since the 1970s. The common view of the Amazon as simply a vast rainforest overlooks the millions of people who live there and the ongoing migration from rural to urban areas. Some studies have documented biodiversity loss in the region (Changoluisa, 2020). Amazonian cities require further research to understand how biodiversity and vibrant urban centers can coexist. This review analyzes and organizes potential pressures on biodiversity while identifying ways to mitigate these pressures and inform future actions. A pressure index framework can facilitate communication between professionals across disciplines and engage the general public in biodiversity conservation. Building on existing literature, this review gathers measurable indicators within the built environment that directly impact biodiversity and can be regulated through urban planning. Drawing on global studies, the review discusses monitoring technologies, references, and metrics for each indicator. The review focuses specifically on Amazonian cities, organizing current research in the Amazon and identifying gaps for future study. Finally, it discusses how lessons learned from literature and peer cities can be applied to Iquitos, the largest city in the Peruvian Amazon.

Urban Pressures on Biodiversity

The indicators in the framework should have clear targets and verifiable outcomes (Pierce et al., 2020). It is essential to gather empirical studies and establish measurable metrics for policy-making in biodiverse cities.

In the built environment section, the effects of these indicators are primarily direct, with the main biodiversity risks being habitat loss and degradation. Changes in land cover and physical factors, along with human activities, directly affect the living patterns of other species. The resource management section focuses on managing critical urban resources, including water, waste, heat, and noise. Urbanization impacts these resources indirectly, potentially extending beyond a single city to its surrounding rural areas and neighboring regions.

Direct impacts are described as the physical replacement of natural habitats with built-up infrastructure such as roads, buildings, and concrete surfaces. Indirect impacts include resource degradation and pollution during the urbanization process (Liu et al., 2025).

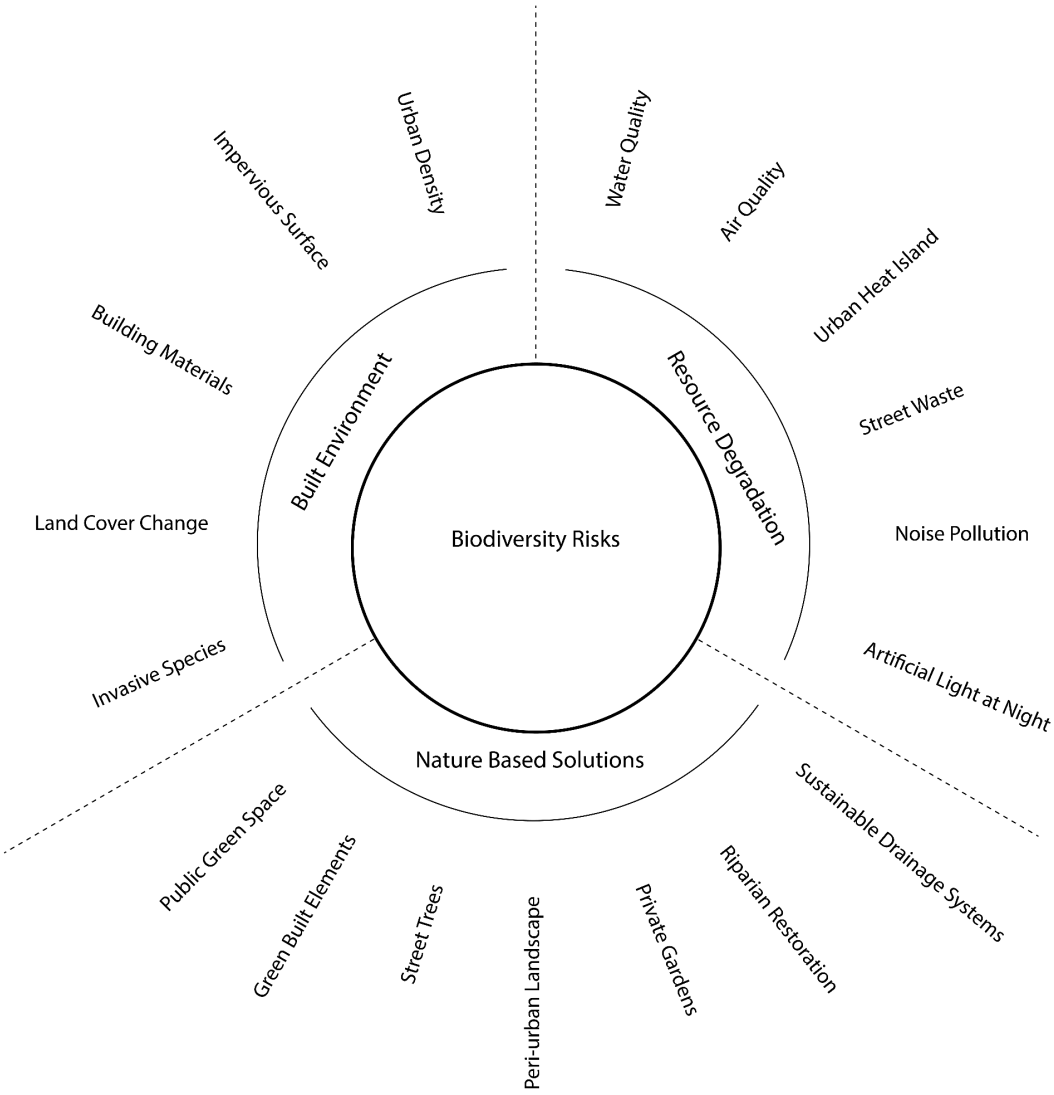

Figure I. Urban Biodiversity Framework. Drawn by the author.

Urbanization as a Compounding Factor

Meta-analyses of existing literature are used to understand the overall impact of urbanization-driven land cover changes on biodiversity. Changes in land cover are the main reason for loss of diversity, leading to 8% of native bird and 25% of native plant species density compared to non-urban estimates globally (J. Aronson et al., 2014). Global-scale empirical studies, facilitated by remote sensing data and statistical models, showed that 24.85% of biodiversity loss resulted from the direct effects of land cover change due to urbanization, as measured by the Biodiversity Intactness Index (Liu et al., 2025). An often overlooked aspect is the environmental effect of construction on biodiversity. The impact of the construction industry on biodiversity and life cycle assessment tools has begun to be studied through production analysis. However, biodiversity impacts have not been examined separately from overall environmental hazards. The construction sector causes extensive resource extraction, accounts for 30% of global biodiversity loss, and greatly contributes to climate change (MacNamara et al., 2023).

Urban Density | Global Studies

Evaluating urban density through the lens of biodiversity reveals the linkage between urban and surrounding non-urban development. Dense cities facilitate land sharing, can slow urban growth, and thus slow the overall land cover change, which is crucial for remnant species, especially those that are urban-sensitive (McDonald et al., 2023). Within urban areas, high density also has environmental benefits. A 10% increase in urban density in their sample is associated with a decrease of approximately 8% in transportation energy (McDonald et al., 2023).

The challenges of dense cities lie in the competing land use between buildings and green space. Some research measured urban density in terms of population and found a negative correlation with the amount of green space, leading to reduced biodiversity performance in indices of richness. Bird abundance, however, correlated with urban density in Valdivia, Chile (Silva et al., 2015). The relationship is more nuanced across species. Normal native species and urban-sensitive species benefit the most from compact city development because it preserves large green spaces. Non-native species see their distributions expand due to sprawling development (McDonald et al., 2023).

While density and green space are not necessarily conflicting, no significant correlation was found between tree cover and density through a study of cities in Europe. Green interventions at the neighborhood level can shrink the footprint of building areas and incorporate green space. Compact, high-density cities are proven to be more biodiversity-friendly globally (McDonald et al., 2023), as high density facilitates land sharing, slows overall land cover change, and thus minimizes the conversion of remnant habitats, thereby protecting biodiversity. Research comparing compact and sprawling urban growth patterns in relation to bird distributions suggests that compact development slows

Urban Density | Amazonia Studies

No urban density research was found in Amazonian areas. However, at a larger regional scale in the Brazilian Amazon, deforestation due to human disturbances accounted for nearly one-third of total deforestation, with demographic pressure being one of several factors driving deforestation (Tritsch & Le Tourneau, 2016). In many densely settled regions of the Amazon, comparatively high population densities can coincide with relatively low levels of deforestation (Tritsch et al., 2016).

These trends suggest that density may differ from pressure and can provide insights into preserving both urban biodiversity and overall biodiversity. They also indicate the potential to design human settlement patterns compatible with biodiversity conservation. Case-specific public policies and research are needed to inform policy development.

biodiversity loss at the city level in Australia (Sushinsky et al., 2012).

Impervious Surface | Global Studies

Reducing impervious surfaces is a top priority for biodiversity-friendly cities (Souza et al., 2019).

Urban plant diversity decreased as the percentage of total impervious surface areas increased. High PTIA was associated with a reduced number of endemic species and an increased proportion of exotic species. Research conducted in Wuhan found that a threshold of 40% of the total impervious surface area will create a significant decrease in plant diversity (Yan et al., 2019). A comparison of soil microbial activities in Beijing across five types of surfaces—impervious surfaces (concrete), permeable pavement, shrub coverage, lawns, and roadside trees—revealed that impervious surfaces have dramatically inactive bacterial communities and severe contamination from heavy metals. The other four types of surfaces did not differ much in their soil microbial activities. This result indicates the effectiveness of permeable surfaces in cities (Hu et al., 2018). Bird richness and abundance in Valdivia, Chile, have been found to negatively correlate with the presence of impervious surfaces (Silva et al., 2015).

Impervious Surface | Amazonia Studies

The direct impact of impervious surfaces in urban areas on biodiversity has not been well-researched within the region. However, in the adjacent areas, reducing impervious surfaces has benefited Cerrado hotspot bird communities. The impervious surface area could explain 20-51% of the variability in richness, with species richness being negatively affected by impervious surfaces (Souza et al., 2019).

Meanwhile, technologies are making such studies easier. Remote sensing has made impervious surface area easier to detect, and in the Brazilian Amazon, it is possible to cross-validate findings with different imagery sources (Li et al., 2013).

Building Forms | Global Studies

The extraction and production of various building materials require natural resources (MacNamara et al., 2023). The direct impact of building materials on ecosystems is evaluated through lifecycle assessment (Christiansson Roos, 2023). The selection of building materials affects biodiversity via the microclimate. Concrete and asphalt exacerbate the urban heat island effect, creating a thermal barrier that can be detrimental to heat-sensitive species. However, selecting alternative building materials can reduce the environmental impact of urban development. Certain structural elements can be designed to support native climbing plants, and experiments in Japan have explored the use of edible vegetation on building façades. Green façades have also been shown to enhance arthropod diversity (Madre et al., 2015).

Building Forms| Amazonia Studies

Indigenous housing incorporates bioclimatic strategies that can serve as a reference even for buildings in cities. These materials are locally harvested, renewable, and reflect low-impact construction methods that help conserve surrounding vegetation. Building on stilts and using open-air designs also minimize disturbance to ground-level ecosystems and maintain habitats for native flora and fauna. The sustainable use of local plant species such as ubim, bacaba, and paxiúba for roofing and structural elements demonstrates these principles in practice (Anjos et al., 2021).

Non-Native Species | Global Studies

Homogenized urbanization, along with globalization and historical colonization, has opposing effects on the distribution of widespread birds, increasing similarity across regions (Sun et al., 2022). This pattern of urban ecological homogenization is evident in cities worldwide. For example, almost all grassland

Non-Native Species| Amazonia Studies

The widespread planting of non-native species in urban areas stems from inadequate planning by municipal authorities. It reflects the colonial legacy of importing plants for aesthetic purposes from former colonial powers. These exotic

species from the studied parks in Santiago are non-native to South America, with nearly all of these being native to Europe and frequently reported from urban grasslands in various parts of Europe (Fischer et al., 2016).

species often adapt rapidly to non-native environments, competing for natural resources and threatening local biodiversity. This pattern is evident in the Brazilian Amazon, where exotic species were more abundant than native species in 29 cities, comprising nearly 42% of all inventoried plant individuals (Vieira & Panagopoulos, 2020).

Resource Degradation

Essential resources such as water, light, heat, noise, and air in ecosystems can be degraded by urban activities. These resources are crucial for many species; thus, if degraded, they could become significant stressors for biodiversity. These stressors can interact with one another, influencing individual species, their behavioral patterns, and their composition. Empirical research has established correlations and evidence regarding these stressors. However, less research has been conducted in the Global South, which aligns with other literature reviews. Additionally, the research gap lies in the lack of comprehensive studies on these stressors and the inability to inform policy with measurable insights.

Light Pollution | Global Studies

Artificial light at night serves as a key indicator of the intersection between biodiversity and light pollution. In urban environments, it manifests through streetlights, advertising illumination, and skyglow. The current measurements used by lighting engineers focus on luminosity, which is not relevant to biodiversity.. Hyperspectral radiometry in visual ecology encounters challenges related to long-term and accurate measurement. Moreover, the adverse impact of light pollution on biodiversity is well-documented in scholarly work. Yet, it lacks a comprehensive understanding that incorporates effects from species to landscape and ecosystem levels, as well as the long-term consequences for community composition and ecosystems (Hölker et al., 2021).

New technologies that integrate high-resolution digital cameras improve the measurement of radiometry. A meta-analysis that assesses the sensitivity traits of species helps build an understanding across species and beyond ecological and biological domains. Synthetic modeling of different light sources and their combined effects also contributes to this understanding. Recent research explores the compounding impacts of night warming and light pollution (Miller et al., 2017), as well as the interplay between noise pollution and light pollution (Dominoni et al., 2020).

Light Pollution | Amazonia Studies

An example of the impacts of light pollution in the Amazon involves fruit bats, which are crucial for seed dispersal but actively avoid illuminated areas. Experiments demonstrated that bats were significantly less likely to feed in illuminated zones. This avoidance behavior suggests that light pollution could hinder rainforest regeneration and habitat connectivity by disrupting essential seed dispersal services (Metcalfe, 2014).

Urban Heat Island | Global Studies

Urban Heat Island | Amazonia Studies

Urban heat is a component of the city's microclimate. The impact of urban heat on biodiversity is often linked to land cover, vegetation cover, and other factors, as cooler sites typically have more vegetation and less impervious surface. However, research suggests that urban heat islands are associated with declines in large, heat-sensitive species; they act as a thermal barrier, filter out heat-sensitive species, and cause biotic homogenization (Cabon et al., 2024). Additionally, heat is a more critical variable than surrounding urban land cover for abundance and richness in the LA Basin (McGlynn et al., 2019). A direct relationship has been identified between urban-induced heat effects and bird richness in Chinese cities, regardless of the city's size, location, or season, indicating that urban heat islands lead to birds moving away from urban areas (Cai et al., 2023). More research is needed to achieve a comprehensive understanding.

Urban heat island monitoring technologies primarily include remote sensing and thermal sensors, utilizing satellites, radiosondes, and remote sensing data from Landsat missions. The data collected will be processed for statistical modeling. Key indicators in this research include land surface temperature and land use/land cover. In recent years, machine learning and artificial intelligence have been utilized to enhance understanding of urban heat islands and to simulate the local bioclimatic environment. (Almeida et al., 2021)

The combined effect of deforestation and global warming scenarios contributed to extreme levels of heat stress risks in most of the Amazon region, with increases up to 11.5 degrees Celsius by the end of the 21st century (Fátima et al., 2021). This is much more severe than in other parts of South America. The biodiversity loss associated with heat risks has not been quantified in research.

Noise Pollution | Global Studies

Urban noise from traffic, construction, and other sources has a proven influence on biodiversity. Existing research has primarily focused on its impact on bird species richness and composition. Studies reveal that noise affects bird behaviors during breeding when comparing urban parks with natural areas. Anthropogenic noise could be a significant factor driving bird species out of cities and away from highways, even when other habitat requirements are still adequate (Slabbekoorn & Ripmeester, 2008). Furthermore, research indicates that the impact of noise extends beyond individuals and communities, affecting the meta-community level, as noise pollution causes significant changes in bird species richness and composition (González-Oreja et al., 2012). Urban noise does not only occur in cities; with infrastructure development, roads, and highways, it also infiltrates rural forested areas (Slabbekoorn & Ripmeester, 2008).

However, we lack cross-disciplinary analysis and sufficient concrete evidence that could inform policy. Current measures to mitigate noise pollution include noise barriers, using absorbent materials in urban design, and noise regulation during specific hours (also for human health), among others.

Noise Pollution | Amazonia Studies

Human-generated noise may mask acoustic signals and disrupt behavior. Pied tamarins decreased their syllable repetition rate in response to anthropogenic noise. Long calls are important for group cohesion and intergroup communication in Manaus, Brazil (Sobroza et al., 2024).

While noise detection sensors are well-developed, there is a shortage of synthetic data analysis. Computing technologies provide opportunities to predict and extrapolate noise levels spatially based on traffic flow, vehicle types, and distance from the road (Warren et al., 2006).

Waste Disposal | Global Studies

No research has yet been found to study the direct, short-term relationship between waste management and urban biodiversity, but the conglomerate of plastics, metal fabrication, organic waste, and municipal waste originating from households, industrial, and commercial activities contributes to soil contamination, thus having direct impacts on soil animals, plants, and other species that rely on those species (Kolawole & Iyiola, 2023).

Waste Disposal | Amazonia Studies

The direct impact of waste hasn't been thoroughly researched. In monitored street markets, there were no waste storage facilities; solid organic waste is linked to the occurrence and abundance of Black Vultures in the largest city of the Amazon. Beyond the presence of black vultures, waste in the streets also increases the likelihood of bird strikes and contributes to other forms of environmental pollution that negatively affect biodiversity (Araujo et al., 2018).

Water Pollution | Global Studies

In urban ponds, water quality, nutrients, and pollutants have influence on species richness and threaten some species on the red list. Amphibians are known from research to have been impacted by water quality (Oertli & Parris, 2019). There has been a decline in fish and macroinvertebrate diversity downstream of urban areas in Brazil (Pompeu & Alves, 2005).

Water Pollution | Amazonia Studies

Most of the wastewater produced in Amazonian cities is discharged untreated into Amazonian freshwater ecosystems (Rico et al., 2021). Urban activities have a significant impact on stream water quality in Brazil. Problems such as inadequate sewage systems, the presence of landfills, increased domestic waste, and intensified weathering all contribute to poor water quality (Ferreira et al., 2021). Research has found that these urban areas are hotspots for contamination with various chemicals, resulting in long-term effects on up to 50-80% of aquatic species in the vicinity of urban areas. Other species, such as Zygoptera, have also been found to be affected by water pollution (Monteiro Júnior et al., 2015).

Air Pollution | Global Studies

Trees have a dust capacity and can mitigate air pollution. Researchers collected heavy metals from the air on leaf surfaces; these metals can adhere to and translocate to other parts of the plants. The pollutants cause changes in foliar morphology and affect plant metabolism. However, many plant

Air Pollution | Amazonia Studies

Measurement of air quality in Amazonia is undertaken in dry and wet seasons (Paralovo et al., 2019), and the measurement has also been done in peri-urban areas in Amazon basins.

species also show high resilience and tolerance against air pollution (Rai, 2016). Honey bee mortality increases with poor air quality (Coallier et al., 2025). High NO2 levels reduce photosynthesis in some species of urban trees, indicating that improving air quality will enhance photosynthesis. Historical declines in NO2 have led to improved photosynthesis in urban trees (Matsuura et al., 2025).

However, no research has been found to identify the air pollution impact on biodiversity.

Nature-based Solutions for Biodiversity

Nature-based solutions are inspired and supported by nature, offering cost-effective approaches that simultaneously provide environmental, social, and economic benefits while building resilience. Research on metrics measuring the biodiversity impact of nature-based solutions reveals significant gaps, including limited geographical representation, insufficient research from the Global South, and difficulties in isolating individual elements to create clear indicators for specific measures. Despite these measurement challenges, many nature-based solutions show great potential for biodiversity conservation, particularly in Amazon regions.

Public Green Space

Studies acknowledge the ecological value of green spaces for biodiversity. Nuanced research has been conducted to understand the characteristics of green spaces that support biodiversity. Complex urban grasslands with increased mowing heights and the introduction of more native species have been shown to enhance functional biodiversity (Cabon et al., 2024). Similarly, intact urban vegetation supports higher levels of native biodiversity (J. Aronson et al., 2014). Notably, areas with lower maintenance intensity also exhibit positive relationships with species richness, suggesting that ecological value may increase with more "natural" or passive management approaches (Mueller et al., 2018). Patches over 50 hectares have been found to support area-sensitive species (Beninde et al., 2015). However, homogenization of parks is found in Latin America, which is dominated mainly by European species (Silva et al., 2015).

Green Roofs and Facades

Green roofs can support biodiversity by improving habitat connectivity, particularly when native plants and heterogeneous substrates are used (Williams et al., 2014). However, poor ecological design risks creating ecological traps or losing native habitat functions (Perrelet et al., 2024). Their ecological contribution varies significantly depending on planting schemes and maintenance (Filazzola et al., 2019).

Street trees

Street trees provide habitat and ecological corridors that enhance species movement and urban connectivity. A meta-analysis confirmed that corridors can increase species movement by approximately 50%, improving both abundance and genetic flow across fragmented urban landscapes (Gilbert-Norton et al., 2010). This supports prior findings that tree-lined streets contribute to connectivity and patch dynamics, though tree species diversity and placement strongly influence outcomes.

Peri-urban Landscape

Peri-urban areas are crucial for biodiversity conservation, particularly for species that require large, continuous habitats. Studies highlight their role in forming ecological corridors and preserving remnant species (Singh et al., 2019). Interstitial and unplanned green spaces within cities—such as wastelands—also offer surprising biodiversity value. These areas often host higher species richness than managed green spaces, despite potential challenges with invasive species (Bonthoux et al., 2014). Wastelands could thus be

integrated into long-term planning as dynamic green infrastructure. Similarly, non-municipal or informal green areas, like those studied in Valdivia, Chile, provide complex habitats and food resources for birds (Silva et al., 2015).

Sustainable Drainage Systems

Sustainable Drainage Systems (SuDS)—such as stormwater ponds and bioretention systems—can support diverse species while providing ecosystem services like flood regulation and pollutant removal. One meta-analysis found that SuDS supports species richness and functional diversity comparable to natural wetlands, provided they include native vegetation and heterogeneous structure (Filazzola et al., 2019). However, risks include hydrological alteration and the spread of invasive aquatic plants, making biodiversity-sensitive design essential

Riparian Restoration

Riparian corridors support biodiversity by maintaining aquatic-terrestrial connectivity, improving water quality, and creating multi-functional habitat zones. Monitoring approaches include water quality sensors, macroinvertebrate indices, and spatial mapping techniques. Studies demonstrate that restored riparian zones significantly boost species diversity, particularly among invertebrates and riparian birds (Santiago et al., 2023). This finding aligns with the broader blue-green infrastructure principle that biodiversity enhances ecological function and system resilience (Perrelet et al., 2024).

Discussion

Lack of Engagement in Biodiversity Management

Research on urban biodiversity started in the 1990s, and empirical studies have accumulated to better understand the integration of nature and cities (Rega-Brodsky et al., 2022). The literature on urban stressors and solutions aims to develop metrics and establish clear relationships for measuring and monitoring these stressors and solutions to biodiversity challenges, as well as assessing the relevance and impact of these indicators (Aronson et al., 2017). Technologies involved in this research include: a) point measurement, which involves using various sensors operated by researchers, setting up sensors at observation stations, and employing satellite monitoring (Jansen et al., 2024); b) high-resolution satellite imagery and remote sensing data collected from Landsat missions and other sources, processed to derive numerous urban indicators, while street images are also used to quickly estimate certain urban metrics (Carranza, 2024; Biljecki & Ito, 2021); c) traditional statistical modeling, which relies on collected and historical data and utilizes geospatial analysis, with regression models often applied to identify correlations between complex factors and produce tangible metrics for understanding biodiversity impacts (Ziliaskopoulos & Laspidou, 2024); d) machine learning and other artificial intelligence technologies, which leverage enhanced computing power and advanced techniques to recognize complex data patterns (Pettorelli et al., 2024). These technologies have opened new research opportunities and provided more tools for remote data collection and large-scale analysis, offering the potential to better understand the complexity of urban biodiversity. However, without incorporating the nuanced experiences of people and ensuring that policymakers and residents understand this complexity, it will not lead to effective action or societal change (Voigt-Heucke et al., 2023).

Public participation is rarely included in empirical studies. Citizen science has been used to collect real-time data, often through mobile apps or volunteer efforts, presenting a great opportunity to expand data representation (Dickinson et al., 2010; Oliveira, 2025). Cost-effective methods, rather than sophisticated

measurement techniques, are especially suitable for developing countries seeking to build their monitoring systems (Oliveira, 2025). Indigenous knowledge of biodiversity can provide evidence of changes and help communicate its status, while also offering insights into academic research directions (Tengo et al., 2014). Nevertheless, citizen science focuses mainly on data collection and does not involve communities throughout the entire process (Mandeville et al., 2023). Communities should be engaged in monitoring biodiversity, understanding local indicators, communicating about biodiversity within their contexts, and developing policies that incorporate local knowledge into decision-making (Tengo et al., 2014; Mandeville et al., 2023). This gap highlights the need for greater conceptual innovation, deeper policy engagement, and the use of creative technologies. For example, participatory mapping platforms that integrate indigenous knowledge with remote sensing data, or virtual reality tools that help communities visualize biodiversity changes and collaboratively design conservation strategies (Pettorelli et al., 2024).

Takeaways for Amazonian Biodiversity Hotspot Cities

Species-Sensitive Urban Form Through Community-Driven Planning

The benefits of compact versus sparse urban forms for biodiversity have been controversial. Yet, multiple sources demonstrate that a compact form is more sustainable from a biodiversity perspective (Sushinsky et al., 2012). Compact urban form can slow urban growth and reduce land cover changes, which are the biggest threats to biodiversity (McDonald et al., 2023). More open space on the edges of cities creates ecological corridors and serves as buffer zones for species that require large territories (Canedoli et al., 2018). Furthermore, even dense urban areas have the potential to serve as biodiversity refugia, helping preserve rare species through reproduction and human-mediated conservation efforts (Knapp et al., 2021). Bright spots in cities have been found to feature both high density and abundant green space. Neighborhood-level planning and greening help to achieve density while maintaining urban nature (McDonald et al., 2023). A more nuanced understanding of how urban density affects biodiversity is also reflected in its different impacts on species. Common species tend to rely more on generally available habitat, while rare species depend on specific local environmental conditions such as the abundance of particular plant species, microclimates, and decisions by stakeholders involved in economic activities related to these species (Casanelles-Abella et al., 2021). Density is one characteristic that reflects urban form; however, focusing solely on density makes little sense when considering the broader question of where and how to urbanize, given that growth is inevitable. Research suggests that species-sensitive mapping can guide urban development decisions. Data from 12 UK cities show that planned housing developments significantly affect bat populations. However, when housing is constructed in regions with low populations of urban-sensitive species, the impact can be reduced by 46% (Border et al., 2017). Such predictive modeling could provide valuable insights for Amazonian urbanization. However, current research in Amazonian areas employs geospatial techniques to understand urbanization through historical satellite imagery and future growth predictions, yet these approaches often overlook biodiversity considerations. One study in Manaus, the largest city in the Brazilian Amazon, uses multiple criteria to measure urbanization levels, including paved streets, urban luminosity, population density, distances from urban patches to deforested areas, oil pollution points, and mining pollution points (Albán & Durán, 2023). Integrating Amazonian biodiversity research with lessons from empirical studies could significantly inform planning efforts to guide urban growth and prepare for rural-to-urban migration.

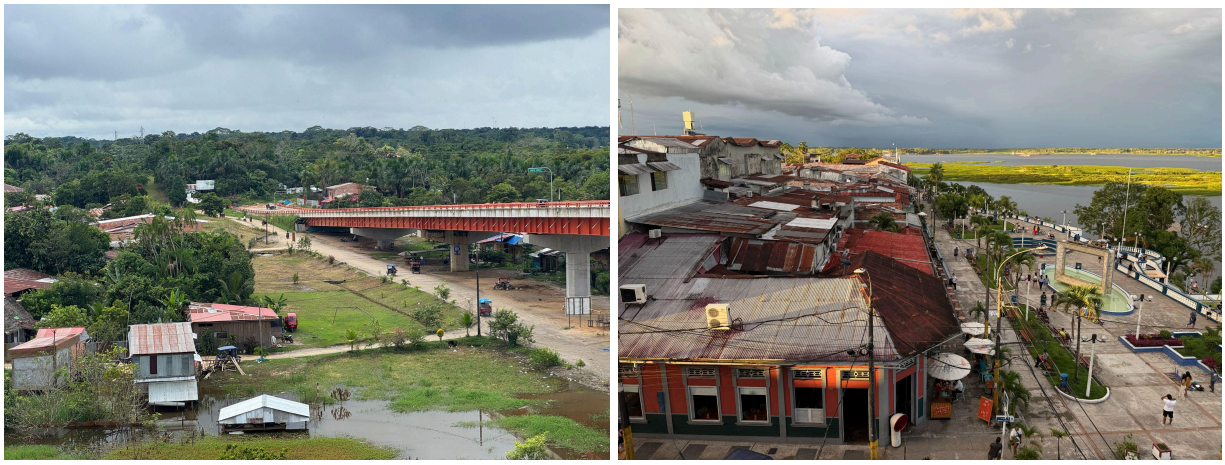

Figure II. Peri-urban landscape. Floodplain near urban center, Iquitos. Photo by the author.

Iquitos, as the only major city in the Loreto region, has attracted rural populations and experienced rapid growth over the past half-century. Since 1984, Iquitos has tripled in size, with an average annual growth of 58.4 hectares (Alexia Jimena et al., 2024). The urban center mainly consists of low-rise houses, with taller buildings designated for hospitality and hotels. The sprawling pattern leads to rapid land cover change and has significant ecological implications, as it connects to the Amazon River and other waterways in a strategically important geopolitical location, being the largest city in the Peruvian Amazon. The ecological importance and ongoing trends of rural immigration underscore the need for effective urban growth planning. However, planning cannot be solely top-down, and it should not involve relocation without considering cultural and social factors. The failure of the Belén neighborhood relocation exemplifies the importance of involving communities in decision-making processes and making socio-bioethical decisions. The Belén neighborhood consists of immigrants from the rainforest who migrate along the Amazon River in search of economic opportunities. The relocation plan started in 2015, moving residents to Nuevo Belen, 14 km outside Iquitos. So far, only around 400 households have moved to the new settlement due to differences in risk perception between the government and communities (Gorenstein, 2018). The government views floods as risks, while communities perceive living with river changes as a reality. Relocation disrupts culture, economy, and even biological aspects—new settlements are poorly planned, with only 9 out of 50 unplanned plants being native species (Andrews et al., 2024).

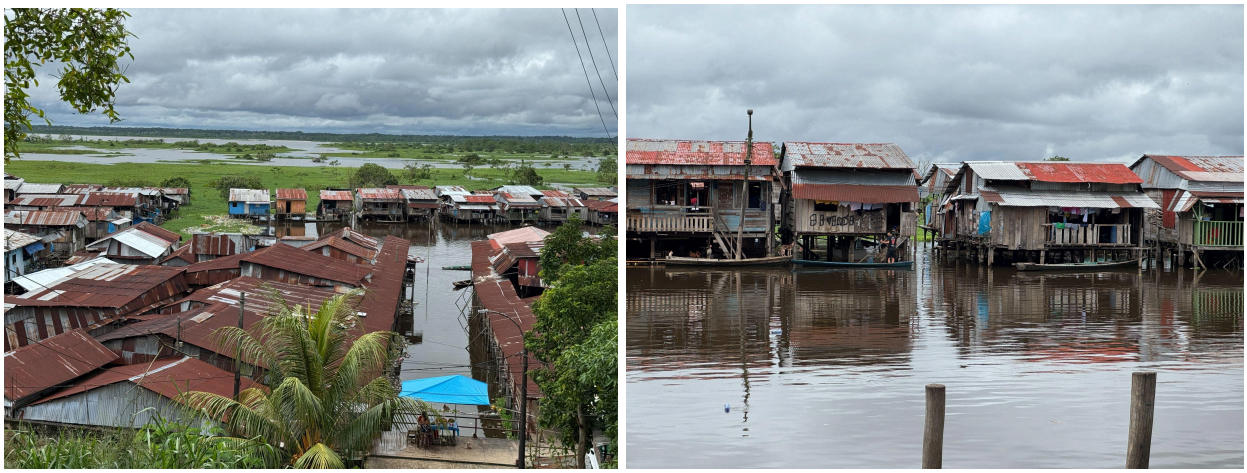

Figure III. Belén neighborhood, Iquitos. Photo by the author.

Simplistic approaches using environmental or political indices should not be limited; instead, they should encompass understanding natural or anthropogenic disturbances in depth, including cosmovision for Indigenous communities, biodiversity linked to spiritual, recreational, and educational benefits of urban nature, psychological effects of biodiversity on humans, and bioeconomy that relies on biodiversity (Changoluisa, 2020). Community knowledge is invaluable for biodiversity analysis. Species-sensitive maps produced by static modeling and remote sensing could be integrated with community input. Locals have generations of experience living alongside Amazonian rivers and have acquired the knowledge to work in harmony with nature and its changing dynamics. By collectively and consciously empowering communities in biodiversity management efforts, risks can be transformed into opportunities to address inequalities and mitigate ecological challenges. Reflection on environmental research and knowledge production has been significantly influenced by colonization, which has employed exclusionary Western approaches. Decolonizing expertise and increasing access are crucial steps in creating inclusive teams and making data more accessible (Trisos et al., 2021). The view of the Amazon as a primordial forest minimally impacted by dispersed groups until recent changes in the last century are being challenged. Looking into biocultural history, some areas have been constructed and domesticated through human interventions (Heckenberger et al., 2007). Native peoples developed unique ways to interact with the land over time, managing rather than taming the natural environment. Indigenous knowledge offers ready-made alternatives, with previous experiments providing insights into the knowledge required for biodiverse cities in contemporary times(Heckenberger et al., 2007). Research questions and directions should incorporate local lived experiences and indigenous knowledge about the natural environment. Low-cost technologies like open source sensors, mobile platforms can be integrated into community engagement frameworks, with projects demonstrating pathways to enhance knowledge production and policy-making through the use of participatory technologies. This analysis suggests species-sensitive maps to guide urban development and planning. Community input should be incorporated into these mapping processes. Pilot projects can begin on floodplains at the urban edge, which have high ecological value and are essential for planning future growth both ecologically and socially.

Building Equitable Urban Infrastructure for Humans and Biodiversity

Disparities in green infrastructure lead to uneven distribution of biodiversity within cities. Research has shown a positive link between high socioeconomic status and access to biodiversity. Socioeconomic status is a complex measure of social standing and relative power tied to income, education, and occupation within a community. Economic factors enable individuals to live in landscapes rich in biodiversity because those with higher socioeconomic status have the means to choose their residence. These mechanisms create a two-way relationship where social economy influences biodiversity and vice versa (Lerman and Warren, 2011). Understanding how equity, green infrastructure, and biodiversity intersect requires examining the unique socioeconomic conditions of Amazonian cities, which exhibit more autonomous growth patterns compared to well-studied cities in the Global North. The distinct socioeconomic development of Amazonia shapes its characteristics of green infrastructure. In Latin America, non-municipal space refers to areas not managed by the government, which can benefit biodiversity. This concept aligns with the idea of wilderness within cities. Research indicates that green areas with minimal management have the highest species richness, exceeding 12 species (Casanelles-Abella et al., 2021). Biodiversity planning differs from traditional approaches that focus solely on improving management levels for infrastructure; instead, it involves understanding infrastructure through a biodiverse lens (Aronson et al., 2023; Benedict & McMahon, 2006). Green infrastructure aimed at supporting biodiversity must consider the local social context, creating opportunities to enhance biodiversity while also addressing social issues. Policies that recognize the specific role of the social economy, such as targeted green space improvements in informal settlements where green space is scarce (Roy et al., 2018), aim to boost ecosystem services and may elevate overall urban biodiversity. When intentionally designed to produce edible fruits with high nutritional value, these interventions can increase city resilience during crises and offer communities opportunities to develop (Vieira & Panagopoulos, 2020).

Disparities in water infrastructure reflect and reinforce patterns of socio-ecological inequality with direct implications for biodiversity. Neighborhoods with limited political and economic power, such as Belén, face chronic underinvestment in sewage and waste systems. Untreated wastewater is often discharged into rivers, while the absence of formal waste collection leads to informal dumping, contaminating aquatic habitats and degrading surrounding ecosystems (Rico et al., 2021; Race for Water Foundation, 2020). These failures are shaped by decisions about whose environments are protected and whose are neglected. Belén is located in a floodplain on a branch of the Amazon River. Floodplain studies from cities like Puyo demonstrate that peri-urban floodplains possess high ecological value and potential for sustainable livelihoods, including eco-tourism and bioenterprise (Lucero et al., 2020). In the Brazilian Amazon, ten cities located along floodplains received 15.3% of the total immigrants of the entire Brazilian Amazon. While floodplains provide forest, agropastoral, and aquatic resources linked to urban forests, they lack fiscal frameworks and administrative capacity to collect taxes for investment, and infrastructure limitations restrict development (Costa & Brondízio, 2011). To advance biodiversity goals, water infrastructure planning must move beyond reactive and exclusionary approaches. Recognizing the ecological richness and social complexity of floodplain environments is essential. A more equitable model would integrate biodiversity conservation with water management, prioritizing both ecological function and human well-being, as well as long-term resilience.

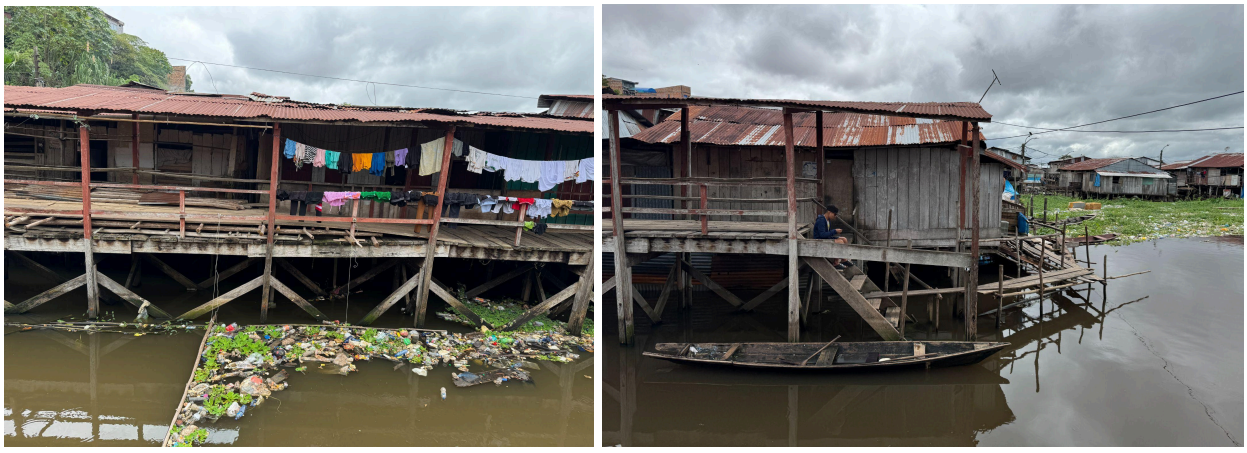

Figure IV. Belén neighborhood, Iquitos. Photo by the author.

Reference

IPBES. (2019). Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (E. S. Brondizio, J. Settele, S. Díaz, & H. T. Ngo, Eds.). IPBES Secretariat. https://doi.org/10.5281/zenodo.3553579

United Nations. (2024). Cities and pollution. UN Climate Change. https://www.un.org/en/climatechange/climate-solutions/cities-pollution

United Nations Department of Economic and Social Affairs. (2018, May 16). 68% of the world population projected to live in urban areas by 2050, says UN. UN DESA. https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html

World Bank. (2024). Urban development overview. The World Bank Group. https://www.worldbank.org/en/topic/urbandevelopment/overview

World Bank. (2024). Urban population (% of total population) - World. World Bank Open Data. Retrieved from Trading Economics. https://tradingeconomics.com/world/urban-population-percent-of-total-wb-data.html

Aronson, M. F. J., La Sorte, F. A., Nilon, C. H., Katti, M., Goddard, M. A., Lepczyk, C. A., Warren, P. S., Williams, N. S. G., Cilliers, S., Clarkson, B., Dobbs, C., Dolan, R., Hedblom, M., Klotz, S., Kooijmans, J. L., Kühn, I., MacGregor-Fors, I., McDonnell, M., Mörtberg, U., … Winter, M. (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), 20133330. https://doi.org/10.1098/rspb.2013.3330

Bonthoux, S., Brun, M., Di Pietro, F., Greulich, S., & Bouché-Pillon, S. (2014). How can wastelands promote biodiversity in cities? A review. Landscape and Urban Planning, 132, 79–88. https://doi.org/10.1016/j.landurbplan.2014.08.010

Ikin, K., Le Roux, D. S., Rayner, L., Villaseñor, N. R., Eyles, K., Gibbons, P., Manning, A. D., & Lindenmayer, D. B. (2015). Key lessons for achieving biodiversity-sensitive cities and towns. Ecological Management & Restoration, 16(3), 206–214. https://doi.org/10.1111/emr.12180

McDonald, R. I., Aronson, M. F. J., Beatley, T., Beller, E., Bazo, M., Grossinger, R., Jessup, K., Mansur, A. V., Puppim de Oliveira, J. A., Panlasigui, S., Burg, J., Pevzner, N., Shanahan, D., Stoneburner, L., Rudd, A., & Spotswood, E. (2023). Denser and greener cities: Green interventions to achieve both urban density and nature. People and Nature, 5(1), 84–102. https://doi.org/10.1002/pan3.10423

Sing, K.-W., Luo, J., Wang, W., Jaturas, N., Soga, M., Yang, X., Dong, H., & Wilson, J.-J. (2019). Ring roads and urban biodiversity: Distribution of butterflies in urban parks in Beijing city and correlations with other indicator species. Scientific Reports, 9(1), 7653. https://doi.org/10.1038/s41598-019-43997-8

Souza, F. L., Valente-Neto, F., Severo-Neto, F., Bueno, B., Ochoa-Quintero, J. M., Laps, R. R., Bolzan, F., & Roque, F. de O. (2019b). Impervious surface and heterogeneity are opposite drivers to maintain bird richness in a Cerrado city. Landscape and Urban Planning, 192, 103643. https://doi.org/10.1016/j.landurbplan.2019.103643

Sun, B., Lu, Y., Yang, Y., Yu, M., Yuan, J., Yu, R., Bullock, J. M., Stenseth, N. Chr., Li, X., Cao, Z., Lei, H., & Li, J. (2022). Urbanization affects spatial variation and species similarity of bird diversity distribution. Science Advances, 8(49), eade3061. https://doi.org/10.1126/sciadv.ade3061

Sushinsky, J. R., Rhodes, J. R., Possingham, H. P., Gill, T. K., & Fuller, R. A. (2013). How should we grow cities to minimize their biodiversity impacts? Global Change Biology, 19(2), 401–410. https://doi.org/10.1111/gcb.12055

Samhouri, J. F., Shelton, A. O., Williams, G. D., Feist, B. E., Hennessey, S. M., Bartz, K., Kelly, R. P., L., J., Sheer, M., Stier, A. C., & Levin, P. S. (2022). How much city is too much city? Biodiversity and ecosystem functioning along

an urban gradient at the interface of land and sea. Frontiers in Marine Science, 9, 931319. https://doi.org/10.3389/fmars.2022.931319

Yan, Z., Teng, M., He, W., Liu, A., Li, Y., & Wang, P. (2019). Impervious surface area is a key predictor for urban plant diversity in a city undergone rapid urbanization. Science of The Total Environment, 650, 335–342. https://doi.org/10.1016/j.scitotenv.2018.09.025

Anjos, V., Celis, A. M., & Rodrigues, A. K. (2021). *The appropriation of the indigenous architecture in northern Brazilian Amazon for the architectural design process with bioclimatic strategies*. In Creating Through Mind and Emotions; First Edition (pp. 221–225).

Hu, Y., Dou, X., Li, J., & Li, F. (2018). Impervious Surfaces Alter Soil Bacterial Communities in Urban Areas: A Case Study in Beijing, China. Frontiers in Microbiology, 9. https://doi.org/10.3389/fmicb.2018.00226

Fransson Christiansson, M., & Roos, T. (2023). Building materials and their impacts on biodiversity A comparison of wood and concrete building frames. http://hdl.handle.net/20.500.12380/306132

Eva MacNamara, Lottie Macnair(2023).The Embodied Biodiversity Impacts of Construction Materials.https://expedition.uk.com/project/embodied-biodiversity-impacts-of-construction-materials/

Madre, F., Clergeau, P., Machon, N., & Vergnes, A. (2015). Building biodiversity: Vegetated façades as habitats for spider and beetle assemblages. Global Ecology and Conservation, 3, 222–233. https://doi.org/10.1016/j.gecco.2014.11.016

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. https://doi.org/10.1111/ele.12427

Hölker, F., Bolliger, J., Davies, T. W., Giavi, S., Jechow, A., Kalinkat, G., Longcore, T., Spoelstra, K., Tidau, S., Visser, M. E., & Knop, E. (2021). 11 Pressing Research Questions on How Light Pollution Affects Biodiversity. Frontiers in Ecology and Evolution, Volume 9-2021. https://doi.org/10.3389/fevo.2021.767177

Hölker, F., Moss, T., Griefahn, B., Kloas, W., Voigt, C. C., Henckel, D., Hänel, A., Kappeler, P. M., Völker, S., Schwope, A., Franke, S., Uhrlandt, D., Fischer, J., Klenke, R., Wolter, C., & Tockner, K. (2010). The Dark Side of Light: A Transdisciplinary Research Agenda for Light Pollution Policy. Ecology and Society, 15(4). http://www.jstor.org/stable/26268230

Miller, C. R., Barton, B. T., Zhu, L., Radeloff, V. C., Oliver, K. M., Harmon, J. P., & Ives, A. R. (2017). Combined effects of night warming and light pollution on predator–prey interactions. Proceedings of the Royal Society B: Biological Sciences, 284(1864), 20171195. https://doi.org/10.1098/rspb.2017.1195

Dominoni, D., Smit, J. A. H., Visser, M. E., & Halfwerk, W. (2020). Multisensory pollution: Artificial light at night and anthropogenic noise have interactive effects on activity patterns of great tits (Parus major). Environmental Pollution, 256, 113314. https://doi.org/10.1016/j.envpol.2019.113314

McGlynn, T. P., Meineke, E. K., Bahlai, C. A., Li, E., Hartop, E. A., Adams, B. J., & Brown, B. V. (2019). Temperature accounts for the biodiversity of a hyperdiverse group of insects in urban Los Angeles. Proceedings of the Royal Society B: Biological Sciences, 286(1912), 20191818. https://doi.org/10.1098/rspb.2019.1818

Cabon, V., Quénol, H., Dubreuil, V., Ridel, A., & Bergerot, B. (2024). Urban Heat Island and Reduced Habitat Complexity Explain Spider Community Composition by Excluding Large and Heat-Sensitive Species. Land, 13(1), Article 1. https://doi.org/10.3390/land13010083

Cai, Z., La Sorte, F. A., Chen, Y., & Wu, J. (2023). The surface urban heat island effect decreases bird diversity in Chinese cities. Science of The Total Environment, 902, 166200. https://doi.org/10.1016/j.scitotenv.2023.166200

Almeida, C. R. d., Teodoro, A. C., & Gonçalves, A. (2021). Study of the Urban Heat Island (UHI) Using Remote Sensing Data/Techniques: A Systematic Review. Environments, 8(10), 105. https://doi.org/10.3390/environments8100105

Monteiro Júnior, C. da S., Juen, L., & Hamada, N. (2015). Analysis of urban impacts on aquatic habitats in the central Amazon basin: Adult odonates as bioindicators of environmental quality. Ecological Indicators, 48, 303–311. https://doi.org/10.1016/j.ecolind.2014.08.021

González-Oreja, J. A., De La Fuente-Díaz-Ordaz, A. A., Hernández-Santín, L., Bonache-Regidor, C., & Buzo-Franco, D. (2012). Can human disturbance promote nestedness? Songbirds and noise in urban parks as a case study. Landscape and Urban Planning, 104(1), 9–18. https://doi.org/10.1016/j.landurbplan.2011.09.001

Slabbekoorn, H., & Ripmeester, E. a. P. (2008). Birdsong and anthropogenic noise: Implications and applications for conservation. Molecular Ecology, 17(1), 72–83. https://doi.org/10.1111/j.1365-294X.2007.03487.x

Warren, P. S., Katti, M., Ermann, M., & Brazel, A. (2006). NOISE-Urban bioacoustics: It's not just noise. Animal Behaviour, 71(3), 491–502. https://doi.org/10.1016/j.anbehav.2005.07.014

Araujo, G. M. de, Peres, C. A., Baccaro, F. B., & Guerta, R. S. (2018). Urban waste disposal explains the distribution of Black Vultures (Coragyps atratus) in an Amazonian metropolis: Management implications for birdstrikes and urban planning. PeerJ, 6, e5491. https://doi.org/10.7717/peerj.5491

Rico, A., de Oliveira, R., de Souza Nunes, G. S., Rizzi, C., Villa, S., López-Heras, I., Vighi, M., & Waichman, A. V. (2021). Pharmaceuticals and other urban contaminants threaten Amazonian freshwater ecosystems. Environment International, 155, 106702. https://doi.org/10.1016/j.envint.2021.106702

Rai, P. K. (2016). Biodiversity of roadside plants and their response to air pollution in an Indo-Burma hotspot region: Implications for urban ecosystem restoration. Journal of Asia-Pacific Biodiversity, 9(1), 47–55. https://doi.org/10.1016/j.japb.2015.10.011

Coallier, N., Perez, L., Franco, M. F., Cuellar, Y., & Vadnais, J. (2025). Poor air quality raises mortality in honey bees, a concern for all pollinators. Communications Earth & Environment, 6(1), 126. https://doi.org/10.1038/s43247-025-02082-x

Matsuura, T., Okamoto, Y., Matsumoto, M., Kiyomizu, T., Kumpitsch, L., Kume, A., & Hanba, Y. T. (2025). The impact of air pollution control measures and the COVID-19 pandemic on photosynthesis in urban trees. Scientific Reports, 15(1), 1453. https://doi.org/10.1038/s41598-024-85080-x

Silva, C. P., García, C. E., Estay, S. A., & Barbosa, O. (2015). Bird Richness and Abundance in Response to Urban Form in a Latin American City: Valdivia, Chile as a Case Study. PLOS ONE, 10(9), e0138120. https://doi.org/10.1371/journal.pone.0138120

Fischer, L. K., Rodorff, V., von der Lippe, M., & Kowarik, I. (2016). Drivers of biodiversity patterns in parks of a growing South American megacity. Urban Ecosystems, 19(3), 1231–1249. https://doi.org/10.1007/s11252-016-0537-1

Ferreira, S. J. F., Pinel, S., Ríos-Villamizar, E. A., Miranda, S. Á. F., Pascoaloto, D., Vital, A. R. T., Monteiro, M. T. F., da Silva, M. do S. R., da Cunha, T. R. B., dos Santos, A. S., Bender, S., & da Cunha, H. B. (2021). Impact of rapid urbanization on stream water quality in the Brazilian Amazon. Environmental Earth Sciences, 80(8), 316. https://doi.org/10.1007/s12665-021-09621-7

Andrews, L., Jhonston Vela, A., Valdivia Zavaleta, X., Alarcón Piscoya, J. A., Garland-Lewis, G., Wolf, K. L., Valdez, U., Cubas Poclin, S., Ampudia Gatty, C., Tapia del Águila, C., Bachman, R., Flores, C., & Wolf, C. (n.d.). Tres Comunidades, Un Río: Supporting Urban Amazonian Floodplain Communities Through Data and Art. Ground Works, 2024(1). https://doi.org/10.48807/2024.0.0154

Border, J. A., Newson, S. E., White, D. C. J., & Gillings, S. (2017). Predicting the likely impact of urbanisation on bat populations using citizen science data, a case study for Norfolk, UK. Landscape and Urban Planning, 162, 44–55. https://doi.org/10.1016/j.landurbplan.2017.02.005

Casanelles-Abella, J., Chauvier, Y., Zellweger, F., Villiger, P., Frey, D., Ginzler, C., Moretti, M., & Pellissier, L. (2021). Applying predictive models to study the ecological properties of urban ecosystems: A case study in Zürich, Switzerland. Landscape and Urban Planning, 214, 104137. https://doi.org/10.1016/j.landurbplan.2021.104137

Jimena Yuijan Rodriguez Prieto, A., Fransheska Quispe Roldan, J., Ian Breytner Sanchez Rosales, K., Casasola Lescano, X., Milen Sanjinez Viera, Y., & Francisco Giraldo Malca, U. (2024). Climate variation in the Amazonian peneplain due to deforestation and urban expansion in Iquitos—Peru, between 1984 and 2023. Proceedings of the LACCEI international Multi-conference for Engineering, Education and Technology. https://doi.org/10.18687/LACCEI2024.1.1.1828

Knapp, S., Aronson, M. F. J., Carpenter, E., Herrera-Montes, A., Jung, K., Kotze, D. J., La Sorte, F. A., Lepczyk, C. A., MacGregor-Fors, I., MacIvor, J. S., Moretti, M., Nilon, C. H., Piana, M. R., Rega-Brodsky, C. C., Salisbury, A., Threlfall, C. G., Trisos, C., Williams, N. S. G., & Hahs, A. K. (2021). A Research Agenda for Urban Biodiversity in the Global Extinction Crisis. BioScience, 71(3), 268–279. https://doi.org/10.1093/biosci/biaa141

Kowarik, I., & von der Lippe, M. (2018). Plant population success across urban ecosystems: A framework to inform biodiversity conservation in cities. Journal of Applied Ecology, 55(5), 2354–2361. https://doi.org/10.1111/1365-2664.13144

Kuras, E. R., Warren, P. S., Zinda, J. A., Aronson, M. F. J., Cilliers, S., Goddard, M. A., Nilon, C. H., & Winkler, R. (2020). Urban socioeconomic inequality and biodiversity often converge, but not always: A global meta-analysis. Landscape and Urban Planning, 198, 103799. https://doi.org/10.1016/j.landurbplan.2020.103799

Rega-Brodsky, C. C., Aronson, M. F. J., Piana, M. R., Carpenter, E.-S., Hahs, A. K., Herrera-Montes, A., Knapp, S., Kotze, D. J., Lepczyk, C. A., Moretti, M., Salisbury, A. B., Williams, N. S. G., Jung, K., Katti, M., MacGregor-Fors, I., MacIvor, J. S., La Sorte, F. A., Sheel, V., Threfall, C. G., & Nilon, C. H. (2022). Urban biodiversity: State of the science and future directions. Urban Ecosystems, 25(4), 1083–1096. https://doi.org/10.1007/s11252-022-01207-w

Roy, M., Shemdoe, R., Hulme, D., Mwageni, N., & Gough, A. (2018). Climate change and declining levels of green structures: Life in informal settlements of Dar es Salaam, Tanzania. Landscape and Urban Planning, 180, 282–293. https://doi.org/10.1016/j.landurbplan.2017.11.011

Trisos, C. H., Auerbach, J., & Katti, M. (2021). Decoloniality and anti-oppressive practices for a more ethical ecology. Nature Ecology & Evolution, 5(9), 1205–1212. https://doi.org/10.1038/s41559-021-01460-w

Alves de Oliveira, B. F., Bottino, M. J., Nobre, P., & Nobre, C. A. (2021). Deforestation and climate change are projected to increase heat stress risk in the Brazilian Amazon. Communications Earth & Environment, 2(1), 207. https://doi.org/10.1038/s43247-021-00275-8

Cabrera-Barona, P., Albán, D., & Durán, G. (2023). Describing the Urban Jungle: A Multicriteria Urbanization Index for the Amazon. ISPRS International Journal of Geo-Information, 12(10), Article 10. https://doi.org/10.3390/ijgi12100430

Costa, S. M., & Brondízio, E. S. (2011). Cities Along the Floodplain of the Brazilian Amazon: Characteristics and Trends. In M. Pinedo-Vasquez, M. L. Ruffino, C. Padoch, & E. S. Brondízio (Eds.), *The Amazon Várzea: The Decade Past and the Decade Ahead* (pp. 83–97). Springer Netherlands. https://doi.org/10.1007/978-94-007-0146-5_6

Gorenstein, S. (2018). Estado y producción de riesgo: Estudio de caso de las comunidades ribereñas de Belén-Iquitos, Perú. Debates En Sociología, 46, 63–80. https://doi.org/10.18800/debatesensociologia.201801.003

Heckenberger, M. J., Christian Russell, J., Toney, J. R., & Schmidt, M. J. (2007). The legacy of cultural landscapes in the Brazilian Amazon: Implications for biodiversity. Philosophical Transactions of the Royal Society B: Biological Sciences, 362(1478), 197–208. https://doi.org/10.1098/rstb.2006.1979

Huera-Lucero, T., Salas-Ruiz, A., Changoluisa, D., & Bravo-Medina, C. (2020). Towards Sustainable Urban Planning for Puyo (Ecuador): Amazon Forest Landscape as Potential Green Infrastructure. Sustainability, 12(11), Article 11. https://doi.org/10.3390/su12114768

Kolawole, A. S., & Iyiola, A. O. (2023). Environmental Pollution: Threats, Impact on Biodiversity, and Protection Strategies. In S. C. Izah & M. C. Ogwu (Eds.), Sustainable Utilization and Conservation of Africa's Biological Resources and Environment (pp. 377–409). Springer Nature. https://doi.org/10.1007/978-981-19-6974-4_14

Li, G., Lu, D., Moran, E., & Hetrick, S. (2013). Mapping impervious surface area in the Brazilian Amazon using Landsat Imagery. GIScience & Remote Sensing. https://www.tandfonline.com/doi/abs/10.1080/15481603.2013.780452

Liu, N., Liu, Z., & Wu, Y. (2025). Direct and Indirect Impacts of Urbanization on Biodiversity Across the World's Cities. Remote Sensing, 17(6), Article 6. https://doi.org/10.3390/rs17060956

Metcalfe, J. (2014, March 14). How Urban Light Pollution Could Be Killing Rainforests. Bloomberg.Com. https://www.bloomberg.com/news/articles/2014-03-14/how-urban-light-pollution-could-be-killing-rainforests

Oertli, B., & Parris, K. M. (2019). Review: Toward management of urban ponds for freshwater biodiversity. Ecosphere, 10(7), e02810. https://doi.org/10.1002/ecs2.2810

Paralovo, S. L., Barbosa, C. G. G., Carneiro, I. P. S., Kurzlop, P., Borillo, G. C., Schiochet, M. F. C., Godoi, A. F. L., Yamamoto, C. I., de Souza, R. A. F., Andreoli, R. V., Ribeiro, I. O., Manzi, A. O., Kourtchev, I., Bustillos, J. O. V., Martin, S. T., & Godoi, R. H. M. (2019). Observations of particulate matter, NO2, SO2, O3, H2S and selected VOCs at a semi-urban environment in the Amazon region. Science of The Total Environment, 650, 996–1006. https://doi.org/10.1016/j.scitotenv.2018.09.073

Pompeu, P. S., & Alves, C. B. M. (n.d.). The Effects of Urbanization on Biodiversity and Water Quality in the Rio das Velhas Basin, Brazil.

Sobroza, T. V., Gordo, M., Dunn, J. C., Pequeno, P. A. C. L., Naissinger, B. M., & Barnett, A. P. A. (2024). Pied tamarins change their vocal behavior in response to noise levels in the largest city in the Amazon. American Journal of Primatology, 86(5), e23606. https://doi.org/10.1002/ajp.23606

Tritsch, I., & Le Tourneau, F.-M. (2016). Population densities and deforestation in the Brazilian Amazon: New insights on the current human settlement patterns. Applied Geography, 76, 163–172. https://doi.org/10.1016/j.apgeog.2016.09.022

Vieira, T. A., & Panagopoulos, T. (2020). Urban Forestry in Brazilian Amazonia. Sustainability, 12(8), Article 8. https://doi.org/10.3390/su12083235

Richards, P., & VanWey, L. (2015). Where Deforestation Leads to Urbanization: How Resource Extraction Is Leading to Urban Growth in the Brazilian Amazon. Annals of the Association of American Geographers, 105(4), 806–823. https://doi.org/10.1080/00045608.2015.1052337

Biljecki, F., & Ito, K. (2021). Street view imagery in urban analytics and GIS: A review. Landscape and Urban Planning, 215, 104217. https://doi.org/10.1016/j.landurbplan.2021.104217

Carranza, M. L. (2024). Remote sensing for urban biodiversity: A review and meta-analysis. Remote Sensing, 16(23), 4483. https://doi.org/10.3390/rs16234483

Dickinson, J. L., Zuckerberg, B., & Bonter, D. N. (2010). Citizen science as an ecological research tool: Challenges and benefits. Annual Review of Ecology, Evolution, and Systematics, 41, 149–172. https://doi.org/10.1146/annurev-ecolsys-102209-144636

Jansen, M., Beukes, M., Weiland, C., et al. (2024). Engaging citizen scientists in biodiversity monitoring: Insights from the WildLIVE! project. Citizen Science: Theory and Practice, 8(1), 30. https://doi.org/10.5334/cstp.665

Mandeville, C. P., Nilsen, E. B., Herfindal, I., et al. (2023). Participatory monitoring drives biodiversity knowledge in global protected areas. Communications Earth & Environment, 4, 240. https://doi.org/10.1038/s43247-023-00906-2

Oliveira, R. (2025). Cost-effective biodiversity monitoring through citizen science in low-income urban areas. Environmental Research & Innovation, 12(1), 99–109.

Pettorelli, N., Williams, J. J., Schulte to Bühne, H., & Crowson, M. (2024). Deep learning and satellite remote sensing for biodiversity monitoring and conservation. Remote Sensing in Ecology and Conservation. https://doi.org/10.1002/rse2.415

Rega-Brodsky, C. C., Aronson, M. F. J., Piana, M. R., et al. (2022). Urban biodiversity: State of the science and future directions. Urban Ecosystems, 25(4), 1–21. https://doi.org/10.1007/s11252-022-01207-w

Tengo, M., Brondizio, E. S., Elmqvist, T., Malmer, P., & Spierenburg, M. (2014). Connecting diverse knowledge systems for enhanced ecosystem governance: The multiple evidence base approach. Ambio, 43(5), 579–591. https://doi.org/10.1007/s13280-014-0501-3

Voigt-Heucke, S. L., Müller, M., & Rostin, J. (2023). How citizen science projects contribute to urban biodiversity monitoring and conservation frameworks: A German case study. Citizen Science: Theory and Practice, 8(1), 30. https://doi.org/10.5334/cstp.585

Ziliaskopoulos, K., & Laspidou, C. (2024). Using remote-sensing and citizen-science data to assess urban biodiversity for sustainable cityscapes: The case study of Athens, Greece. Landscape Ecology, 39(1), Article 9. https://doi.org/10.1007/s10980-024-01793-4

Appendix 1:

Domain	Urban Indicators	Biodiversity Impacts	Monitoring Technologies	Units of Measurement	Reference Level
Urban Form	Land Cover	habitat fragmentation, habitat loss, habitat degradation, biotic homogenization, edge effect(altered microclimate)	satellite, GIS, simulation modelling	Changes are quantified by area and percentage. Percentage of forest cover lost in the urban region.	1. Human land cover best explains current and lost diversity. 2. Compact urban form is more friendly to biodiversity. 3. Targeted housing placement can reduce negative biodiversity impacts (46%).
Urban Form	Impervious Surface	habitat fragmentation, habitat loss	Remote sensing (Landsat TM5), field surveys, geostatistical analysis	percentage of total impervious surface	1. 40–60% of the total impervious surface threshold is recommended for effects on plant diversity.
Urban Form	Building Materials	habitat loss, habitat degradation	material lifecycle analysis, building audits	type of materials	1. Bio-based, renewable materials are generally recommended. 2. Potentials of materials for green facade, for noise absorbent is recommended
Urban Form	Ubran Density	impact change of land use, correlates to noise,	satellite, street images	Population Density Building Height and Concentration Level	1. Urban density is negatively correlated with vehicle miles traveled, indirectly reducing noise and air pollution caused by transportation. 2. High density can free up land and minimize the land covered by urbanization.
Urban Form	Invasive Species	Displace native species, alter ecosystem functions, reduce native biodiversity. Change habitat structure and	multispectral/hyperspectral imaging; microchip/IoT sensors; Field surveys	coverage % of area invaded; percentage of invasive	1. Impacts are strongest on islands and freshwater ecosystems. 2. Biotic homogenization occurs: cities across the globe increasingly share the same

		nutrient cycling.		species in areas	dominant invasive taxa (e.g., pigeons, starlings, kudzu). 3. Invasive species (often ornamental plants or synanthropic birds) increase in urban cores and replace functionally unique native species.
Light Management	Artificial Light at Night (ALAN)	species evolution, species distribution, interaction between species	[small scale] single point ground-based measurements with limited spatial, temporal and spectral resolution; [large scale] remote sensing(only proxies), satellite[limited spatial, temporal and spectral resolution [skyglow] single channel spectral and spatial measurements at zenith possibility to model for a synthetic analysis Meta-analyses to understand light sensitivity across species	multi-spectral night-time radiance	1. Radiance has a more severe impact on light-sensitive species 2. light corridor. networks(road lights) could influence species movement. induce more impact at scale 3. LED energy efficient but natural loss of biodiversity
Water Management	Sewage Systems	Alteration of aquatic habitat chemistry; Promotes eutrophication, algal blooms, oxygen depletion	Level, pump, water quality sensors; smart network systems	flow rate; liquid level; nutrients, gas level...	1.Untreated or poorly treated sewage introduces organic pollution, nutrients, and pathogens, which reduce dissolved oxygen and alter habitat quality. 2. Directly affects aquatic invertebrates, fish, and amphibians. Sensitive taxa like Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) are the first to disappear. 3. Native fish and amphibian

					reproduction is often disrupted due to endocrine-disrupting chemicals (EDCs) in sewage
Water Management	Water Quality	Lower richness, dominance of pollution-tolerant taxa in impacted cities,. Reduced fish reproductive success, metal accumulation, benthic richness loss, proliferation of tolerant species; bird declines	water quality sensors, spectrophotometers/ Probes, remote sensing(help identify correlation) citizen science sampling kits	parameters of water quality(Dissolved Oxygen, pH, turbidity,Conductivity temperature, Nitrate, heavy metals	1. Zygoptera richness declines with urbanization, polluted water 2. In large cities in the Brazilian Amazon(Manaus, Santarém, Macapá, Belém), water contamination was found to have a long-term effect on 50-80% aquatic species.
Waste Management	Public Space Waste	Attract Certain Species. Species Distribution	observational field survey	Waste amount, Waste Type	1. Vulture abundance positively correlated with exposed animal waste and lack of containers 2. GLMMs showed waste container presence reduces vulture numbers ~25%
Noise Management	Noise Pollution	Behaviour patterns change, species distribution	Sound Level Meters (SLMs), Permanent Noise Monitoring Stations Installed in key urban locations (e.g. traffic corridors, parks). Remote Sensing / Satellite Imaging (helps correlate with other factors). Citizen Science via Mobile Apps, IoT-Based Environmental Sensors Point-count bird censuses, digital sound level meters (Extech 407735) Acoustic recording, song playback experiments, noise level mapping Sound Pressure Level meters, noise contour	noise level and frequency	1. The louder the background noise level, the fewer species can be found in the park. 2. Noise pollution promotes ordered changes in the richness and composition of communities. 3. Fewer bird species were found near traffic noise, highways, airports, etc.

			modeling, field audio recording		
Heat Management	Urban Heat Island	species distribution, influence on heat-sensitive species, reduced habitat complexity	satellite, remote sensing, thermal sensors regression modelling, Artificial intelligence for biomicroclimate tool	Land Surface Temperature(LST) Land Use Land Cover(LULC)	1. UHI decreases species and functional diversity in urban birds 2. It has a stronger negative impact during non-breeding seasons 3. Effects are consistent across cities, regardless of size or location
Air Management	Air Quality	photosynthesis and metabolism in trees; species distributions(birds and honey bees	Atomic absorption spectrophotometry, high volume air samplers, biochemical assays Remote sensing (NDVI via Sentinel-2), Air Quality APIs (OpenWeather), beekeeping management software (Nectar) Gas exchange systems (LI-6400XT), isotope ratio mass spectrometers, air quality monitoring stations	Ground-level ozone Common pollutant levels Air Quality Index	1. Honey bee mortality rises with poor air quality, leading to reduced pollination and plant reproductive success due to fewer insect visits and lower seed production in polluted environments. 2. Bird populations, especially small migratory birds, decline at higher ozone levels. 3. Significant drops in flying insect communities are observed: pollinator abundance decreases by up to 48%, and parasitoid wasps fall by 32% under increased diesel exhaust and ozone levels.
Green Infrastructure	Public Green Space(Municipal Green Space)	create habitats. risks of introducing invasive species	Satellite image processing, remote sensing, geospatial analysis, community input	size, vegetation cover, vegetation structure	1. Habitat patches larger than 50 ha are critical for supporting area-sensitive species. 2. Complex landscapes enhance biodiversity. 3. Local, biotic, and management factors are more influential than landscape or abiotic factors. 4. Parks exhibited high homogenization with 95% introduced species, mostly European.

Green Infrastructure	Green Built Elements(Roofs, walls)	habitat creation, degradation prevention, and exotic species invasion	green building audits, street image analysis	species of vegetation, position, and maintenance level	1. Green roofs enhance connectivity and biodiversity, especially for mobile species Green roofs can support generalist and some rare species
Green Infrastructure	Street Trees	habitat creation, ecological corridors	green roof/wall audits, drone imagery	species of trees, tree canopy area	1. Corridors increased species movement by ~50% on average 2. Greater effectiveness observed in natural vs. manipulated corridors 3. Large isolated trees didn't support forest bird species as expected
Green Infrastructure	Peri-urban Green Space, Wasteland, "Wild" urban space	create habitats, retain remnant species	satellite, remote sensing	size, vegetation cover, vegetation structure, connectedness	1. Peri-urban zones showed slight seasonal variations but maintained similarity with preserved zones.
Blue Infrastructure/ Aquatic NbS	Riparian Restoration	habitat creation, habitat connection	riparian zone mapping, water quality sensors	Riparian Habitat Diversity Index (	1. Riparian Habitat Diversity Index (RHDI) (quantifying riparian vegetation/habitat complexity) and benthic macroinvertebrate community metrics (total abundance, taxonomic diversity, and evenness) declined with urban drainage/urbanization in Amazonian areas.
Blue Infrastructure/ Aquatic NbS	Sustainable Drainage Systems	Alters hydrology and habitat connectivity; excess runoff leads to erosion, sedimentation, migration of invasive aquatic species; green drainage improves habitat	Hydrological sensors; remote sensing; GI drawdown sensors; ecological surveys; citizen science (flood mapping)	flow rate; liquid level; nutrients, gas level...	1. Stormwater ponds often support species richness comparable to natural reference ponds

Appendix 2: Biodiversity metrics

Metric	Explanation
Simpson Index	Measures the probability that two individuals randomly selected from a sample will belong to the same species; lower values mean higher diversity.
Shannon Index (Shannon-Wiener Index)	Accounts for both abundance and evenness of species; higher values indicate greater biodiversity.
Beta Diversity	Compares species diversity between ecosystems or habitats, highlighting changes or turnover in species composition.
EPT Richness	Counts the number of Ephemeroptera, Plecoptera, and Trichoptera taxa — sensitive aquatic insects — used to assess freshwater health.
Riparian Habitat Diversity Index	Assesses the variety and quality of vegetation and physical features along riverbanks, indicating habitat complexity and health.
Invasive/Native Species Richness Ratio	Compares the number of invasive species to native ones; a high ratio can indicate ecological imbalance or degradation.
Trophic Niche Overlap	Measures the degree to which species share similar food resources; high overlap can suggest competition or habitat stress.
Species Richness	Simply counts the number of different species in an area; a basic indicator of biodiversity.
Functional Diversity	Assesses the range of different biological roles or traits among species in an ecosystem, important for resilience.
Phylogenetic Diversity	Considers the evolutionary relationships between species, with greater values reflecting broader evolutionary history.

Appendix 3: Biodiversity Management Policies

Kunming-Montreal Global Biodiversity Framework
https://www.unep.org/resources/kunming-montreal-global-biodiversity-framework
EU 2020 Biodiversity Strategies
https://www.eea.europa.eu/policy-documents/eu-2020-biodiversity-strategy
Urban Biodiversity and Ecosystem Services Strategy 2022 Peru
https://www.gob.pe/institucion/minam/campa%C3%B1as/7178-estrategia-de-biodiversidad-urbana-y-servicios-ecosistemicos
City Biodiversity Index Singapore
https://www.nparks.gov.sg/nature/singapore-index-cities-biodiversity