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Urban Nature Indexes tool offers comprehensive and flexible approach to monitoring urban ecological performance

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We present the Urban Nature Indexes (UNI), a comprehensive tool that measures urban ecological performance under one standard framework linked to global commitments. The UNI was developed by interdisciplinary experts and evaluated by practitioners from diverse cities to capture each city's ecological footprint from local to global scale. The UNI comprises six themes (consumption drivers, human pressures, habitat status, species status, nature's contributions to people, and governance responses) that encompass measurable impacts on climate change, biodiversity loss, ecosystem services, pollution, consumption, water management, and equity within one comprehensive system. Cities then adapt the UNI to their context and capacity by selecting among indicator topics within each theme. This adaptability and holistic approach position the UNI as an essential instrument for nature-positive transformations. With the institutional support of IUCN, the UNI offers an opportunity for cities to assess and enhance their contributions towards a more sustainable and biodiverse future.

Local governments and cities play a pivotal role in addressing the global biodiversity crisis, as acknowledged by several global goals, targets, initiatives, and commitments[1,2]. Parties to the Convention on Biological Diversity (CBD) have underscored the significance of engaging cities and local governments in biodiversity conservation and sustainable use[3]. The CBD's Decision X/22 "Plan of Action on Subnational Governments, Cities and Other Local Authorities for Biodiversity" urges national governments to collaborate and support local and subnational governments to achieve CBD targets[4].

Yet, inconsistencies and sectoral fragmentation among political, financial, and governance institutions have traditionally undermined efforts towards more effective biodiversity governance[5,6]. To bridge the gap between aspirational global targets and local implementation, various partnerships, knowledge platforms, and policy documents have been established. For example, UN-Habitat's New Urban Agenda, adopted by the UN General Assembly in 2016, includes a commitment in its vision statement to: "Protect, conserve, restore and promote their ecosystems, water, natural habitats and biodiversity, minimize their environmental impact and change to sustainable consumption and production patterns"[7]. The Global Platform for Sustainable Cities' (GPSC) initiated a Cities 4 Biodiversity program in 2021 to provide technical and financial assistance to cities to integrate biodiversity and climate solutions into urban planning[8]. However, while recognizing that progress towards global targets is rooted in local actions, these frameworks do not address how to effectively translate one into the other[6].

Resources like The Urban Butterfly Effect (TUBE) offer some support for aggregating local activities to contribute to global targets[9], but clear directives are still needed. In particular, additional support is needed to systematize and mainstream the connections between local actions and global targets[10]. The CBD Secretariat released the Edinburgh Declaration on biodiversity to invite cities and regional governments to commit to action for biodiversity by signing the commitment directly[11]. It represents a key milestone in elevating the role that cities and local authorities have in delivering national and international biodiversity commitments[2]. To date, more than 130 cities, subnational governments and their networks have signed the Edinburgh Declaration. Many cities have also adopted a

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multitude of nature-related actions such as conservation planning, access to nature, regulations and education, as well as communications campaigns to protect biodiversity and integrate it into urban planning and decision-making. The database by the Urban Biodiversity Hub has counted at least 123 local governments from 31 countries that have developed biodiversity-oriented strategies or reports worldwide[12,13]. Differences in how cities address biodiversity and ecosystem services coupled with the lack of accountability measures are hindering the success of biodiversity planning and conservation targets[14–16]. Despite these initiatives and the fact that many cities have incorporated biodiversity-oriented strategies or reports, the efficacy of these measures is limited by differences in approach and a lack of accountability[2,12].

Cities significantly influence ecosystem integrity and biodiversity, both within and beyond their geographical boundaries[5]. Urban environments consume more than 75% of resources, generate 80% of greenhouse gases, and are largely responsible for some of the primary drivers of habitat and biodiversity loss through urban sprawl and consumption patterns[4,17–19]. Decisions made by city inhabitants directly and indirectly affect biodiversity and thus play a critical role in addressing the direct and indirect impacts that stem from urban areas[10]. With rapid urbanization expected to raise the proportion of the global population residing in urban areas from 55% to over 68%[20], cities' local and far-ranging environmental impacts must be tackled in order to achieve global biodiversity targets[21].

Despite the high impact of city-level action, coordination across local governments is lacking. One major challenge for halting biodiversity loss and reaching sustainable development is a lack of standardized indicators to measure the impact that cities have on nature. The challenge of reaching global nature targets with local actions underlines the urgent need for a strategic and operational tool similar to the Global Protocol for Community-Scale Greenhouse Gas Inventories (GPC) to help promote more widespread action by cities and report the aggregated results of local actions on biodiversity[22]. Carbonn.org has tracked climate mitigation commitments by thousands of cities using the GPC, and a similar standardized protocol for cities to measure impact on nature could increase the number of local governments measuring and reporting their impacts on biodiversity manifold.

A compounding factor complicating effective governance for urban sustainability is the increasing complexity of urban systems, the nature of which includes interdependencies and feedback loops affecting the efficacy of interventions and monitoring. However, effective governance for urban sustainability is complicated by a lack of standardized indicators for measuring cities' impact on nature and by the increasing complexity of urban systems[22,23]. Monitoring biodiversity and developing qualitative and quantitative indicators are crucial for managing natural capital and addressing the current biodiversity crisis[14,24]. However, indicators are often developed in isolation, using inconsistent methodologies, thus hindering meaningful comparisons and decision-making[25]. This approach is far from the ideal principles for indicator selection from more established fields[26]. Given this context, users are presented with both a dearth of quality frameworks and a "paradox of choice" that hinders decision-making[27]. Despite efforts to monitor and assess urban biodiversity, such as the Singapore Index on Cities' Biodiversity (SICB), tools often focus on local impacts and require customization for diverse local contexts[28]. Given the accelerating loss of biodiversity worldwide, the substantial potential for cities to either mitigate or exacerbate the ecological crisis, the need to enhance urban climate resilience, and the necessity for institutions to contribute measurably to targets in the post-2020 Global Biodiversity Framework (GBF), the harmonization and standardization of urban nature indicators has become a pressing priority.

The aim of this study is to introduce a comprehensive system of indicators that is flexible enough to accommodate a broad spectrum of users while also being robust enough to facilitate cross-comparisons. The Urban Nature Indexes (UNI) were developed to fill gaps in existing measurement tools, respond to cities' needs, align with global targets, and draw upon theoretical frameworks for ecological impact (Fig. 1).

The question guiding our research is: How could a new framework measure the ecological performance of cities in a way that is both comprehensive and responds to cities' needs? To answer this, our analysis delves into the gaps in current approaches for measuring cities' ecological performance, as well as the requirements city staff have in evaluating their ecological performance.

The development of the UNI is rooted in two conceptual frameworks that assess the links between anthropogenic pressures and ecosystem changes. First, the Drivers-Pressures-State-Impacts-Responses (DPSIR) framework is broadly adopted to conceptualize the pressure- state change associations (Fig. 2b)[29]. Second, the Urban Bioshed Impact Areas model provides insight into cities' extensive and varied ecological impacts that extend beyond city boundaries (Fig. 2a)[30].

These conceptual frameworks guide the identification and organization of indicators required for a comprehensive evaluation of urban ecological performance. Consequently, UNI is developed through identifying gaps in existing measurement tools, understanding cities' needs, aligning with global targets, and incorporating theoretical frameworks for ecological impact. UNI emerges as a comprehensive, flexible tool with the potential to harmonize and standardize urban nature indicators.

Results

Cities' current nature monitoring practices

The survey conducted with cities' practitioners around the world ($n = 24$), predominantly from upper-middle to high-income cities, revealed a substantial gap in the standardization of monitoring practices for urban nature. The majority of cities are not adhering to any international standard for monitoring nature (Fig. 3a). However, the most common standard used is the Sustainable Development Goals (SDGs) (46%), which do not focus specifically on urban nature, albeit some goals are nature-oriented. In a

Theme	ID	Indicator Topics
1 Consumption Drivers	1.1	Material Consumption
	1.2	Harmful Harvest & Trade
	1.3	GHG Emissions from Energy
	1.4	Unsustainable Diets
	1.5	Water Withdrawal
2 Human Pressures	2.1	Urban Sprawl
	2.2	Water Pollution
	2.3	Noise Pollution
	2.4	Light Pollution
	2.5	Invasive Species
3 Habitat Status	3.1	Land Use/Protection
	3.2	Ecosystem Restoration
	3.3	Shorelines & River Banks
	3.4	Vegetation Cover
	3.5	Connectivity
4 Species Status	4.1	Animal Species
	4.2	Plant Species
	4.3	Functional Diversity
	4.4	Microbiota and Fungi
	4.5	Endemic Species
5 Nature's Contributions to People	5.1	Exposure to Nature
	5.2	Access to Nature
	5.3	Human Health
	5.4	Livelihoods
	5.5	Sacred Natural Sites
6 Governance Responses	6.1	Planning
	6.2	Legislation & Regulation
	6.3	Education
	6.4	Management
	6.5	Incentives & Participation

Fig. 1 | Urban nature indexes. The Urban Nature Indexes (UNI) are organized into six themes, each of which contain five indicator topics. Participants choose from the indicator topics according to their capacity, context, and priorities.Within the indicator topics, there may be several indicator options, such as more basic or advanced versions or alternatives from other indices.

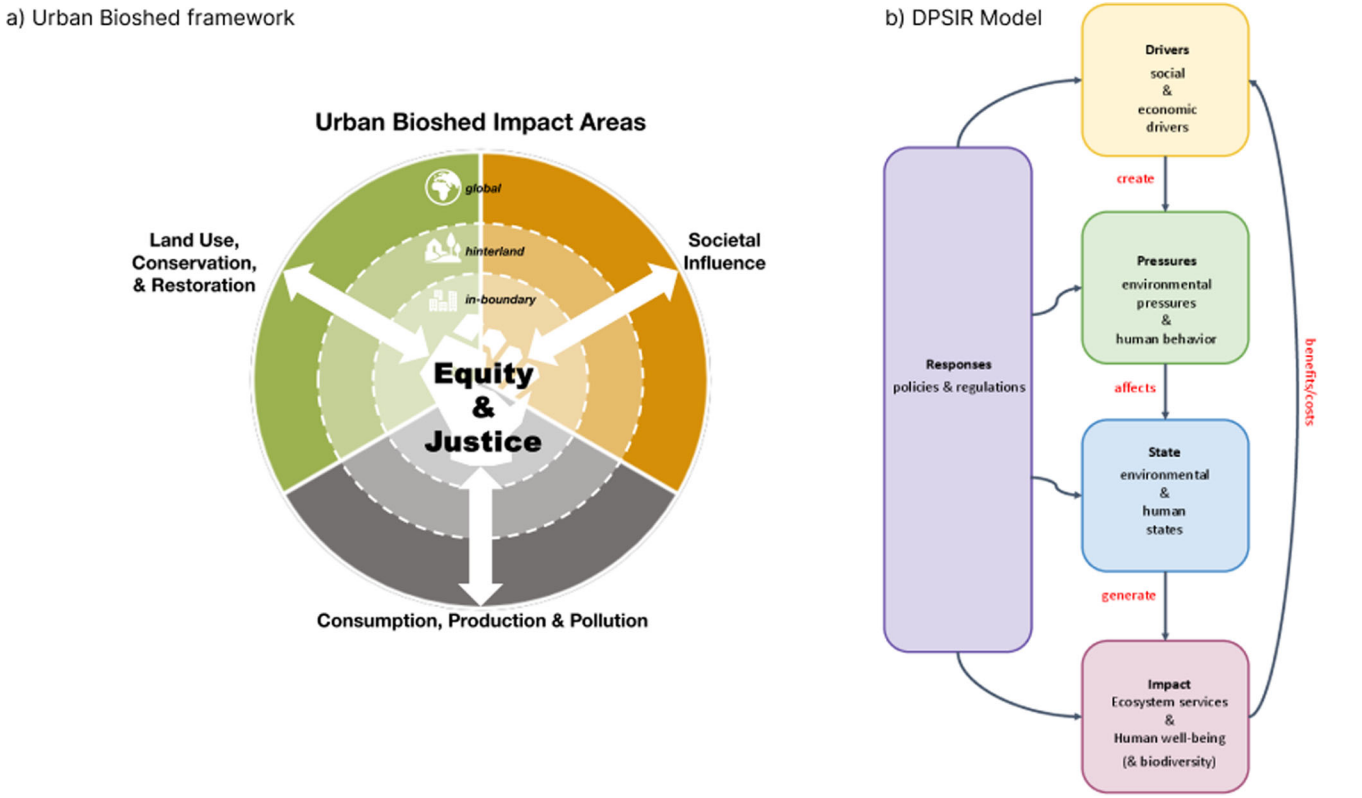

Fig. 2 | Theoretical frameworks: the Bioshed and the DPSIR Model. These two diagrams represent the two main conceptual frameworks used to develop the Urban Nature Indexes (UNI). The Urban Bioshed Impact Areas model (**a**) describes the ecological impacts cities have across sectors both within and well beyond their boundaries. The bioshed centers equity and justice for all life (human and non-human) and emphasizes that urban areas have wide ranging impacts on nature through three impact areas; (1) social influence, (2) consumption, production, and pollution, and (3) land use, conservation, and restoration. Each of these impact areas generate impacts across a range of scales from local to global. The Drivers-Pressures-State-Impacts-Responses (DPSIR) framework (**b**) describes the pressure-state change associations between environmental and human factors where social and economic drivers create pressure on the environment and human behavior, which then affect the environmental and human states, generating impacts on human well-being, ecosystem services, and biodiversity. These impacts then impose costs and benefits on the environmental and human drivers in a feedback loop, and human responses in the form of policies and regulations further modify the drivers, pressures, states, and impacts. Figure 2(a) is shared via a Creative Commons Attribution-Non Commercial-No Derivatives 4.0 license.

shared second place, cities followed nationally-determined standards (38%) or did not specify their monitoring standards (38%). Seven of the cities report not following any monitoring standard (29%).

All investigated cities report monitoring some or multiple impacts on nature (Fig. 3b). The most important impacts on nature monitored, as identified by participating cities, are water quality (79%), waste generation (79%), and urban sprawl (75%). As expected, cities mostly monitored nature locally (79%) or regionally (42%), with an even smaller proportion of the surveyed cities monitoring their impact on nature at the national (25%) or global scales (4%) (Fig. 3c). These results indicate that participating cities are monitoring nature and ecosystem services locally, but lack a unified approach in doing so. In response to this lack of standardized indicators to measure the impact that cities have on nature, we compiled the UNI, consisting of a comprehensive set of 30 indicator topics nested across six themes.

Cities' priorities of proposed initial set of UNI indicators and perceived barriers to monitoring

Through the survey, the participating cities were presented with an initial set of proposed UNI indicator topics under each of the six themes of Species (Theme 1), Habitats (Theme 2), Pollution (Theme 3), Consumption (Theme 4), Benefits and impacts on people (Theme 5), and Responses (Theme 6). The cities were then asked to rank the indicator topics associated with each of the six themes by priority (Fig. 4). The results show a high degree of variability from among the survey responses. Most notably, the pollution and consumption themes had the greatest variation in the ranking of their indicator topics. Within both these themes, the highest ranked indicator topic was, on average (more than 4 out of 5), air pollution (3 A), water pollution (3B), waste (4 A), and energy (4B), while the other indicator scored, on average (less than 3 out of 5), lower.

Within each theme, cities' highest priority indicator topics to measure were: native species status (1 A), terrestrial habitat (2 A), air pollution (3 A), waste generation (4 A), exposure to nature (5 A), and law and policy combined with planning (6 A; 6B). Cities' least important indicator topics within each theme were: microbiota (1D), soil function (2E), light pollution (3E), purchasing (4E), sacred heritage (5E), and reporting (6E). These results could indicate that cities prioritize measures that are typically easier to quantify and assign value in terms of financial and human health impacts, such as costs incurred/saved, and rates of diseases linked to environmental factors, and were therefore selected as a higher priority than indicators often perceived as more difficult to quantify (e.g., microbiota, soil function, etc.).

Cities' perceived barriers to monitoring UNI indicators

Cities' greatest barriers to monitoring nature are, on average, a lack of resources and technical expertize (Fig. 5). Cities with lower income appear to rank barriers' differently than high income cities. In general, lower income cities report a lack of political and public priority as their main barrier. Whereas, cities with higher income report a lack of financial or human resources as their main barriers to monitoring nature, driving the average ranking.

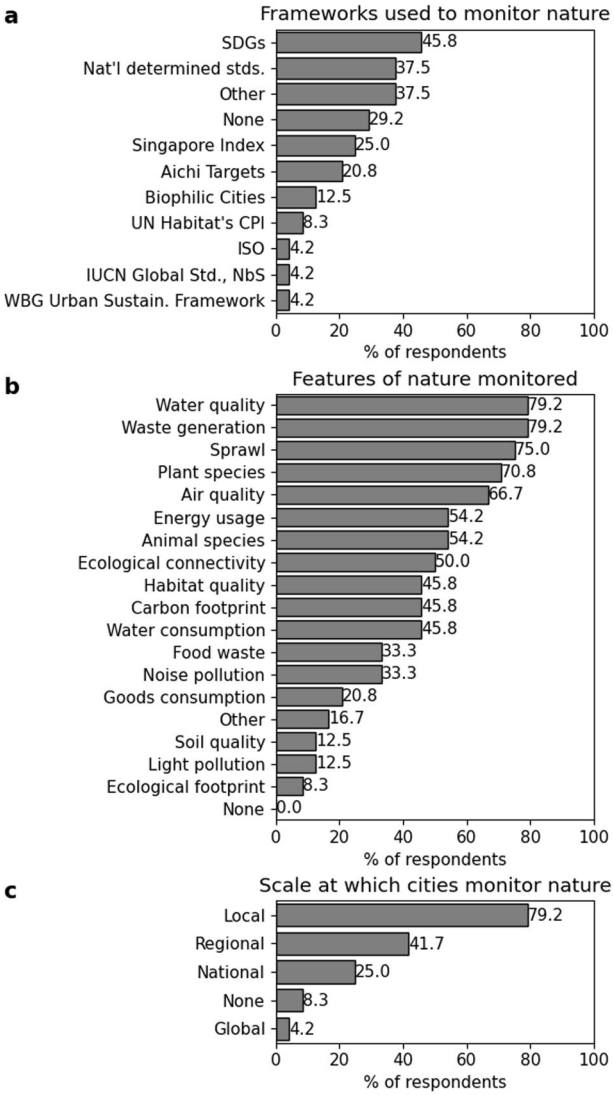

Fig. 3 | Bar graphs illustrating how the surveyed cities monitor nature. Results from close-ended multiple-choice questions in a survey of 24 cities representing all global regions are as follows: **a** Shows the different framework(s) used by the participating cities to monitor nature. **b** Indicates the specific features of and impacts on nature that are monitored by participating cities. Responses are not mutually exclusive, and respondents could select more than one feature or impact. **c** Depicts the spatial scales at which the participating cities monitor their impacts on nature. Abbreviations used in the diagram are: Sustainable Development Goals (SDGs), nationally determined standards (national), Singapore Index on Cities' Biodiversity (SICB), International Standards Organization (ISO), IUCN Global Standard for Nature-Based Solutions (Global Standard for NBS), World Bank Urban Sustainability Framework (USF).

The urban nature indexes

These survey findings were used to further develop the Urban Nature Indexes (UNI) framework (Fig. 1). This flexible framework allows cities to comprehensively monitor their impacts on nature, covering six thematic areas: (I) consumption drivers, (II) human pressures, (III) habitat status, (IV) species status, (V) nature's contributions to people, and (VI) governance response. Moreover, it does so over multiple spatial scales, while remaining flexible to cities' capacity to monitor and adjust to developments in science.

The UNI covers all scales and dimensions of the Urban Bioshed (Fig. 2a)[30]. It also overlaps with large parts of the Singapore Index on Cities' Biodiversity (SICB) and the GBF (see Supplementary Table 1). In contrast to the Singapore Index, the UNI considers equity and justice and focuses more on the hinterland and global scales. In comparison to the GBF, the UNI focuses more on the hinterland and in-boundary scales, but less so on equity and justice. Generally, the UNI has a more even distribution across the Urban Bioshed, while also incorporating equity and justice, than other nature frameworks. This comprehensive approach provides the benefit of a holistic and just approach to monitoring urban nature, recognizing linkages between socio-economic concerns and environmental ones.

The UNI is especially flexible due to its inclusion of cities' capacity to monitor. In particular, the UNI does not require participating cities to monitor all the indicators. Participating cities' initial Capacity Assessment Questionnaire estimates their capacity broadly on population, GDP, priority, and expertize in biodiversity assessments. The resulting capacity score helps identify the level of monitoring a city is able to do. Low-capacity cities start with the fewest indicators to monitor, where with every increment of capacity, a city monitors an additional indicator per theme. The highest capacity cities will monitor the full extent of the UNI. This unique feature of the UNI is important because it allows every city to monitor nature to the best of their capacity.

The UNI is designed to establish ecological trends by incorporating monitoring data every 1 to 5 years. The resulting trends for each indicator are then assessed as either: worsening, static, improving, target achieved, and averaged within their respective themes. The averaged theme score is then characterized as either critical, significant concern, some concern, or good. This score per theme indicates, at a glance, how well cities are performing ecologically. Importantly, this method allows for rapid cross-comparison of cities' efforts to increase ecological performance across the globe. With the state-of-the-art monitoring techniques ever-evolving, we intend for the UNI to evolve alongside these new techniques. To capture changed and improved monitoring techniques over time, we created a methodological framework document to help inform and guide future improvements to the UNI. Simultaneously, as cities use the UNI, feedback from them will be incorporated to enhance the user-friendliness of the UNI. The UNI is available at https://iucnurbannatureindexes.org/en.

Discussion

We developed and examined a set of indicators, called the UNI, intended to measure urban ecological performance while meeting diverse cities' needs and monitoring capacities. Our findings suggest that because users can select indicators within each theme and since the number of indicators selected is based on the city's capacity level, the proposed UNI provides flexibility that can meet the needs of cities piloted across IUCN regions and income levels. Additionally, the UNI's Capacity Assessment Questionnaire guides users in selecting appropriate and feasible indicators for their context. The UNI was developed by experts from several areas of expertize working across multiple scales, and due to it being structured in line with international ecological measuring criteria and goal setting approaches, the tool has the potential to raise ambition at the local level, prompting action toward achieving biodiversity targets at the global level.

Key to cities implementing global and national biodiversity goals are effective monitoring and science-based targets with metrics that show progress in relative and absolute terms. Although several sets of indicators exist to monitor urban biodiversity, most are rigid and inadequately reflect the complexity inherent in cities, as well as the multiple scales at which impacts of biodiversity loss are felt by cities[31,32]. Further, no internationally agreed upon approach to measuring biodiversity at the local level exists. This gap can hinder the successful implementation of biodiversity conservation plans 15,14. Further, the UNI was generated using a deductive conceptual framework focusing on measurable impacts across scales. It can therefore guide cities in achieving biodiversity and nature restoration goals within and beyond their boundaries.

The intention for the UNI is to be flexible yet standardized such that a wide array of cities can complete urban nature assessments in a comparable way within each thematic category. This flexible approach to indicators is especially important, as urban sustainability is a nascent field that is still establishing its foundational principles for research and practice. It is also

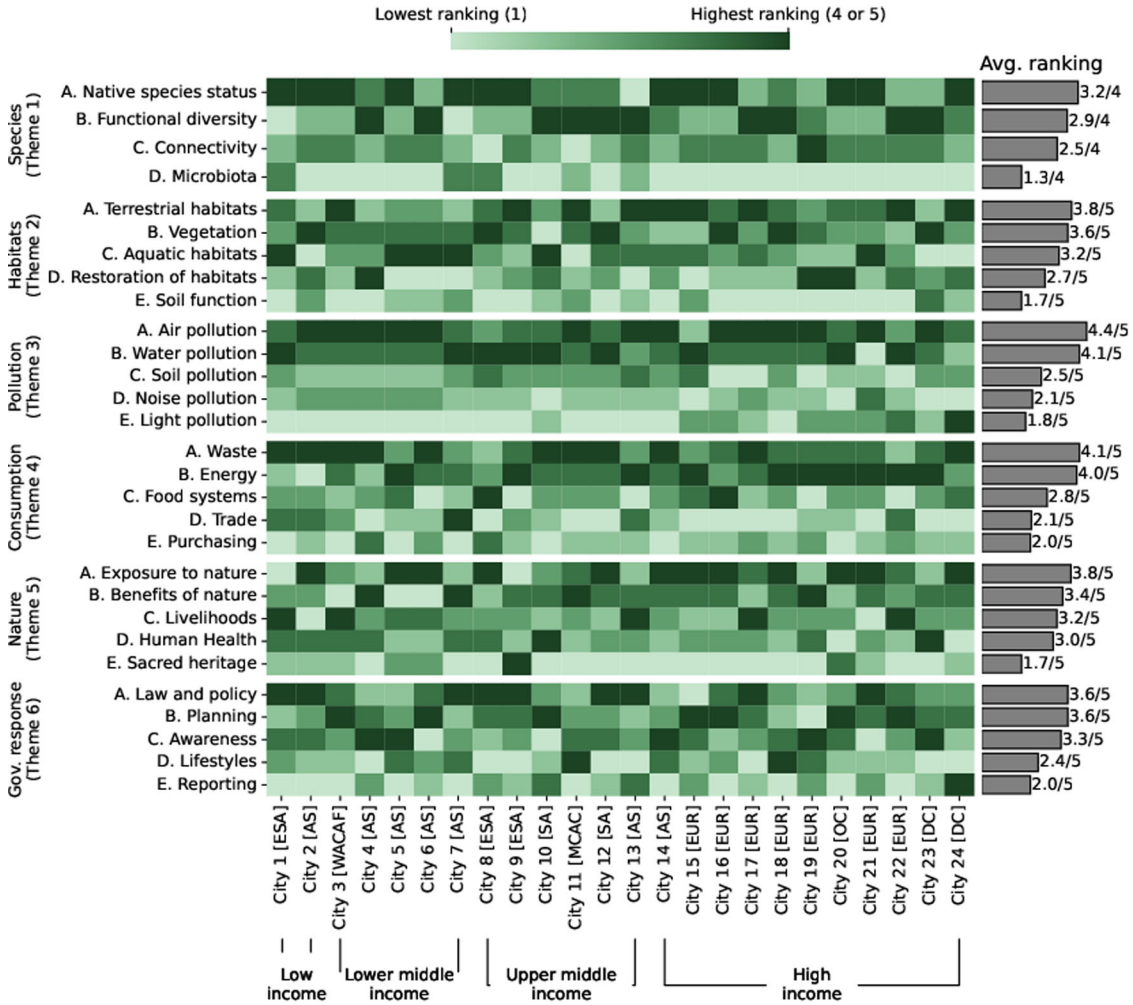

Fig. 4 | Heatmap displaying the survey results ranking the initially proposed UNI indicator topics grouped by the six themes. The heatmap shows the distribution of indicator prioritization across each of the 24 cities which participated in the survey. These participating cities were grouped by gross national income (increasing from left to right) as classified by the World Bank for 2022–2023: Low income - < 1085 USD, Lower-middle income - 1086–4255 USD, Upper-middle income - 4256–13,205 USD, High-income - >13,205 USD. The letters in brackets next to the city indicate the location of the city given by IUCN region: AS (Asia), ESA (Eastern and Southern Africa), EUR (Europe), MCAC (Mexico, Central America and the Caribbean), OC (Oceania), SA (South America), DC (Washington, DC office - United States and Canada), WACAF (West and Central Africa). The set of bar graphs to the right represent the average ranking score of the indicator topics, where a higher ranking means a higher priority.

meant to be sufficiently robust to provide a meaningful measure while also being feasible enough for cities with a range of capacities to update every 1 to 5 years. We found that while city representatives mention the SDGs or other nationally determined standards as guiding monitoring efforts, no international standard for monitoring nature and biodiversity in cities was being followed consistently. Among the selected cities, most report monitoring some or several features of, or impacts on, nature, yet how they measure and prioritize them differs vastly.

The UNI framework places emphasis on "indicator topics" within its six overarching themes. These topics are deliberately designed to be broad, allowing for a variety of indicator approaches that can adapt and evolve over time, considering the intricate and multifaceted nature of urban ecology. The aim was to propose a spectrum of possibilities that can be customized to suit the specific circumstances of individual urban areas. The UNI indicator set does not claim to fully align with the principles of an ideal set of indicators as discussed by Etches et al.[26], but it is a substantial step forward in standardizing the monitoring of urban ecological performance. Future iterations, in collaboration with practitioners and experts, aim to enhance the UNI framework, increasing its relevance, robustness and effectiveness for urban sustainability.

Cities lack guidelines that address their ecological impacts across multiple scales, from local to global. Furthermore, priorities among cities differ significantly enough to hinder comparability across locations and aggregation of impacts of local action at larger scales. However, some more straightforward and quantifiable topics such as pollution and waste were more commonly measured. This may in part be attributable to concerted efforts in the 1990s to early 2000s and the need for cities to measure and report on material flows and progress toward achieving the Millennium Development Goals, predecessor to the SDGs, with explicit focus on gauging economic growth and efforts to improve public health[33]. These types of straightforward measures differ from indicators that attempt to capture the interconnected well-being of ecological systems and humans[34]. Addressing socio-ecological systems as a whole also responds to the call to improve global monitoring of human development which is central to the SDGs [20,35].

Through this research, we find that nearly half of cities surveyed used the SDGs to guide monitoring efforts, although the 17 SDGs, which are accompanied by 169 targets and roughly 250 indicators, are designed to measure progress toward sustainability, and not ecological performance. Less commonly, piloted participant cities followed nationally determined standards, or non-binding national plans or policies mostly focused on

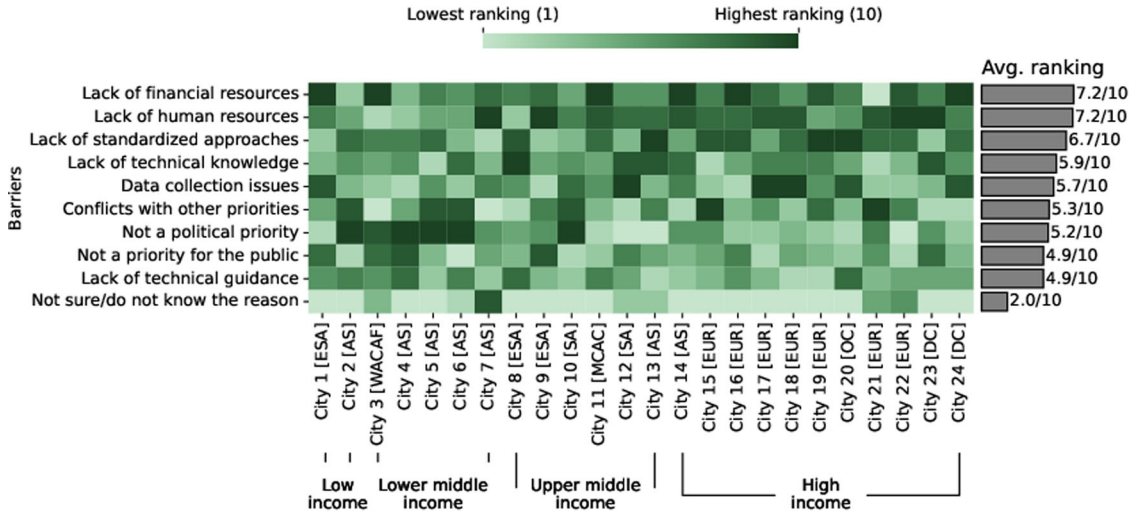

Fig. 5 | Heatmap displaying the survey results of the barriers impeding efforts of each city to monitor nature. The heatmap shows the distribution of barriers across each of the 24 cities which participated in the survey, These participating cities were grouped by gross national income (increasing from left to right) as classified by the World Bank for 2022–2023: Low income - < 1085 USD, Lower-middle income - 1086–4255 USD, Upper-middle income - 4256–13,205 USD, High-income - >13,205 USD. The letters in brackets next to the city indicate the location of the city given by IUCN region: AS (Asia), ESA (Eastern and Southern Africa), EUR (Europe), MCAC (Mexico, Central America and the Caribbean), OC (Oceania), SA (South America), DC (Washington, DC office - United States and Canada), WACAF (West and Central Africa). The set of bar graphs to the right represent the average ranking score of the indicator topics, where a higher ranking means a higher priority.

climate change mitigation, including but not limited to climate-related targets to measure reductions in greenhouse gas emissions[36].

Although climate change, biodiversity decline, unsustainable land use and inequitable natural resource extraction are tightly interlinked and cumulatively degrade human well-being[37], their associated targets and indicators are not interchangeable and cannot be used as proxies to infer ecological performance. Anthropogenic climate change, biodiversity decline[38], land degradation[39], and natural resource exploitation[40] directly impact ecosystem stability and the benefits society receives from nature[41]. These impacts vary in their nature and occur across different timescales.

The uneven distribution of benefits resulting from natural resource extraction and use often leads to social and economic disparities, which indirectly drives biodiversity loss. The synergistic effects of these factors on ecological performance pose a significant risk to human well-being. Therefore, targets and indicators that amalgamate measures across these drivers may provide misleading reports on urban ecological performance.

Further, nationally determined standards are, as implied by their name, typically measured and reported at the country-level. As a result, they rarely offer local-level monitoring guidance or opportunities for cross-comparison opportunities[42,43].

One local-level tool currently in use is the Singapore Index for Cities' Biodiversity (SICB), which provides a broad range of indicators but has limitations concerning its application and coverage[44]. Unlike UNI, the SICB focuses solely on impacts within city boundaries and lacks institutional support for global application. The development of the UNI addresses this gap by recognizing and emphasizing the broader ecological footprint of cities, encompassing both local and global scales[45]. The key novelty of the UNI is its application of the urban bioshed model that underscores the telecoupled impacts of cities beyond their physical boundaries. The inclusion of urban, city-bioregional, and global scales within a comprehensive framework acknowledges the complexities of urban-ecological systems and provides a path for cities to participate in sustainable environmental action effectively.

Despite the interest and engagement in urban ecological well-being, the study shows that a lack of resources and technical expertize remains the most common obstacle hindering effective monitoring efforts. This discrepancy highlights the necessity for a tool like the UNI, which is designed to be robust yet feasible for cities with various capacities. For cities, especially those classified as low- to lower-income, the use of the UNI can provide numerous benefits, including facilitating the establishment of larger-scale programs that direct support and funding to the local level. This, in turn, may elevate the priority given to nature and biodiversity conservation in city governance, as well as assist local governments in forming and implementing their conservation strategies. By incorporating telecoupling - the ecological impacts of cities beyond their local footprint - the UNI provides an innovative approach to track urban nature in a way that is adaptable to specific city contexts and resources. This innovative index offers cities a mechanism to contribute to national, regional, and global monitoring efforts, thereby enhancing transparency and accountability in environmental monitoring and promoting local action for nature.

The UNI, backed by institutional support from the IUCN, presents a solution to the limitations faced by cities in tracking their impact on biodiversity and environmental sustainability. It provides a common standard and a methodologically rigorous yet adaptable tool for cities to evaluate their ecological health and to inform their biodiversity policy development. In contrast to many existing tools, the UNI takes into account the cross boundary impacts of urban environments and the multi-scalar nature of ecological phenomena, offering a more holistic approach to urban nature monitoring. Beyond the immediate benefits of a more robust monitoring system, the UNI also fosters a global community of cities working collaboratively towards shared ecological objectives. This international network can serve as a platform for knowledge sharing, capacity building, and mutual support, reinforcing global commitments to urban nature conservation. The provision of an online platform by IUCN for practitioners with diverse knowledge and skill sets furthers this collaborative potential, providing a virtual space for the exchange of best practices and the co-creation of innovative solutions. Furthermore, the UNI can also play a pivotal role in mobilizing resources and galvanizing political support for urban biodiversity conservation. By demonstrating the feasibility and importance of tracking ecological health, the UNI can stimulate increased investment in monitoring infrastructure, the training of local environmental professionals, and the development of science-based policies and interventions. For low- to lower-income cities, the UNI can also help attract international funding and technical assistance, thereby mitigating the resource constraints that often impede effective environmental governance.

Additionally, as an IUCN knowledge product, the UNI will be supported by IUCN in terms of application, monitoring, consistency, and evolution over time. IUCN will also ensure the management and

coordination of the UNI web-platform in the long-term and support municipalities in the implementation of the Indexes as part of its activities.

As a standardized framework for urban ecological impacts, the UNI operationalizes targets at subglobal (regional/local) and global scales which are critical to improving conservation approaches that will shape the next 30 years[46]. Consistent guidance for comprehensive targets that link local ecological performance and global impacts have yet to take hold, though targets have been proposed for particular topics such as greenhouse gas emissions, canopy coverage, or access to green spaces. Rockstrom et al.[47] recently proposed a set of targets called Earth System Boundaries to ensure a stable, resilient, biophysical condition to sustain the "global commons" and which also include locally-relevant target-setting. The UNI is in a good position to link its framework to targets such as particular Earth System Boundaries, or those set by local or national governments. The ability to compare performance of cities within widely differing contexts is one of the benefits of a consistent global standard for local actions.

In conclusion, the UNI has the potential to catalyze a paradigm shift in how cities understand and respond to their environmental footprints by making visible the complex interconnections between urban activities and global biodiversity. By contributing to the emergence of a more ecologically-informed urban planning and management, the UNI can transform cities from sources of environmental pressures to leaders in nature-positive transformations. As the UNI continues to evolve, it will increasingly shape urban nature conservation practices and policies worldwide, responding to advancements in monitoring techniques and user feedback. It represents a promising tool that substantially enhances cities' capacity to monitor, understand, and improve their ecological performance, while also laying the groundwork for a more sustainable and inclusive urban future.

Methods

The UNI, developed by the IUCN, is a tool designed to evaluate the ecological performance of cities. The UNI's development commenced in 2019 with the establishment of a Technical Expert Group, which consisted of representatives from IUCN, local governments, and international organizations. The group defined guiding principles for the index, emphasizing addressing ecological impacts on local, regional, and global levels, and aligning with international frameworks like the Sustainable Development Goals (SDGs). A set of 69 proposed indicators were consolidated into six thematic categories by the Urban Biodiversity Hub's consulting team. These were further refined based on the findings from a survey and a series of workshops with city representatives, evaluating UNI's usefulness and potential barriers. The findings of the survey were then used to refine the indicators and the overall framework.

In initiating the UNI's development, the IUCN Urban Alliance convened a Technical Expert Group that comprised 15 representatives from IUCN Members, Commissions, and Secretariat, as well as from the governments of Edinburgh, Lagos, London, and Singapore. The group initiated the UNI's development during an in-person workshop held in Paris on 6–7 June 2019. They identified the following guiding principles for the index:

1. Address three scales of ecological impact: urban, regional, and global (telecoupled).
2. Align with relevant international frameworks and standards, particularly the post-2020 Global Biodiversity Framework and Sustainable Development Goals.
3. Harmonize, standardize, and streamline existing indicators while avoiding duplication.
4. Utilize existing datasets and limit the need for new and additional data collection.
5. Integrate existing tools and knowledge products (Key Biodiversity Areas, etc.).
6. Add value to cities' work, striking a balance between scientific rigour and practical utility.
7. Ensure accessibility to a range of cities, with options for varying degrees of implementation (i.e., a tiered approach).
8. Consider 'nature' in a broad sense (i.e., not just biodiversity and ecosystem services).

The group then divided itself into three subgroups, each addressing a different scale of ecological impact: urban, regional, and global (telecoupled). Over the following year, these subgroups continued to meet virtually and proposed an initial set of 69 indicators for inclusion in the UNI (See Supplementary Table 1). IUCN Urban Alliance staff expanded the potential set of indicators based on twelve international systems for measuring and setting sustainability goals (Sustainable Development Goals, CBD, The New Urban Agenda and the City Prosperity Index, World Bank Urban Sustainability Framework, Singapore Index on Cities' Biodiversity, European Urban Biodiversity Index, European Green Capital Award, Science-based Framework for Building Urban Biodiversity, International Standards Organization, Living Cities: Towards Ecological Urbanism, International Ecocity Framework and Standards, and IUCN Global Standard for Nature-based Solutions). The consulting team at the Urban Biodiversity Hub (UBHub) was then contracted by IUCN to consolidate the brainstormed list into a structured, cohesive framework.

The UBHub team examined the given indicators across the twelve international systems and two theoretical frameworks (Fig. 2) to identify gaps and duplicates. They focused in particular on the scales specified in the urban bioshed framework (local, regional, global) as well as the following global target systems: the Sustainable Development Goals (SDGs), the Post-2020 Global Biodiversity Framework Goals and Targets (then in draft form), and the key leverage points as described in the Global Assessment Report on Biodiversity and Ecosystem Services by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)[41]. This review resulted in the categorization of indicators into six themes (species status, habitat status, pollution, consumption, benefits and impacts, and responses) and the selection of indicator topics within these themes. Each theme includes a series of indicator topics that cover its primary aspects. Indicator topics allow for different indicators addressing the same intent, ensuring flexibility based on data availability, capacity, and cities' pre-existing work while still requiring an objective assessment of a key aspect of ecological performance. During this review, a Capacity Assessment Questionnaire was also developed with five questions (later expanded to seven) about basic characteristics of the city and its prioritization of biodiversity (see Annex). Questions were multiple choice, resulting in a scoring mechanism that categorized the users according to their capacity and would suggest completion of the UNI at different intensity levels. Intensity would be differentiated based on the number of indicators a user would need to complete as well as levels within certain indicators (i.e., basic or advanced).

Feedback Phase 1: broad consultation survey of Cities

This set of indicator topics was then tested through a survey of city representatives. The survey's target population was cities with some interest in ecological performance. A sample set of 66 cities was selected based on city population size, a consideration to ensure representation from the ten IUCN global regions, and known city contacts. After the city contacts were initially invited to complete the survey, two members of the UBHub consulting team followed up with the prospective respondents by email. Completed surveys were received from 24 cities from within nine of the eleven IUCN global regions with no cities completing the survey from within the Eastern Europe and Central Asia, and West Asia global regions.

The purpose of the broad consultation survey was to collate information from cities on the perceived usefulness of the UNI and the current approaches they use to measure ecological performance. The survey sought to gauge the features of and impacts on the natural environment that city respondents may be monitoring, if any, as well as identify barriers that might be impeding their ability to collect data.

The survey consisted of 25 questions (see Supplementary Note 1) that were grouped into four sections. The first section (consisting of four

questions) gathered basic information about the participants who completed the survey on behalf of the participating cities. The second section (consisting of five questions) focused on a separate initiative for reporting, the IUCN Contributions for Nature platform. The responses to the questions in the second section of the survey are not relevant to the development of the UNI and are therefore not discussed in this paper. The third section (consisting of seven questions) queried city respondents on their efforts at monitoring and measuring the natural environment, the means by which they collect data, and the barriers that may be impeding their efforts at monitoring the natural environment within their respective jurisdictions. Lastly, the fourth section (consisting of nine questions) asked the city respondents to prioritize the proposed set of indicator topics for the UNI that were grouped under the six initial themes. The survey was created using the online survey platform, Survey Monkey. Once the survey was created, the automatically generated web link to the survey was shared with the identified contacts in the 66 cities. The survey was launched at the end of April 2021 and closed on July 9, 2021.

Feedback Phase 2: UNI pilot testing workshops with select Cities

Select cities from the survey participated in in-depth workshops to test the UNI's application. The workshops aimed to gauge the effort required by cities of different capacities to complete the UNI. While several cities expressed interest in pilot testing the UNI, six cities took part in the pilot testing: Curridabat, Costa Rica, Saanich, Canada, Lagos, Nigeria, Mexico City, Mexico, Paris, France, and the city state of Singapore.

These workshops comprised three virtual sessions lasting one and a half hours each, spanning a three-week period between June and July 2021. Prior to the first session, the UBHub consultant team provided a Frequently Asked Questions document about the UNI to set the context for the pilot testing sessions. The first session served as a kickoff and a walkthrough of the indicators under themes 1–3. The second session captured feedback on indicators under themes 1–3 and conducted a walkthrough of the indicators under Themes 4–6. The third session captured feedback on indicators under themes 4–6 and concluded the workshop sessions. The workshops were facilitated by the members of the UBHub consulting team and by the former Head of the IUCN Urban Alliance. For the workshops, each participating city was asked to provide a staff representative to attend each of the three scheduled sessions and complete a form (see Supplementary Notes 2 and 3) that covered each indicator topic, and which asked about the ease of completing the indicator and the potential data sources for each. Cities were also asked to select one indicator under each theme to attempt to complete and provide feedback on their efforts. A summary of these results are available in Supplementary Table 2.

Participants needed additional staff time outside the scheduled sessions to dedicate to the pilot testing. If city participants were not able to complete an indicator, they provided feedback to the UBHub/IUCN team to request clarification, more support, or even an alternative measurement option. The consultant team assisted, when requested, with identifying data sources and selecting approaches for completing a particular indicator. If city participants had the data but were unable to complete the indicator, they were invited to explain their challenges or barriers to completing the indicator. All six participating cities completed the form and attended at least some of the sessions. They also provided estimates of the perceived effort to complete each indicator and their likelihood of selecting each of the indicator topics for completion.

The feedback received from the surveys and workshops led to further revisions of the UNI. These revisions included merging the soil function indicator topic into the microbiota indicator, adding two questions to the Capacity Assessment Questionnaire, adjusting some of the "basic" and "advanced" level indicators within some indicator topics in response to data availability and capacity, and adjusting some of the indicator topic and theme names for greater clarity.

Following these revisions, further review by the lead scientist at IUCN resulted in increasing alignment with the DPSIR model, leading to adjustments of the themes and some recategorization of the indicator topics. Additional external reviews by two topic experts and the internal publications team at IUCN also led to further revisions for greater clarity and slight adjustments to the scope and names of particular indicator topics. Feedback is being gathered on an ongoing basis from UNI users, which will inform future development and revisions of this evolving index.

Reporting summary

Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

Data used to inform the UNI has been provided where possible in the supplementary materials for this paper, though individual responses and comments have not been provided in order to maintain confidentiality. The corresponding author can be reached for reasonable requests. The latest version of the UNI can be found on IUCN Library System: https://portals.iucn.org/library/node/50782.

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Author contributions

All but the last two authors contributed to the analysis, discussed the results and implications and commented on the manuscript during all stages. J.R.P, M.H., R.G., and J.H. were part of the original development of the UNI. J.H. originally conceptualized the UNI, promoted and consulted on it and raised funds for its development. R.G. coordinated expert input and provided guidance on global standards to inform early stages of the UNI. M.H. led the facilitation of the practitioner inputs. J.R.P. developed the conceptual frameworks and structure, Figs. 1 and 2, and was the technical lead on the development of the indicators. A.B. and J.M. led the development of the figures and data analysis for Figs. 4 and 5, while M.H. initially reviewed and analyzed the survey data as seen in Fig. 3. The writing team led the conceptualization and writing of the paper, with leads for each section as follows: L.C. Introduction, J.M. results, L.M. discussion and abstract, J.R.P. methods and abstract, C.G. references.

Competing interests

The authors declare no Competing Financial Interests but the following: In their role with the Urban Biodiversity Hub, J.R.P. served as a contractor for IUCN to develop the UNI, and subcontracted M.H. and P.A.L.G. to support the work. R.G. was employed by IUCN to coordinate development of the UNI. The remaining authors declare no competing interests.

Additional information

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