Landscape Architecture

ARTICLE

Rarity-Protected Typology Prioritisation for Urban Nature-Based Solutions under Scale-Constrained Planning

Dr. Marcus Allen*

Department of Urban Design and Landscape Planning Greenfield State University United States

* Correspondence: marcusall@gmail.com

Abstract

Planning of nature-based solution interventions in cities typically starts with typology lists, as opposed to calibration of performance models based on local conditions. Such practice generates practical selection problems in Global South cities where floods, heat stress, water pollution, droughts, biodiversity depletion, erosion, air pollution, and lack of equal access to urban nature are often co-occurring challenges even before the availability of performance evidence on costs, land-use, and performance. Typologies of interventions are selected according to scale-weighted functional leverage, functional range, spatial continuity, and medium coupling criteria for keeping only those intervention families that will be assessed further. Scale-Weighted Functional Leverage (SWFL) is calculated for four types of implementation media: water, land, built structures, and hybrid water–land media. Fourteen resilience functions are kept: biodiversity, heat regulation, water-pollution regulation, pluvial flood regulation, coastal flood regulation, river flood regulation, drought regulation, air-pollution regulation, erosion regulation, river navigation improvement, riverbank erosion regulation, social resilience, coastal flood and erosion regulation, and general flood regulation. The most common medium among 32 interventions is water, accounting for 16 interventions, followed by land, responsible for 12 interventions, built structure for three interventions, and one hybrid water and land intervention. Biodiversity is the most common function represented by 19 interventions, compared to single representation of social resilience, river navigation improvement, and riverbank erosion regulation. Neutral SWFL values result in selection of mangrove restoration, green–blue infrastructure, and urban forest systems as leading solutions, and river management and restoration interventions are also important because they help to preserve rare functions of rivers. Ranking of typologies based on priority weighting puts green–blue infrastructure as number one under heat and air categories, raises rainwater harvesting systems under drought and pluvial challenges, and includes urban gardens as a necessity under social and biodiversity categories. Selection of minimum coverage set demonstrates the need for portfolio of interventions as means of achieving broad resilience coverage.

Keywords: nature-based solutions; Global South; urban resilience; green–blue infrastructure; climate adaptation; functional rarity; typology prioritisation.

Received: 10 April 2025; Revised: 08 August 2025; Accepted: 02 December 2025; Published: 3 December 2025.

doi: 10.70517/la20251154-08

1. Introduction

There is increasing interest in how Global South cities adapt to climate change through nature-based solutions [15]. Cities with limited capacity to develop conventional drainage and energy systems confront an array of challenges involving the spatial coincidence of flooding, water scarcity, informal drainage, heat, air pollution, sanitation, public space, tenure insecurity, and other urban risks [31]. In these contexts, the ability of cities to adapt will depend in part on whether planners can select suitable nature-based interventions efficiently. However, the nature-based solutions inventory is large and varied. Many urban interventions could combine multiple benefits, but which intervention typologies should planners consider before detailed analysis?

The term nature-based solutions has been applied in various disciplines since the early 2000s to describe human interventions using ecological processes. Researchers use the term to describe projects or approaches that restore ecosystems, build resilience, deliver multiple benefits, enhance biodiversity, mitigate impacts, and address climate change [15]. Interventions can include water-based strategies such as mangrove restoration, river rehabilitation, wetlands, and ponds; land-based actions such as urban forests, home gardens, green roofs, bioswales, permeable paving, and green-blue corridors; and built-structure systems, including green building facades, roof gardens, and walls [18, 20]. A wide range of urban challenges is addressed, and numerous ecosystem benefits can result from urban nature-based solutions, including stormwater and runoff attenuation, cooling, improvement of air quality, sediment retention, pollutant removal, habitat creation, shoreline stabilisation, benefits related to food production, and recreational uses [29, 33]. It is the multiple functionality of these interventions that makes them useful in planning.

However, the multiplicity of benefits also creates a difficulty. If planners are interested in nature-based solutions as an alternative to traditional approaches to urban risk, their inventory will not itself determine the right type of intervention to pursue. An extensive literature base shows that nature-based solutions can have diverse positive effects. But the inventory does not provide planners with any guidance on which of these typologies might be prioritised in the absence of modelling and site-specific assessment. There is a clear gap between the nature-based solutions inventory and a set of interventions ready for detailed analysis, which can include hydrological simulation, urban heat modelling, cost estimation, land assembly, maintenance considerations, and community involvement.

Decision-making procedures can provide a tool for selecting alternatives based on their scores against relevant criteria, including technical, economic, environmental, and social aspects [19]. Yet, when planners want to explore nature-based solutions at the initial decision point, there are few criteria available beyond the general knowledge of the typologies' potential and a set of qualitative considerations. At the initial selection stage, it can be valuable to have more structure in decision variables that are relevant at the typology level.

For example, an urban planner might understand whether the typology under consideration involves mainly water or land elements, whether the typical intervention scale is micro, meso, or macro, and what resilience functions are associated with it. The information on each typology in the nature-based solutions inventory would thus enable comparison across types, providing some preliminary insights regarding which of them would be worth further exploration. Scale-Weighted Functional Leverage, or SWFL, allows this preliminary insight to emerge from the inventory.

The contribution lies in providing an analytical approach that can assist planning practice in deciding which urban nature-based solutions typologies to investigate. At the same time, it contributes to understanding the analytical meaning of SWFL scores and distinguishing them from more prioritised interpretations. The paper also highlights how urban nature-based solutions can be assessed for heat–air, drought–pluvial, and social–biodiversity purposes separately using the same inventory.

2. Urban Nature-Based Solutions and Functional Prioritisation

Nature-based solutions emerged as a result of overlapping traditions of ecosystem management, ecological restoration, green infrastructure, ecosystem-based adaptation, water-sensitive urban design, and resilience planning.

 doi: 10.70517/la20251154-08

Nature-based solutions were conceptualised as active components of the problem-solving process rather than as passive subjects of conservation efforts [7, 29]. Urban research linked the concept to green infrastructure, ecosystem services, low-impact development, sustainable drainage systems, and water-sensitive urban design [11, 12, 23]. While the terms in question vary, all of them refer to the planning potential of nature as a way to deliver ecological services that contribute to climate adaptation.

The development of a strong typology framework for nature-based solutions also follows from the need to categorise urban interventions in terms of the benefits they can deliver. The importance of the typology approach for urban nature-based solutions has been highlighted in multiple recent publications. Castellar et al. argue that urban nature-based solutions need better conceptualisation and terminological framing [28]. Typologies are also increasingly studied for the potential connections they can establish with urban challenges and ecosystem services [5]. Urban green infrastructure and multifunctional benefits are the focus in Korkou et al. and Alves et al., respectively [24, 31]. All of these findings make a strong case for the relevance of typology selection as an analytical step prior to site-level engineering or design.

Hydrological functions are particularly significant in nature-based solutions research. Low-impact development and sustainable drainage researchers demonstrate how urban interventions based on water bodies and runoff reduction and attenuation can affect the hydrological balance, reducing peak flows and improving infiltration and stormwater management [2, 11]. Similarly, interactions between urban vegetation and stormwater management systems through canopy interception, evapotranspiration, water movement, and compatibility of urban trees with green infrastructure can be important [27]. River, floodplain, and coastal ecosystem functions add the spatial perspective through flood protection, bank stabilisation, shore buffering, sediment dynamics, and ecological connectivity. Flood as a generic typology indicator would thus be insufficient for urban resilience planning because it ignores the interrelated dimensions of the issue: water bodies, channels, and land use [32]. Thus, pluvial, river, and coastal flooding and related erosion and water-pollution regulation can be included in the inventory of urban nature-based solutions functions.

Other typology functions in the nature-based solutions inventory relate to thermal, air quality, biodiversity, and public health challenges. Urban greening has shown significant potential for urban cooling due to canopy shading and evapotranspiration, although canopy characteristics, urban form, moisture content, tree species, and extent matter in delivering cooling effects [6, 13]. The role of urban greening as a way to address public health issues, promote social interaction, and improve recreation can be substantial, but access, maintenance, governance, cultural fit, and uneven access to green space also need to be considered [10, 16, 21]. Biodiversity, heat regulation, air quality regulation, and social resilience functions follow from these works and can be included in the inventory. However, functional capabilities of an intervention cannot substitute for quantitative measurement of its effectiveness, an aspect of urban nature-based solutions research that needs additional attention.

Similar to the functions, scale also plays an important role. Urban resilience is defined as a phenomenon at the intersection of social, ecological, and physical systems rather than an isolated asset [17]. Local rainfall measures installed at household or building level may contribute to runoff reduction, but may prove ineffective without a broader planning effort, which includes catchment-wide management [12]. On the other hand, large forest and mangrove restoration programmes have a good chance of being successful ecologically, but they may fail to reach vulnerable urban neighbourhoods because of governance, accessibility, or tenure issues [30]. Scale-continuity concerns are therefore crucial in green infrastructure and urban ecosystem services research [1, 3, 4, 9]. The scale-continuity coefficient takes into account such concerns and awards extra points to multiscale typologies.

In addition to functions and scale, there is also research explaining why early screening of typologies cannot be equated with intervention choice. Mainstreaming the use of ecosystem-based adaptation measures in municipalities will require cooperation between multiple municipal agencies, budgets, legislative and regulatory frameworks, and technical and professional expertise [35, 36]. Principles of effective urban nature-based solutions application, according to recent work, imply long-term governance, inclusive design, and awareness of urban context, in addition to the use of intervention types [30]. Screening and ranking are thus important as a first step in an ongoing urban adaptation process, but they should not be mistaken for the only steps.

Finally, equity and potential ecosystem disservices should be considered during urban nature-based solutions implementation. Greening has demonstrated significant positive effects, such as health and environmental quality benefits, but it can also lead to increased real estate prices, inequality, and redistribution of environmental and financial gains toward advantaged residents [14, 25, 37]. Potential negative consequences of urban nature-based solutions interventions can include allergenic pollen release, water demands, maintenance requirements, perceptions of safety threats, and pests [8, 26, 34]. Such disservices cannot be ignored during the interpretation of SWFL, but they should not overshadow functional relevance because this is a separate assessment issue.

In the literature reviewed, the contribution of the paper can be viewed as the calculation to perform at the first decision point, after compiling the nature-based solutions inventory. By taking account of rarity of functions and continuity of scales, the calculation helps ensure that the benefits in question receive due attention during selection, whereas potentially relevant typologies remain on the list.

3. Materials and Analytical Procedure

3.1. Typology classification

The dataset under analysis is an inventory of 32 urban nature-based solution typologies. It has been treated as a list of typology-level planning records, following previous urban nature-based solution typology classification frameworks [28]. Three attributes have been assigned to each typology in the inventory: medium, spatial scale, and resilience function. Four medium classes are water, land, built structures, and combined water–land typologies. As noted above, water-based typologies refer to measures related to water bodies, runoff management, wetlands, drainage, coastal, and river corridors. Land-based typologies relate to soil and vegetative measures, including gardens, forests, or productive land cover. Built structure-based interventions consist of systems located on, or connected with buildings or other construction. Combined water–land typologies are also included as a separate class.

Spatial scale has four options: micro, meso, macro, or a combination of these scales. Micro-scale interventions operate at the household/building, parcel, street, small plot, or urban park level. Meso-scale refers to neighbourhoods, districts, urban subcatchments, and other similar territories. Macro-scale denotes larger areas, such as metropolitan region, coastlines, or peri-urban area. Multiscale typologies are those that link two spatial levels. Spatial scale classification is thus based on the planning need to compare interventions regardless of specific sites [24]. It does not assume that a typology can be used exclusively at one planning level. However, spatial scale differentiation makes it possible to detect multiscale connections within the inventory.

Figure 1 presents a medium-based visual presentation of the coded inventory.

Figure 1 reveals the underlying empirical structure of the inventory before assigning a score. It is interesting that half of the typologies are water-based, so the ranking will be expected to react to such issues as floods, droughts, water quality, rivers, and coastal functions. The relatively low number of typologies of built structures is also telling in terms of inventory structure as its focus is on landscapes, waters, and urban open spaces rather than building retrofits.

In order to retain as much multifunctionality as possible from the existing literature, 14 functional labels were selected, taking into consideration the need to distinguish hydrological pathways for planning reasons [27, 31]. The set includes air-pollution regulation, biodiversity, coastal flood regulation, coastal flood and erosion regulation, drought regulation, erosion regulation, general flood regulation, heat regulation, pluvial flood regulation, river flood regulation, river navigation improvement, riverbank erosion regulation, social resilience, and water-pollution regulation. Labels were separated due to the different physical basis of flood types (coastal flood regulation, river flooding, pluvial flooding, and general flood regulation). Coastal flood regulation cannot be substituted for pluvial flood regulation as the former refers to sea-related events. Riverbank erosion regulation also cannot be considered a variant of surface runoff regulation. In this regard, separation of the listed functions enhances their planning value.

Coded data feature several strong concentrations of functions. Thus, biodiversity is the most frequently mentioned

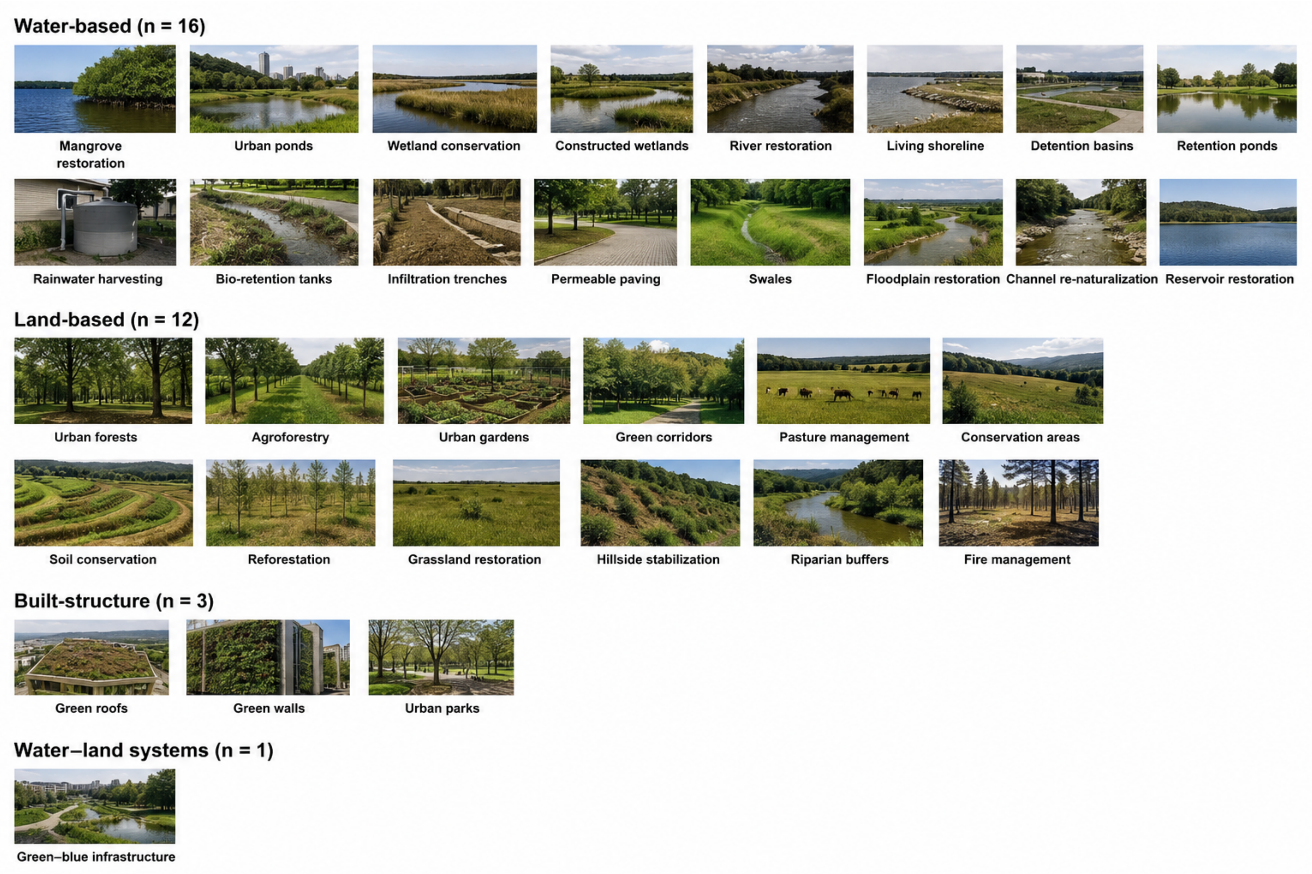

Figure 1. Coded typology inventory by implementation medium.

function, as it features in 19 typologies. After that come heat regulation (11 times), water-pollution regulation (10 times), and pluvial flood regulation (nine times). Erosion regulation, river navigation improvement, riverbank erosion regulation, and social resilience also belong to less frequently met functions. The mentioned rarity of some functions requires implementation of a weighting procedure, since inventory does not have a uniform functional structure. It would be unreasonable to consider a typology carrying a common function superior to another one carrying an uncommon function.

Rarity Profile Figure 2 converts information about frequency of particular functions into rarity profiles used further in the weighting procedure. Largest rarity weights correspond to cases when a function was mentioned only once or twice in the inventory. They imply necessity to protect such functions as social resilience, river navigation improvement, riverbank erosion regulation, and erosion regulation explicitly in the process of typology ordering.

The rarity pattern in Figure 2 endows the weighting process with its strategic meaning. While the use of an umbrella term such as biodiversity is indeed useful, it carries less discrimination power compared to a single-use function. For that reason, the computation to follow will safeguard urban gardens, river-related functions, and erosion typologies, regardless of how they feature in the inventory.

3.2. Functional rarity and breadth scoring

Let $T = \{1, \ldots, n\}$ denote the set of typologies, with $n = 32$, and let $F = \{1, \ldots, m\}$ denote the set of functional labels, with $m = 14$. A binary incidence variable d_{if} is defined as

$$d_{if} = \begin{cases} 1, & \text{if typology } i \text{ is associated with function } f, \\ 0, & \text{otherwise.} \end{cases} \tag{1}$$

The frequency of each function is

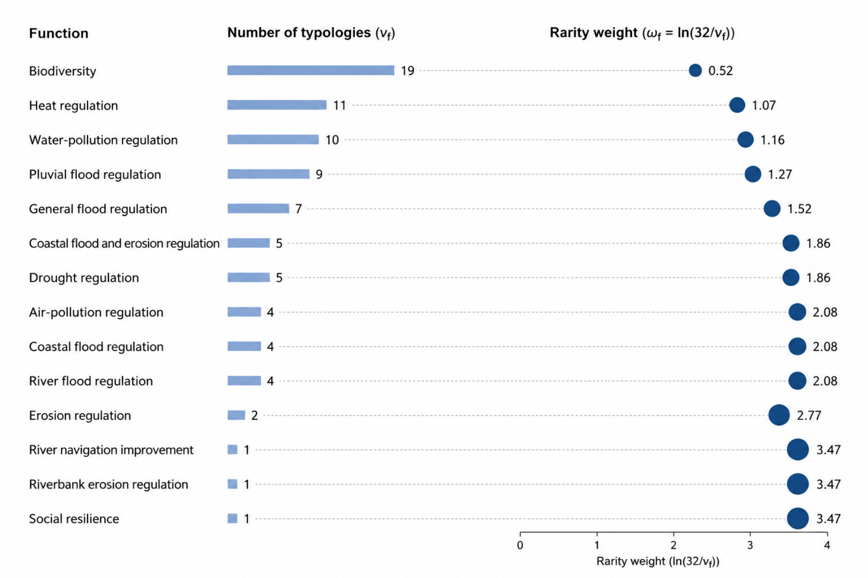

Figure 2. Function frequency and rarity weight.

$$\nu_f = \sum_{i=1}^{n} d_{if}. \tag{2}$$

A rare-function weight is assigned through the logarithmic expression

$$\omega_f = \ln\left(\frac{n}{\nu_f}\right). \tag{3}$$

This expression gives a low weight to a function appearing in many typologies and a high weight to a function appearing in few typologies. The weighting follows the information-theoretic principle that rare attributes carry more discriminatory information than common attributes [22]. The logarithmic form prevents very rare labels from becoming unreasonably dominant while still ensuring that the score does not collapse into a simple count of functions.

The functional breadth of typology i is then calculated as

$$B_i = \sum_{f=1}^{m} d_{if}\omega_f. \tag{4}$$

A typology receives a high B_i value when it combines several functions, especially if those functions are uncommon. A typology with many common functions can rank below a typology with fewer but rarer functions. This is appropriate for early planning because rare needs often disappear in broad catalogues unless they are explicitly protected by the method, especially when social, riverine, and erosion functions are less visible than biodiversity or heat benefits.

3.3. Spatial continuity and medium coupling

Spatial continuity is represented through a scale coefficient. Let s_i be the number of spatial scales assigned to typology i. Single-scale typologies have $s_i = 1$, while typologies spanning macro–meso or meso–micro scales have $s_i = 2$. The scale-continuity coefficient is

$$C_i = 1 + \alpha(s_i - 1), \tag{5}$$

where $\alpha = 0.25$. The value of α is deliberately modest. It acknowledges that cross-scale typologies can support continuity in planning and governance, but it does not allow scale continuity to outweigh functional composition. A typology with weak functional breadth should not become dominant merely because it is multiscale.

A medium-coupling coefficient is also assigned to typologies that explicitly connect water and land. The coefficient is

$$M_i = \begin{cases} 1 + \beta, & \text{if typology } i \text{ is coded as water–land,} \\ 1, & \text{otherwise,} \end{cases} \tag{6}$$

where $\beta = 0.15$. This adjustment recognises that integrated green–blue systems often connect stormwater, public space, vegetation, ecological corridors, and urban form. As with α, the value is conservative. It rewards coupling without letting medium classification dominate the score.

The final Scale-Weighted Functional Leverage score is

$$L_i = B_i C_i M_i. \tag{7}$$

The score is interpreted as early-stage planning leverage. It does not measure cost-effectiveness, hydraulic performance, thermal reduction, land suitability, or social acceptability. It identifies typologies whose functional composition and scale placement make them strong candidates for further assessment.

The score composition in Figure 3 presents the three-part score composition for the leading neutral typologies. The visual arrangement clarifies how the same final quantity combines functional breadth, spatial continuity, and medium coupling while leaving the numerical equations explicit in the text.

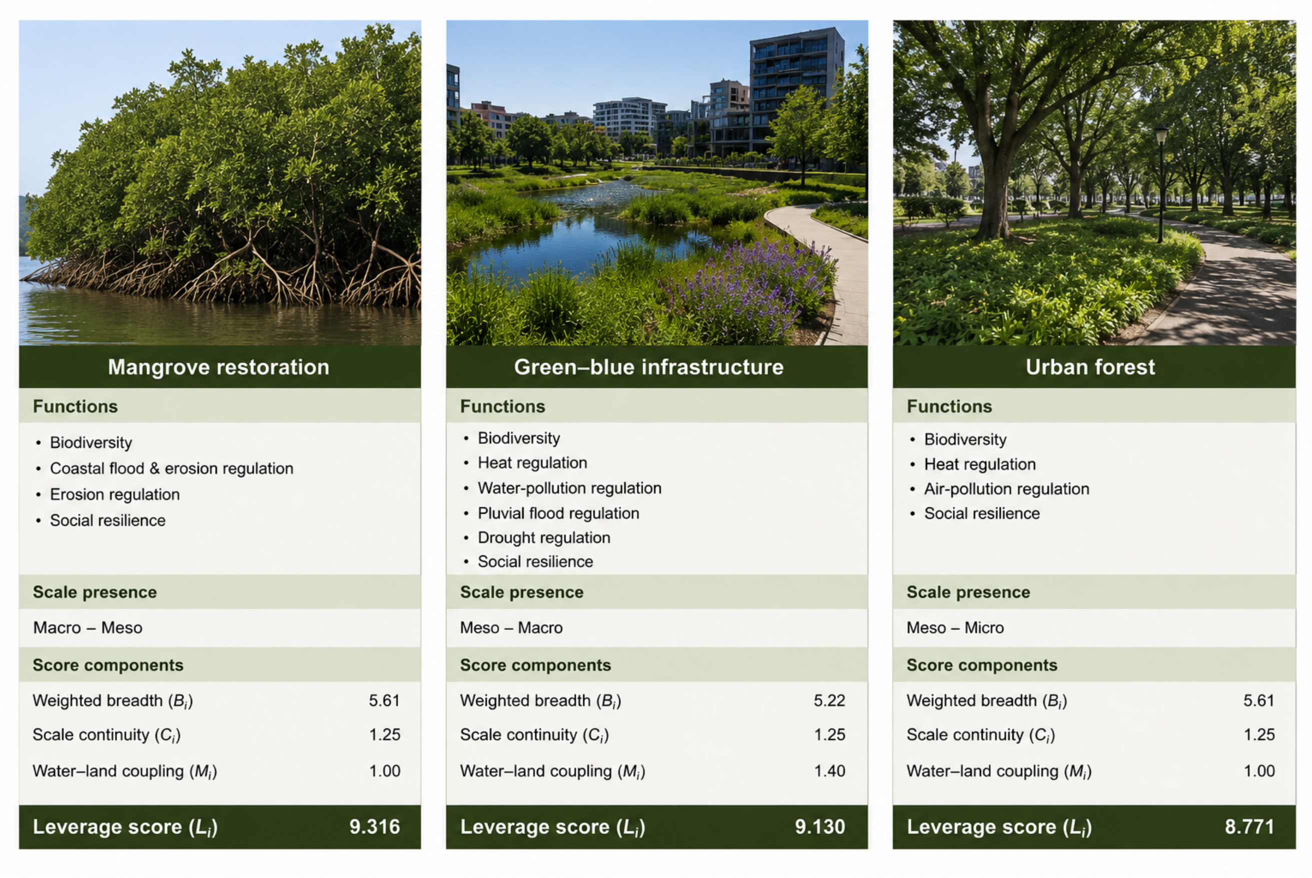

Figure 3. Leverage-score components for the leading typologies.

The component view in Figure 3 is important because the leading scores are not produced by one attribute alone. Mangrove restoration is carried by rare coastal and erosion functions, green–blue infrastructure gains from water–land coupling, and urban forests gain from thermal and air-quality functions combined with meso–micro scale presence. The calculation therefore reads each typology as a bundle of planning properties rather than as a single intervention label.

3.4. Priority-weighted leverage variants

Cities do not face identical priorities. A coastal city may give greater importance to coastal flooding and erosion, an inland city may emphasise pluvial flooding and drought, and a dense heat-exposed city may prioritise thermal and air-quality regulation. To test how the ranking responds to such planning emphasis, a priority multiplier q_f is added to the functional term:

$$L_i^{(q)} = C_i M_i \sum_{f=1}^{m} q_f d_{if} \omega_f. \tag{8}$$

Three priority-weighted readings are examined. The heat–air reading doubles the weights of heat regulation and air-pollution regulation. The drought–pluvial reading doubles drought regulation and pluvial flood regulation. The social–biodiversity reading doubles social resilience and increases biodiversity by 30%. These readings do not represent universal policy preferences. They show how the ordering changes when specific climate and justice pressures become more prominent.

3.5. Minimum functional coverage sets

A second coverage procedure identifies the smallest typology set able to cover a target group of functions. For any candidate set $P \subseteq T$, the covered functions are

$$\mathcal{F}(P) = \{f \in F : \exists i \in P \text{ such that } d_{if} = 1\}. \tag{9}$$

The coverage condition is

$$\min |P| \quad \text{subject to} \quad \mathcal{F}(P) \supseteq F^*, \tag{10}$$

where F^* is the function set required by the planning test. Three coverage sets are considered. The first covers all 14 functions. The second represents coastal or estuarine urban retrofitting and retains functions relevant to tidal, estuarine, riverine, pluvial, heat, water-quality, biodiversity, and social-resilience needs. The third represents inland urban retrofitting and excludes coastal functions while retaining pluvial flooding, drought, heat, biodiversity, water pollution, general flood moderation, erosion, and social resilience.

The coverage-set procedure is not an implementation package. It is a completeness check. If a city selects typologies without considering a rare function, the coverage set reveals which intervention would be needed to cover that missing function. In this sense, function coverage complements leverage scoring. Leverage ranks individual typologies, whereas the coverage set identifies combinations.

4. Results

4.1. Inventory composition across medium and scale

The inventory contains 32 typologies distributed unevenly across media. Water-based measures form the largest group, with 16 entries, representing exactly half of the inventory. Land-based measures account for 12 entries, or

37.5%. Built-structure measures account for three entries, or 9.4%. One entry, green–blue infrastructure, is coded as combined water–land, representing 3.1% of the inventory. This structure confirms that the inventory is organised strongly around water-related planning needs, a distribution introduced visually in Figure 1. It also shows that building-integrated typologies are present but less common.

Scale distribution is also uneven. Micro-scale interventions appear in 15 typologies, or 46.9% of the inventory. Macro-scale interventions appear in 13 typologies, or 40.6%. Meso-scale interventions appear in eight typologies, or 25.0%. These percentages do not sum to 100% because multiscale typologies are counted in each scale to which they belong. Four typologies span more than one scale: mangrove restoration in coastal and estuarine ecosystems, green–blue infrastructure, ecosystem-based adaptation solutions, and urban forest systems. Their multiscale coding is important because they can connect regional or citywide ecological processes with neighbourhood or local benefits. The values in Table 1 establish the inventory's basic asymmetry. Water typologies dominate numerically, while multiscale typologies are few. This means that the later ranking is not simply a reflection of how many entries exist in each class; it must also account for whether a typology carries rare functions or connects more than one spatial level.

The medium pattern has a clear planning interpretation. Water-based typologies dominate because urban climate resilience in many Global South settings is closely associated with runoff, flood exposure, drainage deficits, coastal risk, drought, river corridors, and water pollution. Land-based typologies remain substantial because vegetation, soil management, gardens, forests, and productive landscapes supply several thermal, ecological, and social functions. Built-structure interventions are comparatively fewer, which suggests that building-integrated solutions such as green roofs, green walls, or related systems are not the main organising category of the inventory. This does not mean that built measures lack value. It indicates that, within this typology set, the main resilience vocabulary is organised around water and land systems rather than buildings alone.

Table 1. Coded inventory composition.

Dimension	Class	Count	Share
Medium	Water	16	50.0%
	Land	12	37.5%
	Built structures	3	9.4%
	Water–land	1	3.1%
Spatial scale	Micro	15	46.9%
	Meso	8	25.0%
	Macro	13	40.6%
	Multiscale typologies	4	12.5%

The scale pattern also shows a practical tension. Micro-scale measures are numerous, which is important for incremental urban retrofit, household adaptation, and small-site interventions. Macro-scale measures are also prominent, reflecting the importance of river basins, coastlines, wetlands, forests, productive landscapes, and large open-space systems. Meso-scale measures are less frequent, yet the meso scale is often the level at which municipal departments, neighbourhood plans, and infrastructure corridors interact. This suggests that effective planning may require translating both micro and macro typologies into district-scale programmes, especially where metropolitan governance is fragmented.

4.2. Distribution of resilience functions

The 14 functional labels have sharply different frequencies, as visualised by the rarity profile in Figure 2. Biodiversity appears in 19 typologies, making it the most common function. Heat regulation appears in 11 typologies, water-pollution regulation in 10, and pluvial flood regulation in nine. General flood regulation appears in seven typologies. Coastal flood and erosion regulation, drought regulation, air-pollution regulation, coastal flood regulation, and river flood regulation form a middle group. Erosion regulation appears in two typologies, while river navigation improvement, riverbank erosion regulation, and social resilience appear only once each.

The frequencies in Table 2 show that the inventory is functionally uneven rather than balanced. Common functions define the broad ecological vocabulary of the inventory, whereas one-entry functions reveal planning needs that depend on very specific typologies. This unevenness is the reason that the leverage score uses rarity weighting rather than a simple count.

The frequency distribution shows why simple function counting is insufficient. Biodiversity is important, but it is so common in the inventory that it has limited discriminatory power. A typology associated with biodiversity alone should not necessarily outrank one associated with a rare planning function such as social resilience or riverbank erosion. The same applies to heat regulation, which appears in more than one-third of the typologies. Frequent functions represent broad co-benefits, but rare functions identify planning needs that may be overlooked if the inventory is screened too quickly.

The separation of flood-related labels is also important. Pluvial flood regulation appears in nine typologies, general flood regulation in seven, coastal flood and erosion regulation in five, coastal flood regulation in four, and river flood regulation in four. Together, these labels show that flood resilience is central to the inventory, but the underlying processes are not identical. A rainwater harvesting system, a mangrove belt, a river restoration programme, and a permeable surface all contribute to water-risk management, but they operate at different scales and respond to different hydrological pathways. Combining them into one undifferentiated flood label would reduce the usefulness of the analysis.

Table 2. Resilience-function frequencies.

Function label	Typology count	Share of typologies
Biodiversity	19	59.4%
Heat regulation	11	34.4%
Water-pollution regulation	10	31.3%
Pluvial flood regulation	9	28.1%
General flood regulation	7	21.9%
Coastal flood and erosion regulation	5	15.6%
Drought regulation	5	15.6%
Air-pollution regulation	4	12.5%
Coastal flood regulation	4	12.5%
River flood regulation	4	12.5%
Erosion regulation	2	6.3%
River navigation improvement	1	3.1%
Riverbank erosion regulation	1	3.1%
Social resilience	1	3.1%

4.3. Neutral leverage ordering

The neutral leverage ranking identifies typologies with the strongest combination of rare-function coverage, functional breadth, and spatial continuity. Mangrove restoration in coastal and estuarine ecosystems ranks first with a score of 9.316. It combines coastal flood regulation, river flood regulation, erosion regulation, and biodiversity, and it spans macro and meso scales. Its score is high because it covers several water-related hazards while also carrying an uncommon erosion function. The result reflects the strategic role of estuarine and coastal ecosystems in cities exposed to tides, river mouths, storm surges, and sediment instability.

Green–blue infrastructure ranks second with a score of 9.130. It is the only typology coded explicitly as water–land,

and it spans macro and meso scales. Its functions include flood regulation, biodiversity, water-pollution regulation, heat regulation, and air-pollution regulation. The typology is therefore highly multifunctional even though several of its functions are relatively common. Its position is strengthened by cross-scale continuity and medium coupling. In planning terms, green–blue infrastructure is not simply one intervention but a spatial system through which drainage, vegetation, open space, mobility, and ecological connectivity can be aligned.

Urban forest systems rank third with a score of 8.771. The typology spans meso and micro scales and is associated with coastal/pluvial flood reduction, biodiversity, air-pollution regulation, and heat regulation. Its high ranking reflects the combined importance of thermal moderation, air-quality improvement, and water-risk reduction in dense urban areas. Urban forest systems are especially relevant where heat exposure intersects with limited shade, poor air quality, and unequal access to green space. Their cross-scale coding also matters because individual trees and local groves can be planned as part of wider urban canopy systems.

The full neutral pattern is visualised in Figure 4. The figure places all coded typologies in a single leverage field, allowing the highest-scoring group to be read against lower-scoring micro, meso, macro, and multiscale entries.

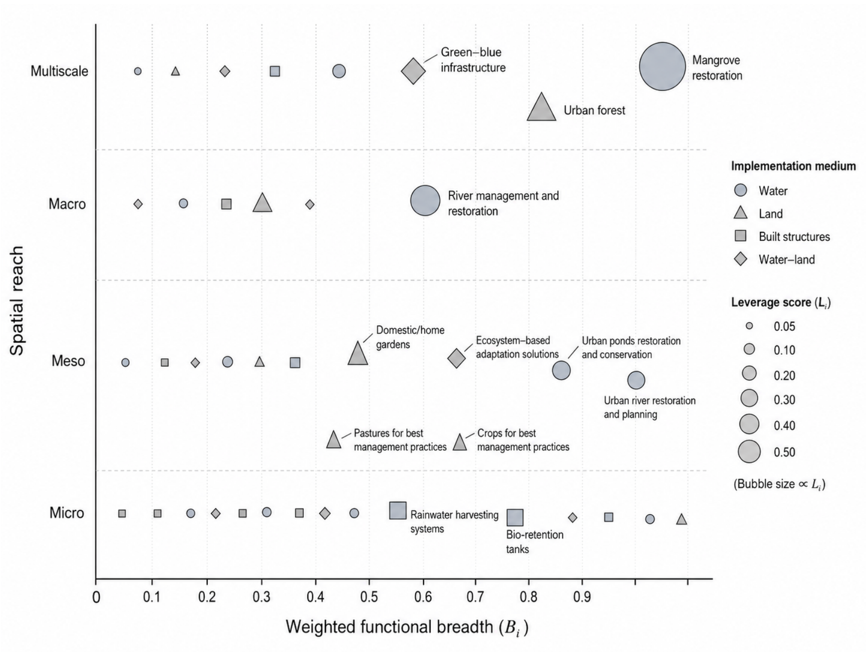

Figure 4. Leverage field for the coded typologies.

The leverage field in Figure 4 separates three patterns that are difficult to see in a table alone. Several micro-scale entries cluster at lower leverage values because they provide narrower function sets. River management and restoration moves upward because it carries rare river functions. Mangrove restoration, green–blue infrastructure, and urban forests occupy the highest region because their scores combine cross-scale presence with function sets that include either rare functions or multiple urban adaptation benefits.

The ranked values in Table 3 show a steep leading tier. The top three typologies are separated from the rest because they combine cross-scale presence with multiple resilience functions. The fourth-ranked entry has a different meaning: river management and restoration is high because its rare functions would otherwise have little representation. The table therefore shows two forms of planning leverage, broad multiscale leverage and rare-function leverage.

The top-12 visual ranking in Figure 5 provides a compact visual reading of the same top-12 ordering. The ranked layout helps distinguish the leading multiscale group from specialised river, household, productive-land, and decentralised water-management typologies.

The ranked visual order in Figure 5 complements the numerical values by showing the intervention families as recognisable planning objects. The first three entries form a clear leading tier, while the middle group contains

Table 3. Highest neutral leverage scores.

Rank	Typology	Medium	Scale	Score	Main coded functions
1	Mangrove restoration in coastal and estuarine ecosystems	Water	Macro–Meso	9.316	Coastal flood, river flood, erosion, biodiversity
2	Green–blue infrastructure	Water–land	Macro–Meso	9.130	Flood, biodiversity, water pollution, heat, air pollution
3	Urban forest	Land	Meso–Micro	8.771	Coastal/pluvial flood, biodiversity, air pollution, heat
4	River management and restoration	Water	Macro	6.931	River navigation, riverbank erosion
5	Domestic/home gardens	Land	Micro	5.882	Biodiversity, erosion, heat, flood
6	Ecosystem-based adaptation solutions	Land	Macro–Meso	5.388	Heat, air pollution, water pollution
7	Urban ponds restoration and conservation	Water	Micro	5.322	Coastal flood, river flood, water pollution
8	Urban river restoration and planning	Water	Meso	4.832	River flood, water pollution, heat, biodiversity
9	Pastures for best management practices	Land	Macro	4.539	Drought, flood, water pollution
10	Crops for best management practices	Land	Macro	4.539	Drought, flood, water pollution
11	Rainwater harvesting systems	Water	Micro	4.288	Water pollution, drought, pluvial flood
12	Bio-retention tanks	Water	Micro	4.272	Water pollution, flood, heat, biodiversity

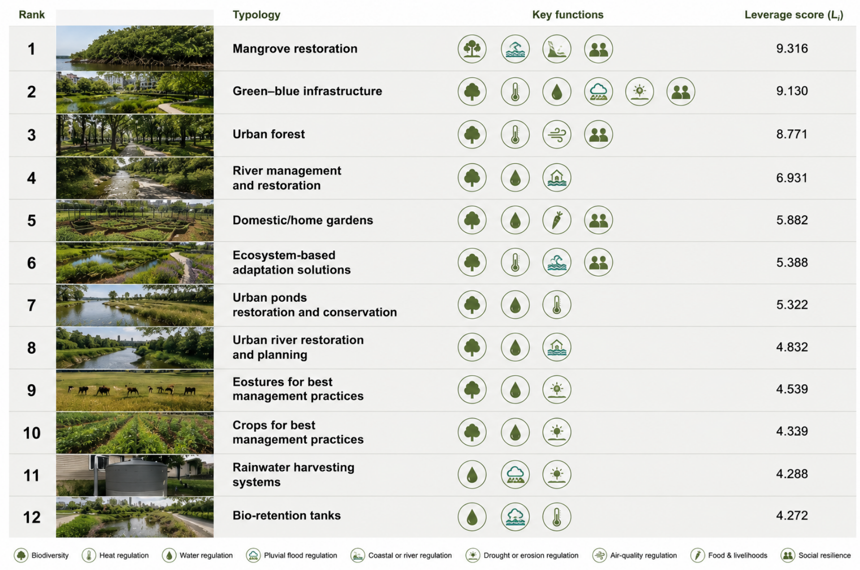

Figure 5. Neutral order of the leading typologies.

more context-dependent options: river corridors, household gardens, ecosystem-based adaptation, ponds, urban river restoration, productive landscapes, rainwater harvesting, and bio-retention. This distinction matters because early screening should not only name the top typology; it should also preserve the next tier for local feasibility assessment.

The fourth-ranked typology, river management and restoration, has a score of 6.931. It is functionally narrower than the leading three, but it carries two very rare labels: river navigation improvement and riverbank erosion regulation. This result demonstrates the purpose of rare-function weighting. A typology can be strategically important even if it does not have the widest range of benefits. In riverine cities where mobility, bank stability, sediment dynamics, and navigability matter, this typology should be examined early rather than excluded because it lacks the broad co-benefit profile of green–blue infrastructure or urban forests.

Domestic/home gardens rank fifth with a score of 5.882. They are coded as micro-scale land typologies and combine biodiversity, erosion regulation, heat regulation, and flood regulation. Their ranking is notable because they operate at household scale rather than metropolitan scale. The score indicates that household and small-plot practices can carry meaningful functional leverage when they combine soil, vegetation, shade, infiltration, and local ecological benefits. In informal or low-income neighbourhoods, such interventions may be especially relevant where large parcels for public green infrastructure are scarce. Their suitability, however, depends on tenure, water availability, maintenance capacity, and social acceptability.

Ecosystem-based adaptation solutions rank sixth with a score of 5.388. They span macro and meso scales and include heat regulation, air-pollution regulation, and water-pollution regulation. Urban ponds restoration and conservation rank seventh with a score of 5.322, combining coastal flood regulation, river flood regulation, and water-pollution regulation at micro scale. Urban river restoration and planning rank eighth with a score of 4.832, combining river flood regulation, water-pollution regulation, heat regulation, and biodiversity at meso scale. These results show that water bodies and river corridors remain important beyond flood protection; they also contribute to temperature regulation, ecological quality, and urban environmental repair.

Pastures and crops under best management practices share the ninth rank, each with a score of 4.539. Their functions include drought regulation, flood regulation, and water-pollution regulation. These typologies indicate that urban and peri-urban resilience cannot be separated fully from productive land management. In many Global South contexts, food systems, peri-urban agriculture, water retention, and runoff control are connected. Rainwater harvesting systems rank eleventh with a score of 4.288, combining water-pollution regulation, drought regulation, and pluvial flood regulation. Bio-retention tanks rank twelfth with a score of 4.272, combining water-pollution regulation, flood regulation, heat regulation, and biodiversity. Their close scores suggest that decentralised water-management typologies can become important when drought, runoff, and water quality are evaluated together.

4.4. Priority-weighted ordering

The priority-weighted tests show that rankings respond meaningfully to different planning priorities. Under neutral conditions, the leading five typologies are mangrove restoration, green–blue infrastructure, urban forest, river management and restoration, and domestic/home gardens. When heat and air-pollution regulation are doubled, green–blue infrastructure becomes the leading typology, followed by urban forest and ecosystem-based adaptation solutions. Mangrove restoration remains in the top group, but it no longer ranks first because the emphasised functions favour vegetated urban networks and tree-based systems more directly.

Table 4. Priority-weighted top rankings.

Priority test	Top typologies	Leading score	Interpretation
Neutral	Mangrove restoration; green–blue infrastructure; urban forest; river management and restoration; domestic/home gardens	9.316	Cross-scale hydrological and biodiversity functions dominate the first group.
Heat–air	Green–blue infrastructure; urban forest; ecosystem-based adaptation solutions; mangrove restoration; domestic/home gardens	13.655	Typologies linking thermal regulation with air-quality improvement become central.
Drought–pluvial	Urban forest; mangrove restoration; green–blue infrastructure; rainwater harvesting systems; river management and restoration	10.356	Rainwater harvesting and permeable water-management systems gain importance where rainfall extremes and dry-period storage must be addressed together.
Social–biodiversity	Mangrove restoration; green–blue infrastructure; urban forest; urban gardens; river management and restoration	9.511	Urban gardens become indispensable because social resilience is otherwise weakly represented.

The priority results in Table 4 demonstrate that the neutral order should not be applied mechanically. The same coded inventory produces different top groups when the planning emphasis changes. This strengthens the method because it allows cities to retain a transparent neutral reference while still adjusting interpretation to local stress conditions.

The rank shifts are shown in Figure 6. The visual comparison makes clear that the leading group remains present across priorities, while rainwater harvesting systems and urban gardens become prominent only when drought–pluvial or social–biodiversity functions are emphasised.

The ordering of Figure 6 indicates that movement of ranks is selective rather than stochastic. Typologies with general urban vegetation and water functions maintain their strength column-wide, while rainwater harvesting systems and urban gardens climb ranks only in instances in which the priority matches its coded functions. This outcome confirms the possibility of using the same typology set to establish both a generic prioritization order and contextually sensitive leverage points without changing the method itself.

Heat–air testing is particularly pertinent for dense urban areas in which heat and air quality interact. Green–blue infrastructure attains the leading score of 13.655 because it encompasses heat regulation, air-pollution regulation, water-pollution regulation, flood regulation, and biodiversity while benefiting from the water–land coupling. Urban forest systems remain high in the order because their functions as canopy and vegetation directly provide heat and air benefits. Ecosystem-based adaptations climb because they incorporate both heat regulation and air-pollution regulation. The ordering thus suggests that heat-exposed cities should investigate the role of networks of vegetation and canopy at early planning stages, particularly if traditional infrastructure programmes do not tackle thermal inequality issues.

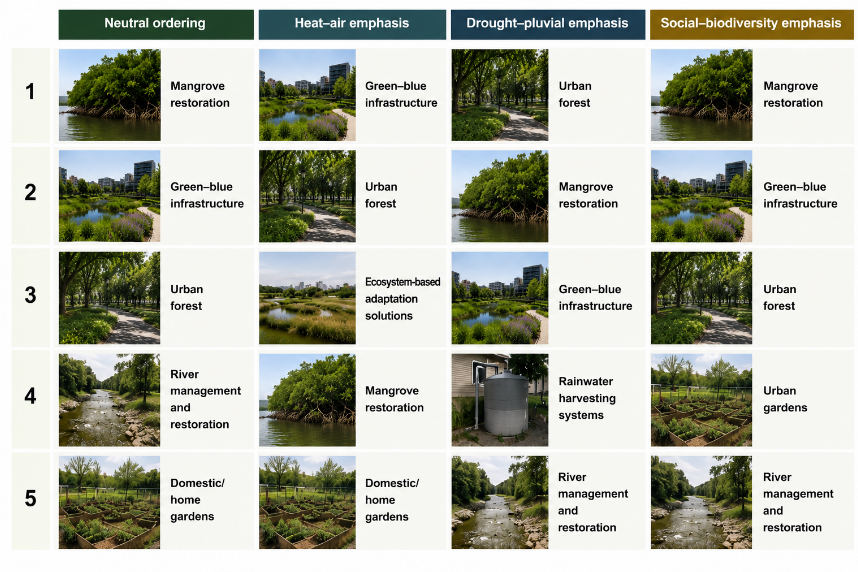

Figure 6. Rank movement under priority-weighted.

The ordering for drought–pluvial conditions yields a quite different ordering. First, urban forest systems attain the leading score. Mangrove restoration and green–blue infrastructure remain part of the high-score group, while rainwater harvesting climbs substantially in rank. This outcome stems from the joint importance of both stormwater collection and dry period availability. While rainwater harvesting systems are not the highest neutral typology, they become very relevant if a city suffers from intense rains and droughts. Additionally, pastures and crops with best management practices become relevant for the current priority because they link water regulation to land use in the face of drought, floods, and water-pollution regulation. As a result, drought-pluvial cities cannot prioritize either too much water or too little water as the only issue.

The ordering of the social-biodiversity priority generates a third pattern. Mangrove restoration, green–blue infrastructure, and urban forest systems maintain a prominent place, while urban gardens climb into the first-tier group. The reason is clear since the latter system is the only one incorporating social resilience. The finding is analytically meaningful since social resilience is a rarely found function, but it becomes a relevant feature in planning precisely because community capacity, public space provision, stewardship, food access, and social cohesion determine whether NBS persist. The testing therefore confirms that rare social functions benefit from methodological treatment.

From a technical point of view, there is consistency among the three priority orders in terms of top-three typologies. While mangrove restoration, green–blue infrastructure, and urban forest systems vary in their precise ordering, they consistently rank high in all three conditions. Such consistency indicates that the selection of typologies does not depend on any of the individual weightings used. Rather, their consistent prominence stems from a combination of multiple functions and urban relevance. In this respect, the emergence of rainwater harvesting and urban gardens depending on priority conditions confirms the necessity of a dual approach: a neutral priority order and contextually meaningful priorities.

4.5. Minimum coverage sets for coastal and inland settings

Minimum coverage set analysis reveals compact sets that fully cover target functions. In the case of 14 different functional labels, at least six typologies are needed to provide full coverage. This number is partly driven by the rarity of several labels, making the minimum coverage partially constrained. The inclusion of river management and restoration is necessary to ensure river navigation improvement and riverbank erosion regulation. The inclusion of urban gardens is essential for social resilience. A coastal living-edge type is required to cover coastal flood and erosion regulation. The rest of functions come from mangrove restoration, rainwater harvesting systems, and green–blue infrastructure.

Table 5. Minimum functional coverage sets.

Planning test	Minimum typology set	Planning meaning
Full 14-function coverage set	One coastal living-edge option; river management and restoration; mangrove restoration; rainwater harvesting systems; green–blue infrastructure; urban gardens	Covers all 14 function labels, including rare functions. The set is useful as a completeness test rather than a universal implementation package.
Coastal/estuarine urban retrofit	Mangrove restoration; rainwater harvesting systems; green–blue infrastructure; urban gardens	Covers 11 urban-relevant functions, including coastal and river flood regulation, heat regulation, water-pollution regulation, drought regulation, biodiversity, and social resilience.
Inland urban retrofit	Rainwater harvesting systems; green–blue infrastructure; urban gardens; domestic/home gardens	Covers nine urban-relevant functions without requiring coastal or estuarine systems. Domestic/home gardens supply erosion and household-scale heat/flood functions.

The coverage sets in Table 5 show that functional completeness is controlled by rare labels. Full coverage requires the inclusion of specialised typologies, while coastal and inland coverage can be smaller because some functions are setting-specific. The table also makes clear that a high-ranked typology is not always enough; portfolios are needed to preserve social, hydrological, thermal, and ecological functions together.

The coverage display in Figure 7 presents the coverage results as three implementation groupings. The visual comparison shows that the coastal/estuarine set depends on mangrove restoration, whereas the inland set replaces coastal dependence with household and neighbourhood land-based measures.

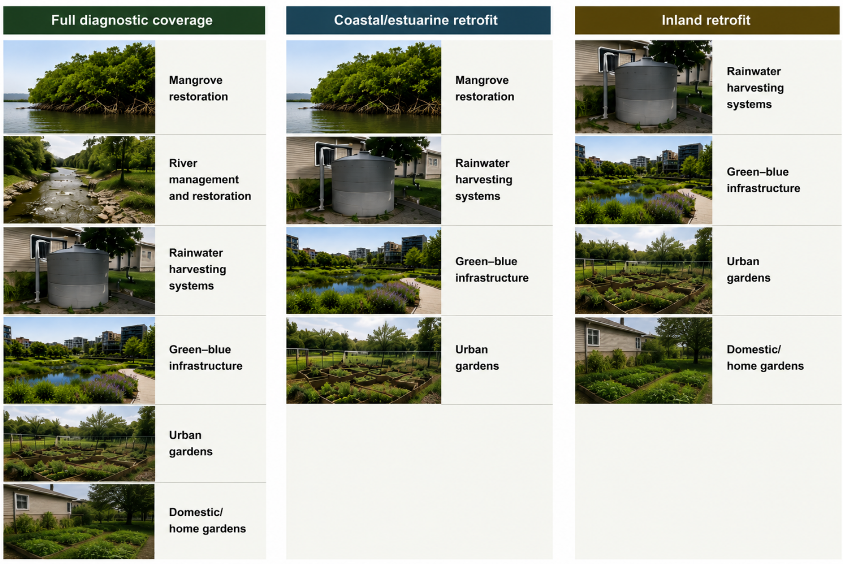

Figure 7. Functional coverage sets.

Three groupings make the coverage results from Figure 7 relevant beyond the simple set notation: full coverage, inland and coastal urban retrofitting. While full coverage requires six typologies since some functions have only one entry, inland and coastal coverage sets exclude irrelevant functions, which reduces their size and includes the same three high-leverage typologies plus urban gardens, namely rainwater harvesting systems, green–blue infrastructure, and urban gardens. Repeat function sets in coverage sets suggest that runoff-storage facilities, green–blue networks, and socially embedded urban nature are key for broad coverage of urban resilience functions.

A coastal/estuarine coverage set consists of mangrove restoration, rainwater harvesting systems, green–blue infrastructure, and urban gardens, covering 11 urban-relevant functions. Mangrove restoration provides coastal and river flood regulation, erosion regulation, and biodiversity. Rainwater harvesting systems provide the link between drought regulation and pluvial flood regulation functions. Green–blue infrastructure provides broad functionality of urban resilience, including regulation of flood, heat, air pollution, water pollution, and biodiversity. Urban gardens maintain social resilience. As shown, urban adaptation in the coastal zone cannot be limited to shoreline protection, as it requires neighborhood-scale water management, citywide green–blue connectivity, and socially embedded urban nature.

An inland urban-retrofit coverage set includes rainwater harvesting systems, green–blue infrastructure, urban gardens, and domestic/home gardens and covers nine urban-relevant functions. In contrast to the coastal coverage set, an inland set does not include any coastal or estuarine ecosystems but uses only green typologies. Thus, rainwater harvesting provides drought and pluvial-flood functions, green–blue infrastructure provides heat, air pollution, water pollution, and biodiversity functions. Urban gardens provide social resilience while domestic/home gardens add additional functions like erosion, heat, flood, and household-level biodiversity regulation. In comparison with full coverage, the inland coverage is narrower in terms of functionality but more realistic for the absence of coastal functions in inland urban settings.

As can be seen, a set of functions cannot be covered by a single flagship typology. Green–blue infrastructure is highly ranked but cannot cover social resilience alone. Mangrove restoration is highly valued as well; however, it applies only to certain coastal and estuarine areas, does not apply to all types of urban functions, and has low neutrality. Rainwater harvesting systems are not the most neutral in terms of functions but play an important role when evaluating drought and pluvial flood regulation. Urban gardens do not have very high neutral breadth, however, are important when considering social resilience. Portfolio planning is thus necessary for effective urban adaptation measures.

The placement of high leverage typologies in the urban context is illustrated in Figure 8, demonstrating the necessity of treating the coverage sets as spatial portfolios.

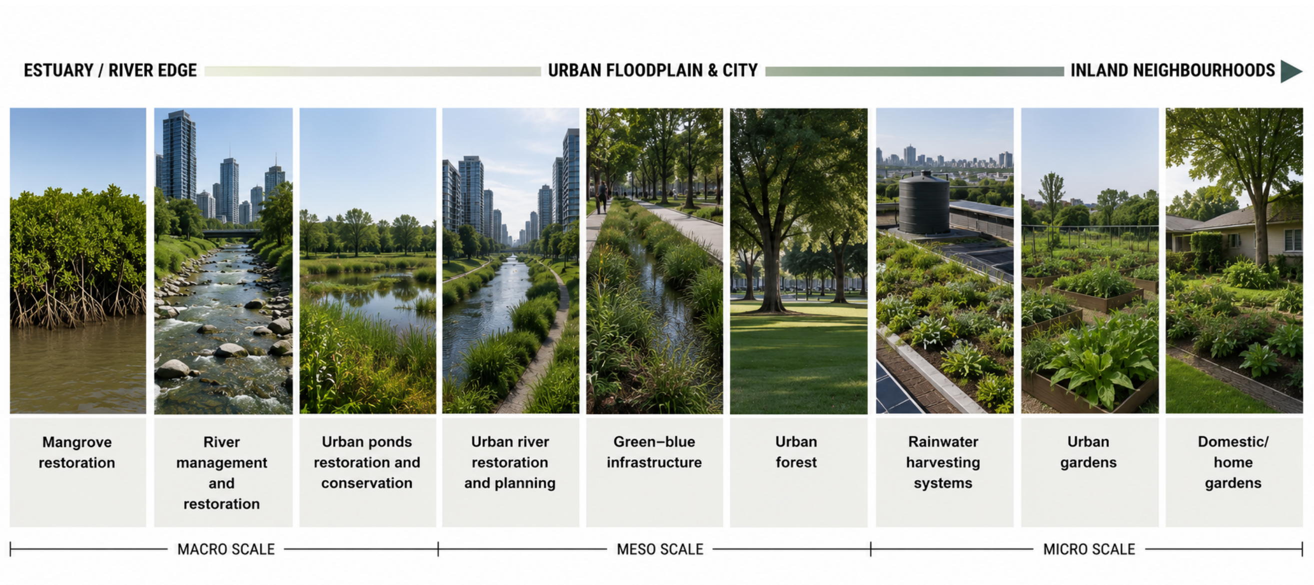

Figure 8. Urban placement transect.

Spatial application of the results follows a specific transect (Figure 8). High-leverage typologies cannot be substitutes for each other because their roles are context-specific. Mangrove restoration pertains to estuarine edges, river management to rivers and river banks, green–blue infrastructure to connecting urban corridors, urban forests to the neighbourhood canopy, rainwater harvesting to building roofs and sites, and gardens to community and domestic spaces. The lesson here is spatial complementarity: a resilient portfolio requires distributing ecological functions through an urban cross-section.

5. Discussion

5.1. Water-related functions in the typology inventory

The analysis revealed a clear structural dominance of water among functions in the inventory. Sixteen types qualify as water-based, while several land-based typologies are also relevant to floods, droughts, erosion, and water pollution regulation. This finding is unsurprising against the background of multiple adaptation pressures experienced in Global South cities, such as rainfall variability, insufficient drainage capacity, water pollution, flood exposure, and scarcity in dry seasons. The inventory can thus be seen as a water-centric urban resilience inventory rather than a generic greening checklist.

The importance of categorizing functions in terms of their physical mechanisms becomes apparent from the results. Nine typologies have pluvial flood regulation function, seven - general flood regulation, five - coastal flood and erosion regulation, four - coastal flood regulation, four - river flood regulation, and ten - water pollution regulation. Such categories differ from each other in terms of their underlying pathways. For instance, pluvial flooding is associated with rainfall intensity, surface imperviousness, capacity to drain, store, infiltrate and maintain infrastructure. Riverine flooding is linked to channel morphology, occupation of the flood plain, amount of runoff and basin governance. Coastal flooding is connected to tidal fluctuations, wave action, erosion, deposition and functioning of coastal ecosystems. Pollution regulation relies on retention capacity, vegetation cover, filtering processes, and pollutant load. Hence, breaking the category down into smaller types provides a finer-grained view.

The unique ranking of mangrove restoration is rooted in its particular position in the risk structure related to water. Specifically, it combines coastal flood regulation, river flood regulation, erosion regulation, biodiversity, and macro-meso scaling. The fact that it ranks first does not mean that it should be implemented in any case regardless of local conditions. On the contrary, its presence implies that, whenever possible in coastal contexts, this typology should be included in early appraisals since it targets a number of interrelated functions. At the same time, its implementation will depend on geomorphology, hydrodynamics, sediment availability, land tenure, ecological appropriateness, and socio-economic conditions.

Another typology, rainwater harvesting, involves a different water logic. It is micro-scale but ranks lower in the neutral ordering. It appears in all three coverage assessments, however, and rises up in the drought-pluvial priority test. This finding is important because it shows that decentralized water harvesting can become an indispensable part of the resilience strategy even without the broadest applicability. Specifically, in cities exposed to heavy rainfall and dry seasons, rainwater harvesting serves as a mechanism to reduce runoff, provide water storage, and increase household or neighborhood supply. The ability of this typology to work successfully is determined by roof area, tank size, rainfall variability, water quality, user behavior, and maintenance practices. Its leverage score does not capture the quantitative estimates, yet, it protects the typology from exclusion at a preliminary stage.

5.2. Effect of rare-function protection

The analysis has made it clear that multifunctionality should be carefully interpreted, especially in the context of urban resilience. The inclusion of several functions in the list does not mean that the benefits provided by the type should be automatically prioritized. First of all, the presence of certain functions in the inventory varies greatly, which means that the planning relevance of some of them might be overlooked. In total, 19 types include biodiversity as a function, and 11 - heat regulation, making them widely accessible in the typology set. However, social resilience, river navigation improvement, and riverbank erosion regulation are found in the inventory once, and erosion regulation - twice. Without rarity weighting, it would be very difficult to notice these low-frequency functions.

River management and restoration provides a good example of that. Despite a narrow function set, it ranks fourth because of including two low-frequency functions, namely river navigation improvement and riverbank erosion regulation. These factors might play an important role in the case of a city along the river. For instance, navigability might be essential in relation to livelihoods, transport and accessibility of the river bank. Stability of riverbanks is also crucial concerning infrastructure construction, people's security, ecological state, etc. Without rarity weighting, this type would receive much lower scores because of its lack of broader co-benefits provided by green-blue infrastructure.

A similar pattern can be seen in another type, which relates to urban gardens. Although its neutral score is far from being the highest one, it makes its way to the top after conducting the social-biodiversity priority test. In this case, the fact that only one typology provides social resilience should not make us dismiss the importance of social functions. Urban gardens might help establish local communities' engagement, improve food security, provide opportunities for recreation, and contribute to environmental revitalization.

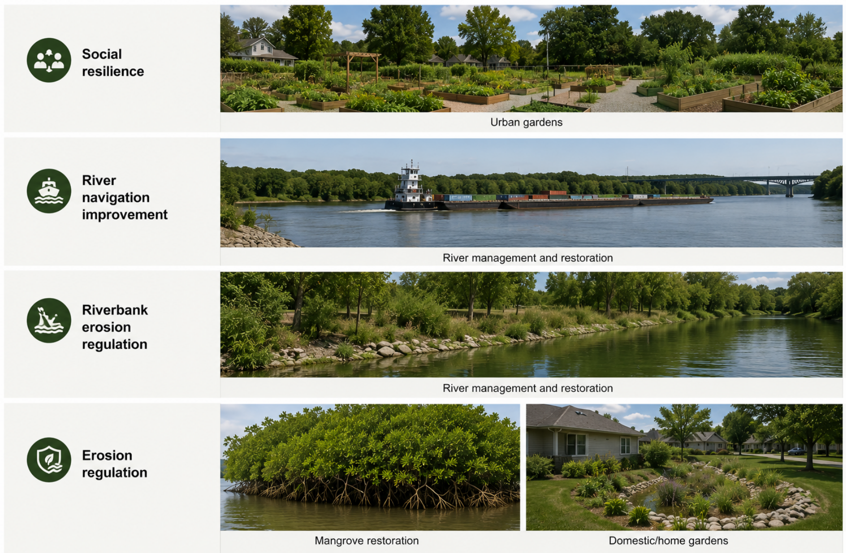

Figure 9. Rare-function carriers.

The rare-function carrier image in Figure 9 offers an immediate visual summary of the low-frequency portion of the inventory. It shows that social resilience depends on urban gardens, river navigation improvement and riverbank erosion protection depend on river management and restoration, and erosion regulation requires mangrove restoration and domestic/home gardens. This clustering indicates that rare functions require active retention during screening rather than assumption that these functions emerge spontaneously within broader greening portfolios.

Two typologies – green-blue infrastructure and urban forest systems – illustrate the difference in interaction between breadth and rarity. Green-blue infrastructure is characterized by multi-benefit breadth and water-land coupling coefficient. Urban forests have very high scores but not due to rare functions. Rather, due to combination of common urban-relevant functions with scale continuity. The significance of such distinction is that while some typologies rise due to rare function preservation, others because they cover multiple common functions across different scales.

5.3. Priority-weighted interpretation across urban pressures

The analysis shows that neutral scores would be inadequate to establish priorities in an actual urban context. Neutral scores indicate the strongest typologies within the inventory's own distribution, but urban planning is

 doi: 10.70517/la20251154-08

typically not a neutral process. Cities experiencing heat exposure in dense districts, those located estuarine settings, water-scarce areas inland, or those situated along rivers require a different initial shortlist. Calculations for heat-air, drought-pluvial, and social-biodiversity priorities provide an example of how the same coded inventory can be read with regard to specific urban priorities.

Heat-air prioritization promotes green-blue infrastructure due to combination of heat regulation, air pollution, water pollution, flood regulation, biodiversity, meso-macro scale coverage, and water-land coupling coefficients. Urban forests continue to stay at the top due to their heat-alleviating properties, including shading, evapotranspiration, canopy structure, and vegetative continuity. At the same time, ecosystem-based adaptation gains priority due to coded functions matching heat and air pollution regulation. This ranking is appropriate for dense urban development, informal settings with limited shade, and polluted neighborhoods where drainage solutions alone will not address climate vulnerability.

Drought-pluvial prioritization produces a new ranking because both drought and flooding aspects of precipitation are addressed at once. Urban forests maintain their high priority position, whereas rainwater harvesting systems get promoted into the leader category. This promotion is not random but demonstrates analytically significant that micro-scale approaches can become crucial in cases of joint water stress, rather than broad multi-functional utility of green spaces. Productive land management typologies increase priority significance since the crops and pastures under best management practices carry drought, flood, and water pollution benefits. Many rapidly growing cities experience urban growth encroachment on peri-urban water resources.

Social-biodiversity prioritization places urban gardens among top priority typologies because their coded functions match the required combination of urban-resilience benefits. It does not imply that these types should substitute thermal or hydrological measures. On the contrary, the fact is significant because the portfolio of urban greening solutions without urban gardens might miss the only coded function – social resilience. Urban social resilience tends to influence implementation decisions about adoption, acceptance, and utilization of nature-based interventions. Social resilience is crucial determinant of whether nature-based solutions are sustained.

5.4. Functional coverage across intervention portfolios

Minimum coverage sets offer a second type of interpretation, beyond the individual score, for the priority ranking. If a typology has a high score, it means that it is strong. If it is included into a coverage set, it means that it participates in achieving a particular function set goal. For the entire set of 14 urban functions, six typologies are necessary because there are a number of functions available through only one entry. This is not inefficiency, but an indication that a number of functions are coded in this way. River management and restoration is necessary for river navigation improvement and riverbank erosion. Urban gardens are needed for social resilience. Coastal living-edge option is crucial for flood regulation and coastal erosion control. Mangrove restoration, rainwater harvesting, and green-blue infrastructure then carry the remainder of the risk functions.

In case of coastal/estuarine setting, the coverage set demonstrates the necessity of combining shoreline ecology with other types of intervention. Mangrove restoration is crucial, but it is far from sufficient. Other functions include rainwater harvesting, green-blue infrastructure, and urban gardens. Together, these interventions link coastal flood and erosion with pluvial runoff moderation, water storage, heat regulation, water-pollution regulation, biodiversity, and social resilience. Thus, the coverage set highlights a serious danger of treating coastal adaptation as a mere boundary protection challenge. It involves also neighborhood management and social integration.

In the case of inland settings, the list does not contain any coastal types, and it uses a domestic/home garden entry. Again, a combination of rainwater harvesting, green-blue infrastructure, urban gardens, and domestic/home gardens allows for covering nine urban-relevant functions. This seems to be a feasible inland urban retrofit option since the approach combines public-space intervention systems with households and neighborhood initiatives. Domestic/home gardens are not merely additional but also carry vegetation, erosion, heat, flood, and biodiversity advantages that could be important where urban public space parcels are limited.

The findings regarding coverage of functions also help to understand the nature of high priority typologies. Thus, although green-blue infrastructure is at the top of the list, it cannot cover social resilience on its own. Mangrove restoration is the first neutral priority but is useful only in appropriate ecological and coastal settings. Rainwater harvesting ranks lower on neutral scores, but appears recurrently due to its functions' prevalence. Finally, the urban gardens are relatively modest concerning neutral priority but offer the unique social resilience function. Consequently, planning should take into account both ranking and coverage sets simultaneously.

5.5. Governance, equity, and implementation challenges

The leverage score cannot be considered as a basis for the decision to implement a specific type. The leverage score is based on the coded attributes: function, rarity, medium, and scale of each typology. Therefore, it does not indicate availability of lands, lifecycle costs, design maturity, maintenance complexity, water requirements, plant survival rates, authority to implement, and social preferences. These and other constraints are particularly critical in Global South cities where issues of land tenure, informal settlement upgrading, institutional competences, and continuous funding are important determinants of the future success.

Multifunctionality also does not guarantee social equity. Green-blue corridors, urban forests, and restored waterfronts can improve urban environment quality while promoting higher property values and diverting public investment from other disadvantaged neighborhoods. Urban gardens and domestic/home gardens can increase social resilience while requiring certain levels of access to lands and water. At the same time, mangrove restoration could enhance protection of coastal communities but potentially could involve social conflicts with restricted livelihood opportunities. The findings therefore highlight the necessity of further socio-economic analysis; they do not claim that the highest-ranked types are socially sustainable.

The analysis nevertheless can contribute to improved governance by offering a clear first-step justification for the selection of the typologies. Often, the reasons why specific solutions are included in the shortlist are unclear, as they depend on familiarity, fundability, visibility, and popularity rather than planned benefits. The leverage score documents what are the reasons why the solution type should be retained for further planning steps. In turn, it helps to facilitate discussion between engineers, planners, environmental agencies, community organizations, and other stakeholders. Moreover, the score helps to recognize potential omissions related to particular urban functions.

5.6. Scope of interpretive application and stability of coefficients

This method stands between two approaches: inventory of nature-based interventions and hydrological or thermal models. The former is usually described qualitatively in narrative terms, and thus, does not allow for objective comparison. The latter involves quantitative modeling at the city level and demands site-specific data from the very beginning. The leverage calculation occupies an intermediate position, which allows the planner to assess the situation at the right step – just before further technical work. The key element of the calculation is the logarithmic rarity weighting, which adds importance to uncommon functions without making them dominating.

Relation to information theory suggests that the greater is rarity of a function, the more its planning relevance increases. Thus, a rare function is more significant than a common function because fewer nature-based solution types can cover this function. The coefficients for scale continuity and water-land coupling offer small bonuses without distorting function composition too much. The coefficient sensitivity test supports the interpretation of the leading set. It shows that mangrove restoration, green-blue infrastructure, and urban forest systems remain the leading category across the tested range of values of α and β.

This coefficient sensitivity in Figure 10 represents only a robustness check of interpretation. The result does not change even if we alter the chosen values of α and β. Thus, the main interpretation is not sensitive to the selection of the coefficients. Instead, it is mainly justified by coded function composition and the cross-scale character of the leaders. This test should not be viewed as an universal validity verification tool but rather as evidence that the main interpretation is robust to the selection of coefficients.

The coefficient sensitivity in Figure 10 demonstrates robustness of interpretation only. The leading set remains unchanged for different combinations of α and β, which indicates that the result is determined not only by the

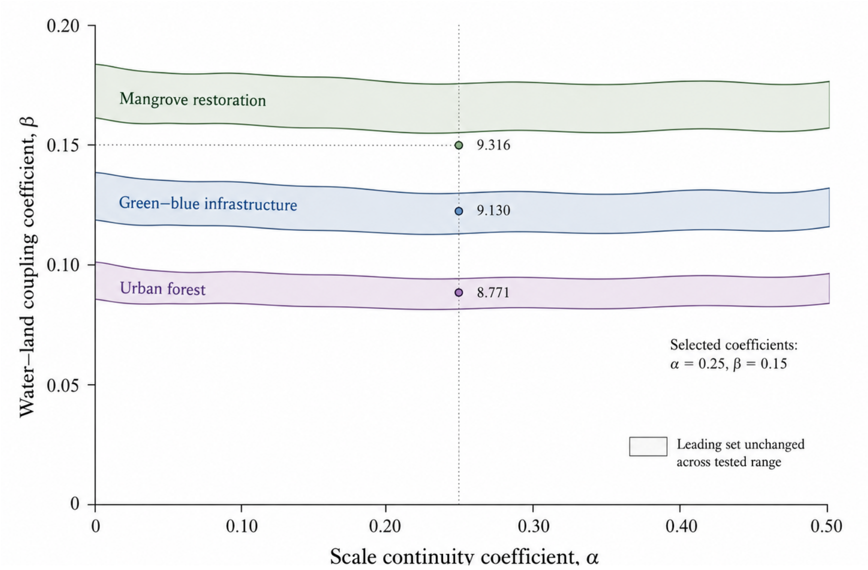

Figure 10. Coefficient sensitivity of the leading set.

coefficients. In general, the result is justified primarily by function composition and the ability of leading solution types to cover several planning functions and to perform at different scales.

There are several limitations inherent in this approach. First, the binary nature of the incidence structure implies that a particular function exists either in the solution type or does not exist. Thus, a solution type coded with heat regulation function has this attribute regardless of specific cooling effect. Second, the method does not consider factors like cost, land demand, time for maturation, maintenance, institutions, social acceptance. All these factors are not subject of the initial assessment but the subsequent phase. The advantage of the analysis presented here is to improve the shortlist selection.

6. Planning Implications

The findings suggest a staging strategy of using this analysis for urban planning. The first stage is an inventory screening stage, where neutrality scores are used to identify high-priority typologies for further planning evaluation. The second stage is priority-adjustment calculation, which adapts neutral scores based on urban concerns like heat, air pollution, drought, flooding, biodiversity, and social resilience. Finally, the coverage assessment verifies whether a shortlist covers functions necessary for a specific planning purpose: coastal, estuarine, inland, or neighborhood planning.

Hydrological interventions must be differentiated rather than selected under the umbrella of flood regulation category. Pluvial flood exposure requires rainwater harvesting, bio-retention, green-blue infrastructure, and other similar measures. On the other hand, riverine setting requires river management, bank stabilization, urban river restoration, and other water-focused solutions. Coastal and estuarine settings require additional actions related to mangroves restoration or living-edge measures in addition to urban flood prevention methods. In any case, the analysis reveals the necessity of proper water risk diagnosis before applying neutral priority sorting to a shortlist formation.

It is important to keep multiscale nature-based interventions in a shortlist since they can serve as bridge solutions between strategy and detailed implementation. Types like mangrove restoration, green-blue infrastructure, ecosystem-based adaptation, and urban forest systems cover different scales and thus can facilitate connection of ecological processes, public space systems, and other urban functions. It is especially important in case of separation of departments and the need to integrate climate adaptation with drainage, park management, housing, transport, informal settlement upgrading, and coastal management.

Uncommon functions should be treated as safeguards for urban resilience portfolio. Since the function of social resilience, river navigation improvement, riverbank erosion regulation, and erosion regulation are coded only once, the shortlist ignoring these functions looks equally multifunctional since it includes more frequent functions like biodiversity, heat, and water pollution regulation. The rare function-protected calculation makes it possible to notice such omission and ask whether the necessary function disappears from the shortlist before further assessment.

7. Conclusion

Leverage Order identifies the set of solution types that should be kept in early urban planning assessment based on coded inventory when these types are assessed for rare functions, scale continuity, and water/land distinction. The set consisting of mangrove restoration, green-blue infrastructure, and urban forest systems becomes the top priority neutral solution set since it contains multiple urban-relevant resilience functions and has cross-scale coverage. River management and restoration requires immediate priority because it protects rare river functions covered by few other typologies. Domestic/home gardens, ecosystem-based adaptation, urban ponds, urban river restoration, productive land management practices, rainwater harvesting, and bio-retention constitute a second priority set.

These priorities are determined by the nature of the inventory used. In particular, 16 out of 32 solution types refer to water management, which means that hydrology is an important factor determining the result. Another 12 solution types are land-related and have important functions of heat and biodiversity regulation, soil erosion, production, and social benefits. There are fewer types with built-structure component, and green-blue infrastructure is the only water-land category in the list. In addition, function frequencies are highly uneven, and rare functions include social resilience, river navigation improvement, and riverbank erosion. Rarity-protected calculation, however, changes the screening logic by adding weight for rare functions.

Priority-weighted calculation shows how the ranking differs based on various urban priorities. Priorities of heat-air cause green-blue infrastructure to become a top-priority typology and promote urban forests and ecosystem-based adaptation. Priorities of drought-pluvial raise rainwater harvesting systems because urban micro-scale interventions acquire significance if both drought and flooding problems occur. Social-biodiversity priorities put urban gardens among top-priority types because this is the only type carrying social resilience function. Thus, the ranking differs according to the urban concern, which indicates that the result is not prescriptive.

Coverage sets determine the number of solution types to cover urban priorities. Since coverage requires all 14 functions, six types must be used due to the rarity of some of them. The coastal/estuarine type requires not only mangrove restoration but also rainwater harvesting, green-blue infrastructure, and urban gardens. Similarly, inland cities can achieve resilience by using rainwater harvesting, green-blue infrastructure, urban gardens, and domestic/home gardens. Thus, a set of solution types must contain both high-priority types and rare-function carriers.

Scale-Weighted Functional Leverage serves as an instrument for first-step planning. It does not replace hydrological modeling, heat modeling, cost analysis, governance, design, and engineering. By providing protection for rare functions, taking into account scale continuity, and distinguishing between water-based, land-based, built-type, and water-land categories, the method offers data-limited cities transparent means to select nature-based interventions worth further consideration.

References

[1] Ahern, J. (2011). From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. *Landscape and Urban Planning*, *100*(4), 341–343.

[2] Ahiablame, L. M., Engel, B. A., and Chaubey, I. (2012). Effectiveness of low impact development practices: Literature review and suggestions for future research. *Water, Air, & Soil Pollution*, *223*, 4253–4273.

[3] Albert, C., Schroter, B., Haase, D., Brillinger, M., Henze, J., Herrmann, S., Gottwald, S., Guerrero, P., Nicolas, C., and Matzdorf, B. (2019). Addressing societal challenges through nature-based solutions: How can landscape planning and governance research contribute? *Landscape and Urban Planning*, *182*, 12–21.

[4] Andersson, E., Barthel, S., Borgstrom, S., Colding, J., Elmqvist, T., Folke, C., and Gren, A. (2014). Reconnecting cities to the biosphere: Stewardship of green infrastructure and urban ecosystem services. *Ambio*, *43*, 445–453.

[5] Babi Almenar, J., Elliot, T., Rugani, B., Philippe, B., Navarrete Gutierrez, T., Sonnemann, G., and Geneletti, D. (2021). Nexus between nature-based solutions, ecosystem services and urban challenges. *Land Use Policy*, *100*, 104898.

[6] Bowler, D. E., Buyung-Ali, L., Knight, T. M., and Pullin, A. S. (2010). Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape and Urban Planning*, *97*(3), 147–155.

[7] Cohen-Shacham, E., Walters, G., Janzen, C., and Maginnis, S., editors (2016). *Nature-based Solutions to Address Global Societal Challenges*. International Union for Conservation of Nature, Gland.

[8] Davoren, E., and Shackleton, C. M. (2021). Urban ecosystem disservices in the Global South. In Shackleton, C. M., Cilliers, S. S., Davoren, E., and du Toit, M. J., editors, *Urban Ecology in the Global South*, 265–292. Springer, Cham.

[9] Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Bhave, A. G., Mittal, N., Feliu, E., and Faehnle, M. (2014). Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *Journal of Environmental Management*, *146*, 107–115.

[10] Elmqvist, T., Setala, H., Handel, S. N., van der Ploeg, S., Aronson, J., Blignaut, J. N., Gomez-Baggethun, E., Nowak, D. J., Kronenberg, J., and de Groot, R. (2015). Benefits of restoring ecosystem services in urban areas. *Current Opinion in Environmental Sustainability*, *14*, 101–108.

[11] Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J. L., Mikkelsen, P. S., Rivard, G., Uhl, M., Dagenais, D., and Viklander, M. (2015). SUDS, LID, BMPs, WSUD and more: The evolution and application of terminology surrounding urban drainage. *Urban Water Journal*, *12*(7), 525–542.

[12] Frantzeskaki, N. (2019). Seven lessons for planning nature-based solutions in cities. *Environmental Science & Policy*, *93*, 101–111.

[13] Gill, S. E., Handley, J. F., Ennos, A. R., and Pauleit, S. (2007). Adapting cities for climate change: The role of the green infrastructure. *Built Environment*, *33*(1), 115–133.

[14] Gould, K. A., and Lewis, T. L. (2016). *Green Gentrification: Urban Sustainability and the Struggle for Environmental Justice*. Routledge, London.

[15] Intergovernmental Panel on Climate Change (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Cambridge University Press, Cambridge.

[16] Keeler, B. L., Hamel, P., McPhearson, T., Hamann, M. H., Donahue, M. L., Meza Prado, K. A., Arkema, K. K., Bratman, G. N., Brauman, K. A., Finlay, J. C., Guerry, A. D., Hobbie, S. E., Johnson, J. A., MacDonald, G. K., McDonald, R. I., Neverisky, N., and Wood, S. A. (2019). Social-ecological and technological factors moderate the value of urban nature. *Nature Sustainability*, *2*, 29–38.

[17] Meerow, S., Newell, J. P., and Stults, M. (2016). Defining urban resilience: A review. *Landscape and Urban Planning*, *147*, 38–49.

[18] Nesshover, C., Assmuth, T., Irvine, K. N., Rusch, G. M., Waylen, K. A., Delbaere, B., Haase, D., Jones-Walters, L., Keune, H., Kovacs, E., Krauze, K., Kulvik, M., Rey, F., van Dijk, J., Vistad, O. I., Wilkinson, M. E., and Wittmer, H. (2017). The science, policy and practice of nature-based solutions: An interdisciplinary perspective. *Science of the Total Environment*, *579*, 1215–1227.

[19] Saaty, T. L. (1980). *The Analytic Hierarchy Process*. McGraw-Hill, New York.

[20] Seddon, N., Chausson, A., Berry, P., Girardin, C. A. J., Smith, A., and Turner, B. (2020). Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *375*, 20190120.

[21] Shanahan, D. F., Lin, B. B., Bush, R., Gaston, K. J., Dean, J. H., Barber, E., and Fuller, R. A. (2015). Toward improved public health outcomes from urban nature. *American Journal of Public Health*, *105*(3), 470–477.

[22] Shannon, C. E. (1948). A mathematical theory of communication. *Bell System Technical Journal*, *27*(3), 379–423; *27*(4), 623–656.

[23] Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kazmierczak, A., Niemela, J., and James, P. (2007). Promoting ecosystem and human health in urban areas using green infrastructure: A literature review. *Landscape and Urban Planning*, *81*(3), 167–178.

[24] Alves, A., Gersonius, B., Kapelan, Z., Vojinovic, Z., and Sanchez, A. (2024). Planning the multifunctionality of nature-based solutions in urban infrastructure transitions. *Cities*, *147*, 104813.

[25] Anguelovski, I., Connolly, J. J. T., Cole, H., Garcia-Lamarca, M., Triguero-Mas, M., Baro, F., Martin, N., Conesa, D., Shokry, G., Del Pulgar, C. P., and Arguelles Ramos, L. (2022). Green gentrification in European and North American cities. *Nature Communications*, *13*, 3816.

[26] Bauer, W., and Muller, F. (2023). Reframing urban nature-based solutions through green gentrification. *Urban Planning*, *8*(1), 133–145.

[27] Berland, A., Shiflett, S. A., Shuster, W. D., Garmestani, A. S., Goddard, H. C., Herrmann, D. L., and Hopton, M. E. (2017). The role of trees in urban stormwater management. *Landscape and Urban Planning*, *162*, 167–177.

[28] Castellar, J. A. C., Popartan, L. A., Pueyo-Ros, J., Atanasova, N., Langergraber, G., Saumel, I., Corominas, L., Comas, J., and Acuna, V. (2021). Nature-based solutions in the urban context: terminology, classification and scoring for urban challenges and ecosystem services. *Science of the Total Environment*, *779*, 146237.

[29] Eggermont, H., Balian, E., Azevedo, J. M. N., Beumer, V., Brodin, T., Claudet, J., Fady, B., Grube, M., Keune, H., Lamarque, P., Reuter, K., Smith, M., van Ham, C., Weisser, W. W., and Le Roux, X. (2015). Nature-based solutions: new influence for environmental management and research in Europe. *GAIA - Ecological Perspectives for Science and Society*, *24*(4), 243–248.

[30] Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., Haase, D., Knapp, S., Korn, H., Stadler, J., Zaunberger, K., and Bonn, A. (2022). Principles for urban nature-based solutions. *Ambio*, *51*, 1388–1401.

[31] Korkou, M., Tarigan, A. K. M., and Hanslin, H. M. (2023). The multifunctionality concept in urban green infrastructure planning: a systematic literature review. *Urban Forestry & Urban Greening*, *85*, 127975.

[32] Liao, K. H. (2012). A theory on urban resilience to floods: a basis for alternative planning practices. *Ecology and Society*, *17*(4), 48.

[33] Pauleit, S., Zolch, T., Hansen, R., Randrup, T. B., and Konijnendijk van den Bosch, C. (2017). Nature-based solutions and climate change: four shades of green. In Kabisch, N., Korn, H., Stadler, J., and Bonn, A., editors, *Nature-Based Solutions to Climate Change Adaptation in Urban Areas*, 29–49. Springer, Cham.

[34] Pereira, P., Yin, C., and Hua, T. (2023). Nature-based solutions, ecosystem services, disservices, and impacts on human well-being in urban environments. *Science of the Total Environment*, *904*, 166977.

[35] Wamsler, C., and Pauleit, S. (2016). Making headway in climate policy mainstreaming and ecosystem-based adaptation: two pioneering countries, different pathways, one goal. *Climatic Change*, *137*, 71–87.

[36] Wamsler, C., Wickenberg, B., Hanson, H., Alkan Olsson, J., Stalhammar, S., Bjorn, H., Falck, H., Gerell, D., Oskarsson, T., Simonsson, E., and Zelmerlow, F. (2020). Environmental and climate policy integration: targeted strategies for overcoming barriers to nature-based solutions and climate change adaptation. *Journal of Cleaner Production*, *247*, 119154.

[37] Wolch, J. R., Byrne, J., and Newell, J. P. (2014). Urban green space, public health, and environmental justice: the challenge of making cities just green enough. *Landscape and Urban Planning*, *125*, 234–244.