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How do nature-based solutions contribute to biodiversity in cities?

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A B S T R A C T

The multifunctional character of nature-based solutions (NbS) in cities, benefiting both biodiversity and human well-being, is gaining increasing attention. Designing multifunctional NbS in cities requires insights in how NbS contribute to biodiversity, since biodiversity supports ecosystem stability and resilience, and benefits for people. While knowledge of urban biodiversity has increased, a comprehensive understanding of how NbS contribute to biodiversity is still lacking. We analyzed the outcomes of 185 urban NbS cases in 87 cities across 33 countries, based on data collected in a systematic literature review. Our results show that 78% of NbS cases contribute positively to improving biodiversity when compared to non-NbS. In some cases, their performance was comparable to that of natural reference sites. Twenty-eight NbS cases evaluating multiple outcomes, beyond biodiversity, predominantly demonstrate win–win solutions for biodiversity and human well-being, although the evidence base remains limited. We showed that current evidence is limited to specific taxa (mostly animals), NbS types (e.g., gardens, forests), and commonly used metrics (e.g., species richness, abundance). We also found that only 39% of cases integrated baseline data, highlighting a lack of comparative studies effectively assessing NbS contributions to biodiversity. Our research provides insights for indicator selection to facilitate the evaluation of NbS for biodiversity and beyond, advancing the understanding of multifunctional NbS, and expanding NbS evaluations to provide accessible information for decision-making and policy.

1. Introduction

Nature-based solutions (NbS) have gained attention on the climate change adaptation and biodiversity agendas, attracting substantial investment as well as increased prominence in research and policy (Seddon et al., 2021). NbS refer to actions that are inspired or powered by nature to address sustainability challenges and benefit both people and nature (Cohen-Shacham et al., 2016; European Commission, 2015). The multifunctional nature of NbS is widely acknowledged and a particularly attractive feature for cities, where space is limited, and urban natural area is constantly under pressure from development (Pineda-Pinto et al., 2021). At the same time, cities are confronted with various challenges including habitat fragmentation, urban heat island effect, flooding, and air pollution, all of which are exacerbated by the growing impacts of climate change and urbanization (Bazrkar et al., 2015; Frantzeskaki et al., 2019; Nesshöver et al., 2017). Consequently, NbS have gained prominence as integrative and multifunctional interventions to address these sustainability issues (Nesshöver et al., 2017).

Although not all NbS definitions explicitly refer to biodiversity (e.g., European Commission, 2015), most definitions agree on the capacity of NbS to simultaneously benefit human well-being and biodiversity (Kabisch et al., 2022; Remme et al., 2024). Sustaining biodiversity is fundamental for the long-term effectiveness of NbS, and provides opportunities for win-win scenarios with human benefits. Actions that support biodiversity also underpin human benefits, mainly because they can boost the delivery of ecosystem services, i.e., the contributions of nature to human well-being (Seddon et al., 2021; Zari, 2018). NbS alter the flows of ecosystem services by modifying the ecosystem and how people interact with the ecosystem (Remme et al., 2024). In this regard, NbS often also deliver benefits for biodiversity, because biodiversity within the modified ecosystems is essential to securing the sustained flow of ecosystem services (Seddon et al., 2021). For example, more biodiverse ecosystems are often more productive, providing higher carbon storage and contributing to climate change mitigation (Mori et al., 2021; Weiskopf et al., 2024). Furthermore, actions that support species-richer ecosystems often enhance the resilience of ecosystems to perturbations and long-term environmental changes, thus securing the provision of services in the long run, such as greater stability of carbon capture and water storage (Biggs et al., 2020; Jactel et al., 2017; Osuri

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et al., 2020). Finally, protecting and enhancing biodiversity through NbS can provide related social and cultural values of biodiversity, such as sense of place, aesthetic appreciation and mental well-being (Hammoud et al., 2024; Southon et al., 2018). Therefore, NbS should be explicitly designed to protect or enhance biodiversity, maintaining healthy, resilient ecosystems that can also sustain long-term benefits to people (Seddon et al., 2021).

Designing multifunctional NbS that benefit both people and biodiversity requires an understanding of how NbS contribute to urban biodiversity, yet such knowledge is currently poorly integrated into NbS planning and design (Kabisch et al., 2022; Xie & Bulkeley, 2020). In urban contexts, research syntheses often focus on the effectiveness of NbS for addressing climate change or human health issues (Esraz-Ul-Zannat et al., 2024; Harvey et al., 2024; Obeng et al., 2023). However, evidence on how NbS improve local biodiversity remains scarce (Parris et al., 2018). More importantly, this lack of understanding hampers the justification of claims for win–win solutions, benefiting both biodiversity and people.

Insufficient attention to biodiversity conservation throughout the NbS planning, implementation, and monitoring process is a key reason for a lacking evidence on NbS impacts on urban biodiversity (Oke et al., 2021). When assessed, biodiversity conservation is often regarded as a co-benefit of urban NbS, rather than as a strategic priority (Mori, 2020; Oke et al., 2021). Additionally, the outcomes of such NbS for biodiversity are not often monitored and reported (Key et al., 2022). Monitoring biodiversity outcomes is important to provide quantifiable data and concrete evidence of how well an intervention has contributed to biodiversity. Lacking such knowledge could lead to ineffective solutions and mislabeling actions as win–win solutions. Evidence for this is available for systems other than urban. For example, a concern arises that large-scale plantations and reforestation efforts for carbon capture and storage have encouraged the planting of fast-growing, exotic trees that largely sequester carbon but could cause local biodiversity loss, and sometimes also lead to food and water insecurity (Heilmayr et al., 2020; Seddon et al., 2021). Comprehensive evidence on biodiversity outcomes of different NbS interventions is crucial to help prevent unintended consequences and develop synergistic strategies that support both biodiversity conservation and human well-being.

While urban ecology is gaining traction as a field of research and insights in urban biodiversity are increasing, these have hardly been linked to NbS planning and design or the outcomes of NbS (Knapp & MacIvor, 2023; Rega-Brodsky et al., 2022). Many urban ecology studies focused on examining how species in cities respond to urbanization gradients (e.g., MacGregor-Fors et al., 2015; McDonnell & Hahs, 2008). There is also knowledge on the importance of individual urban habitat features, such as patch area, temperature, the degree of fragmentation, and connectivity on urban biodiversity (e.g., Aronson et al., 2014; Beninde et al., 2015; Shwartz et al., 2013). To our knowledge, there is no comprehensive evidence base for how NbS contribute to biodiversity in cities. Key et al. (2022) systematically assessed biodiversity as a co-benefit of adaptation and mitigation interventions applied in non-urban areas. A global assessment on urban NbS provided evidence of biodiversity as one of the many outcomes but did not examine specified indicators of biodiversity, such as species richness, abundance, or community composition (Li et al., 2025). Filazzola et al. (2019) conducted a systematic meta-analysis on the contribution of green infrastructure in enhancing species richness and abundance in cities, focusing on a set of completely human-constructed types such as green roofs and detention basins. While knowledge on urban biodiversity and NbS is broadly advancing, there remains a need for understanding how urban NbS contribute to biodiversity across multiple dimensions.

To address this need, we collated global evidence on the biodiversity outcomes of NbS in cities and conducted a systematic analysis to answer three key research questions: **Q1:** How are biodiversity outcomes measured in relation to NbS in urban contexts, considering the different dimensions of biodiversity and taxa studied? **Q2**: How do different types of NbS perform in enhancing biodiversity outcomes, compared to non-NbS, natural references, and other NbS types? **Q3**: What is the evidence base for win–win solutions, where NbS simultaneously contribute to biodiversity and human well-being? Through this research, we contribute to an increased understanding of the contexts in which NbS are effective interventions for biodiversity and human well-being. The analysis can help mainstream biodiversity more effectively into NbS planning and design in cities.

2. Methods

This research was composed of three main steps: (1) defining the scope of the review and selecting relevant studies, (2) coding and extracting relevant data for NbS cases identified, and finally, (3) analyzing the data (Fig. 1).

2.1. Study selection and review scope

We considered data from the scientific literature assessing biodiversity outcomes for NbS and related concepts in cities. Our study selection builds on a literature database which was developed to provide a comprehensive synthesis of evidence on NbS effectiveness to address urban challenges (Li et al., 2025). The original database was based on a systematic search of scientific literature available in Scopus up to October 25th, 2021. The search combined terms related to urban contexts and NbS intervention, which was composed of related concepts representing urban natural features, without specifically framing them as NbS in order to maintain a global scope. Initial screening followed the predefined eligibility criteria concerning Context, Intervention, Outcome, Study type (CIOS) framework (James et al., 2016). Studies were included if they 1) focused on urban environments, 2) studied implemented NbS interventions, 3) reported outcomes explicitly related to the effects of NbS interventions, and 4) presented empirical data. This process yielded 361 publications, which contained data on a broad range of NbS impacts on biodiversity, health and well-being, and regulating ecosystem services.

For the present study, we conducted a secondary screening of the database, specifically targeting biodiversity outcomes with refined selection criteria. The publications were screened to identify if biodiversity outcomes were reported based on a precise evaluation of the biodiversity metrics used. In this context, biodiversity metrics refer to quantitative measurements used to assess and monitor biodiversity, encompassing various measurements such as the number of species and number of native birds (Marshall et al., 2020). Only studies that included measurements of species in urban areas and used these measurements as metrics for assessing biodiversity outcomes were included. We excluded studies that only measured biodiversity as characteristics of NbS, such as vegetation cover and plant composition, rather than as response variables or outcomes. Furthermore, studies only measuring species as bioindicators for human well-being outcomes were excluded. For example, the number of individual mosquitoes in water-featured parks was measured and used as an indicator of NbS effects on human health (Valdelfener et al., 2019). Ultimately, 114 publications were included in the synthesis for which biodiversity outcomes of NbS had been measured with distinct biodiversity metrics (see the full list in Supplementary Data).

2.2. Data extraction

We identified each unique combination of NbS intervention and urban context (location) as a separate NbS case study from the 114 included publications. This resulted in 185 cases. For each case, we extracted the following information: 1) geographical location, 2) NbS, 3) biodiversity outcomes and how they are measured, 4) the performance compared to alternative solutions, and 5) other outcomes along with biodiversity outcomes and their performance, when applicable. The full

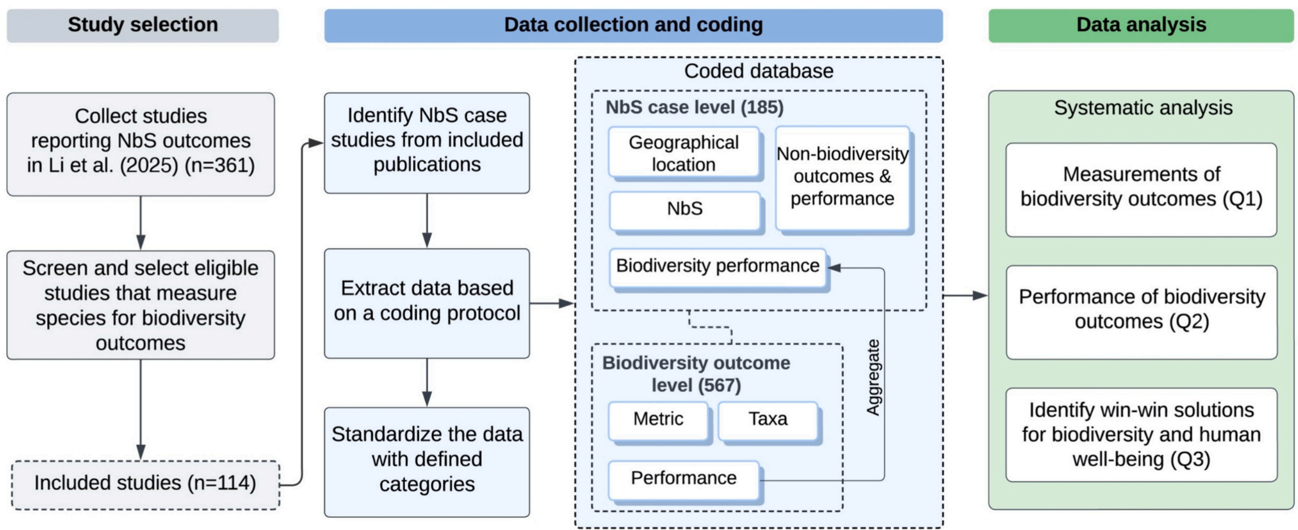

Fig. 1. Workflow diagram of data assembly and syntheses.

data with coding results is available in Supplementary Data.

We clustered the NbS based on the classification of NbS units and NbS measures. As defined by Li et al. (2025), NbS units refer to urban spatial units that comprise different elements of natural and built infrastructure, including 16 distinct unit types (e.g., forests & trees, gardens and natural parks). NbS measures refer to actions to manage, restore, or protect existing NbS units, by applying techniques, encompassing 7 measure types (e.g., extensive mowing and revegetation, and soil rehabilitation). Through this classification, NbS are primarily identified based on units, with each NbS measure being paired with an NbS unit. Hereafter we refer to NbS unit types as NbS types. A full list with detailed definitions of each category can be found in Table S3, Supplementary Information.

We recorded all biodiversity outcomes of NbS, noting that one NbS case can have multiple biodiversity outcomes. To delineate the biodiversity outcomes of each urban NbS case, we formulated a list of metric types, using an inductive coding approach (Table 1). The metric types are clusters of similar measurements related to the same biodiversity dimensions such as species richness. The most detailed level of our data includes single metrics, such as Shannon's diversity index. Single metrics were grouped into defined metric types such as species diversity. The metric types can be grouped into broader categories considering different biodiversity aspects, i.e. diversity, abundance and population size, and ecosystem functioning and community composition.

We also recorded information on measurements of biodiversity outcomes, including taxonomic groups studied, data collection methods, and the temporal range of the study such as cross-sectional or longitudinal. Furthermore, we recorded the comparators applied in the biodiversity outcome assessment to evaluate performance: non-NbS control, natural references, and other NbS types. Non-NbS control represents all conditions without an intervention, such as control sites, and the condition before intervention. Natural references refer to natural sites near the intervention sites such as a remnant forest, representing a benchmark to assess an ecological restoration intervention on degraded sites. The performance of each biodiversity outcome was primarily assessed compared to a non-NbS control and natural references. The framing of an outcome direction adheres to the principle of 'more is better' for biodiversity metrics. For each outcome, the performance was coded as positive (increase in biodiversity metric), negative (decrease), neutral (no change), and mixed (both increase and decrease with changing conditions).

To assess the contribution of each NbS case to biodiversity, we aggregated the performance of outcomes measured by single metrics within the same case into one general performance outcome. For the cases reporting other outcomes alongside biodiversity (i.e., outcomes benefiting humans), we recorded all these distinct outcomes, categorized them into indicator clusters following the approach by Li et al. (2025), and coded the performance in comparison to non-NbS controls. To identify the win–win solutions benefiting both biodiversity and human well-being, we categorized NbS outcomes as either biodiversity outcomes or non-biodiversity outcomes that reflect various human well-being aspects. In this context, non-biodiversity outcomes include those related to ecosystem services (e.g., flood mitigation, greenhouse gas mitigation, and water quality enhancement), as well as broader social-economic benefits (e.g., resources efficiency, social cohesion and living standards). This approach allows for a broad examination of quantified outcomes relevant to a wide range of human well-being benefits.

2.3. *Data analysis*

We mapped the geographical locations of the 185 identified urban NbS cases and analyzed the distribution of the evidence concerning NbS types (Section 3.1). Subsequently, the coded data were used to answer three questions related to the contribution of NbS to biodiversity in cities. To address how biodiversity outcomes are measured for NbS in urban contexts (Q1), we analyzed the frequency of use of different biodiversity metric types and their coincidence within the same case (Section 3.2). We also analyzed the taxonomic groups assessed in outcomes and the taxonomic coverage for each case.

To examine the performance of biodiversity outcomes provided by NbS (Q2), we first analyzed the distribution of positive, negative, neutral and mixed effects compared to non-NbS and natural references (Section 3.3). The performance was analyzed separately for each NbS type and metric type. The synthesis of the performance of an outcome to a non-NbS was based on 189 assessments from 59 NbS cases and the performance compared to a natural reference was based on 55 outcomes from 17 cases. The aggregated performance at the case level was also analyzed.

Additionally, we synthesized NbS cases involving comparisons with other NbS. For this analysis, we used the three most common comparisons among two NbS types in our database: 'General park' versus 'Grassland' (27 comparisons), 'General park' versus 'Garden' (24), and 'Garden' versus 'Grassland' (20). Each comparison involved biodiversity outcomes of the two NbS. We documented which NbS type exhibited a higher biodiversity outcome. If there was no discernible difference, we recorded the result of the comparison as neutral.

Finally, to examine whether NbS provide win–win solutions for both

Table 1
Biodiversity metric types and definitions used to code the biodiversity outcomes.

Broad category	Metric type	Definition
Diversity	Species richness	The number of species represented in an ecological community, landscape, or region (alpha diversity).
	Species evenness	The distribution of abundance among different species within a community, e.g., Pielou evenness index, Simpson's evenness index.
	Species dominance	The degree of dominance of one or a few species within a community measured by the proportional abundance of these species, e.g., Simpson's Index of Dominance
	Species diversity	Metrics combining the number of species present in an ecosystem and the relative abundance of each of those species, e.g., Shannon-Wiener diversity index.
	Taxonomic group richness	The number of different taxonomic groups above species level that are present in a given area.
	Beta diversity	Measures of the differences or similarities in species identity between different locations or communities, e.g., Bray-Curtis dissimilarity and Jaccard's similarity indices.
	Phylogenetic diversity	Metrics capturing phylogenetic differences (the tree of life) between species.
Abundance and population size	Biomass	The total mass of plants, animals, or microbes in a given area or ecosystem, often measured by the dry weight per unit area or volume.
	Species abundance	The number of individuals of a given species within a given area.
	Vegetation cover	The proportional vegetation cover within a given area.
	Stem density	The absolute number or basal area of stems per unit area.
Ecosystem functioning and community composition	Regeneration capacity	Metrics of the capacity of plant regeneration within an ecosystem, focusing on the establishment and growth of new plants including samplings, seedlings and spontaneous plants, measuring their richness and abundance.
	Functional diversity	Metrics assessing the variety and range of functional traits exhibited by organisms within a community or ecosystem, e.g., of reproductive strategies, feeding habits, tropical interactions.
	Persistence probability	Metrics of metacommunity and metapopulation dynamics (i.e., colonization and persistence) between green spaces, e.g., community-level probability of persistence of mammals.
	Indicator species diversity	Metrics of the diversity of species whose presence, absence, or abundance can provide information about the health of an ecosystem. E.g., Ephemeroptera, Plecoptera and Trichopera (EPT) richness for freshwater ecosystems.
	Endangered species diversity	Measures of absolute or proportional richness of threatened species in a given habitat, e.g., species of IUCN red list categories.
	Native species proportion	The proportional abundance or richness of native (or indigenous) species in a given area.

biodiversity and broader sets of human well-being (Q3), we identified 28 cases that reported biodiversity and other outcomes simultaneously (Section 3.4). Out of those, 12 cases compared the outcomes to non-NbS controls, allowing to evaluate their combined performance. For cases reporting multiple non-biodiversity outcomes, we identified pairs between the biodiversity outcome and each of the non-biodiversity outcomes. Following the framework by Hopkins et al. (2021) to identify win–win solutions, we identified the coexistence of two positive outcomes as a win–win scenario while the coexistence of a positive and a negative outcome as a win-lose scenario. Based on this classification, we determined the relationships between biodiversity and human well-being outcomes. Additional data and information supplementing the main results are available in the Supplementary Information and Supplementary Data.

3. Results

3.1. Geographical distribution and types of urban nature-based solutions

Overall, we assessed 567 biodiversity outcomes related to 185 urban NbS cases, resulting from 114 publications. Most publications covered one NbS case (69 %), and fewer covered two (13 %) or more NbS cases (18 %).

The geographic distribution of cases was unbalanced (Fig. 2A). The cases were primarily located in Asia (29 %), Europe (28 %), North America (19 %), and Oceania (15 %), with the fewest coming from South America (5 %) and Africa (4 %). Evidence was reported from 33 countries, with the United States (27), Australia (25), China (19), Germany (16) and India (14) together contributing 55 % of the cases. The NbS cases were linked to 87 cities. Adelaide (11 cases) and New York (10 cases) were most frequently studied.

Most cases on urban biodiversity focused on the NbS unit gardens (17 %), followed by semi-natural parks (15 %), forest & trees (13 %), grasslands (12 %), general parks (10 %), and green roofs & walls (8 %) (Fig. 2B). In 42 out of 185 cases, specific measures were applied to the NbS unit. Especially grasslands, forests & trees, and rivers and canals were subjected to NbS measures (Fig. 2B). Extensive mowing on grasslands was the most studied measure and unit combination (8), followed by revegetation/replanting on forests (5) and combined measures on rivers and canals (4) (Fig. 2C).

The distribution of NbS cases focusing on urban biodiversity varied across regions. Within the United States, forest & trees (26 %), green roofs & walls (19 %) and stormwater basins (15 %) were mostly studied, while in China river & canals (21 %) and general parks (21 %) were most studied. Studies in Australia focused mainly on gardens (24 %), those from Germany on grasslands (31 %) and semi-natural parks (25 %), while studies in India predominantly focused on semi-natural parks (57 %) and gardens (21 %).

3.2. Measurement of biodiversity outcomes

3.2.1. Biodiversity metrics

Biodiversity outcomes were predominantly measured using species richness (32 % of total outcomes). Additionally, most outcomes were assessed using metrics involving diversity (57 %; Fig. 3A). Besides species richness, species diversity (12 %), beta diversity (6 %), and species evenness (4 %) were also commonly used metrics. In ecosystem functioning and community composition outcomes, native species proportion and functional diversity were the most common metrics (8 % each), followed by regeneration capacity (3 %). Only a few outcomes used metrics of endangered species diversity, persistence probability, and indicator species diversity (all covering 1 % of the total assessments). Most outcomes measuring abundance and population size focused on species abundance (17 %), with few others measuring biomass (2 %), stem density (2 %), and vegetation cover (1 %).

The majority of cases (76 %) used two or more metrics to assess

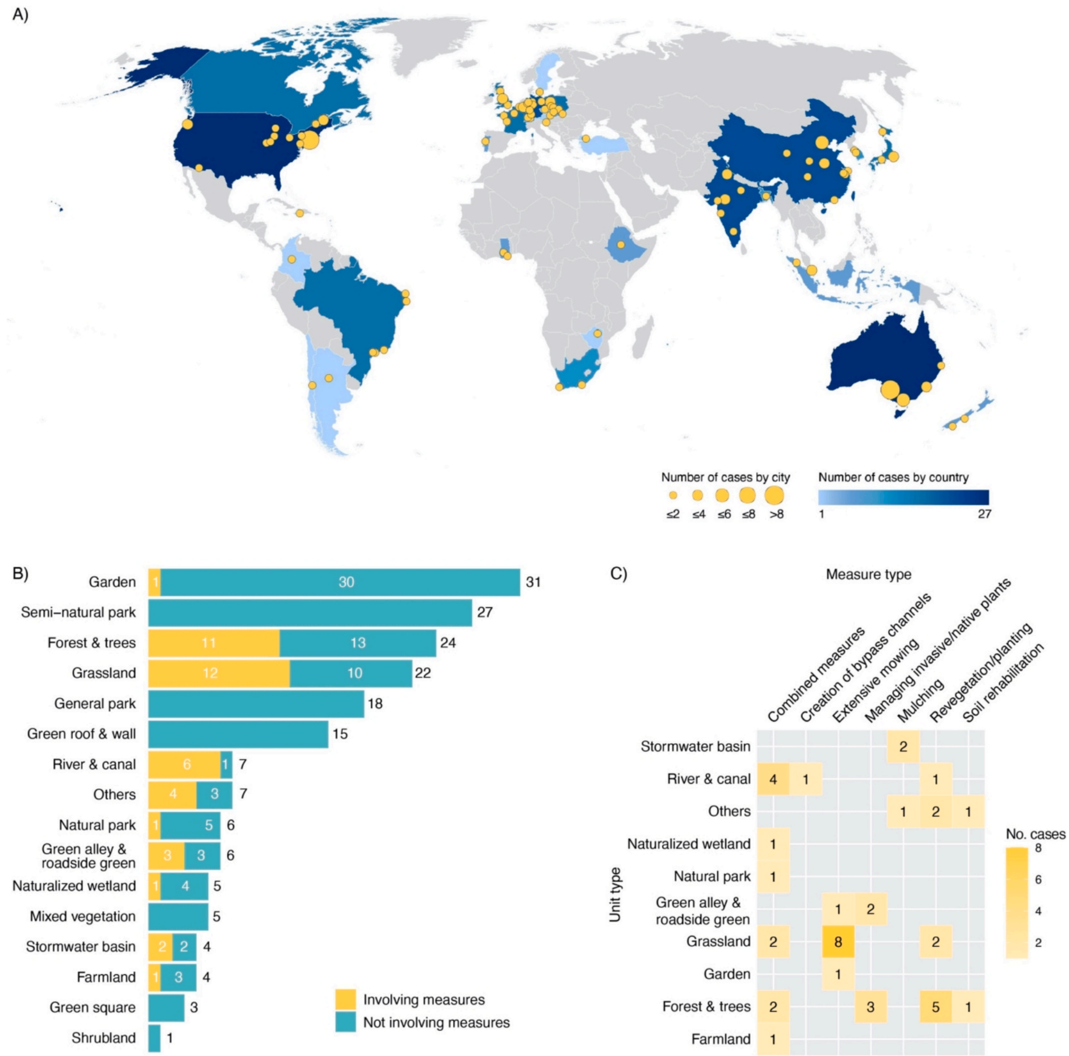

Fig. 2. Overview of urban nature-based solutions (NbS) cases identified in this study. A) Geographical distribution of identified cases, per country and city. B) Frequency of cases per NbS type (n = 185). The NbS are distinguished based on whether they involve measures or not. C) Crosstabulation of NbS types (vertical) and measures applied in those NbS units (n = 42).

biodiversity outcomes. Single-metric cases primarily related to species richness (50 %), species abundance (20 %), and species diversity (13 %). For cases applying multiple metrics, species richness and species abundance were most commonly applied together (59 out of 140 cases; Fig. S2). Species richness was also frequently combined with other diversity metrics, including species diversity (44), species evenness (24), and beta diversity (21). Metrics related to ecosystem functioning and community composition were also frequently combined with others, such as native species proportion with species richness (21), functional diversity with species abundance (16), native species diversity, and regeneration capacity (12).

3.2.2. *Taxonomic groups*

Biodiversity outcomes predominantly involved just one kingdom (89 % of cases), with a greater focus on animals than plants. For example, 51 % of 185 identified NbS cases had evidence for effects solely on animals, while 27 % on plants and 11 % on microbes (Fig. 3B). Cases involving gardens, semi-natural parks, grasslands, and green roofs & walls focused more on only animals than on plants. The opposite was true for forests & trees and natural parks. 8 % of cases reported effects on both plants and animals, most notably for grasslands, gardens, and green alleys and roadside greens.

The focus on animals was also dominant at the NbS outcome level, with 53 % of outcomes involving assessments of animals, and 34 % of plants (Fig. 3C). Outcomes related to animals primarily measured species richness and abundance (65 % combined), with a bias towards invertebrates (67 %) and birds (23 %) (Fig. 3D). Of the invertebrates, bees were the most commonly studied (35 %), followed by butterflies (20 %), insects in general (9 %), spiders (6 %), and beetles (6 %). Outcomes related to plants were mostly assessed by diversity metrics (e.g., species richness and species diversity), and ecosystem functioning and community composition metrics (e.g., native species proportion and functional diversity), accounting for 87 % combined. Biodiversity outcomes involving bacteria (8 %) and fungi (4 %) related to soil and water health, and were both primarily assessed by diversity metrics. Microbes were mostly related to biomass measurements. Outcomes assessing protists were the least common, accounting for only 1 % of the total assessments.

3.3. *Performance of biodiversity outcomes*

3.3.1. *Performance compared to non-NbS controls and natural references*

Of the 189 outcomes that were compared to those of non-NbS controls, 68 % were reported as positive, 23 % reported as neutral, 7 % reported as negative, and 2 % reported as mixed. Outcomes mostly related to forest and trees and grasslands (20 % each; Fig. 4), and species richness was the most frequently used metric (for 48 of 189 outcomes),

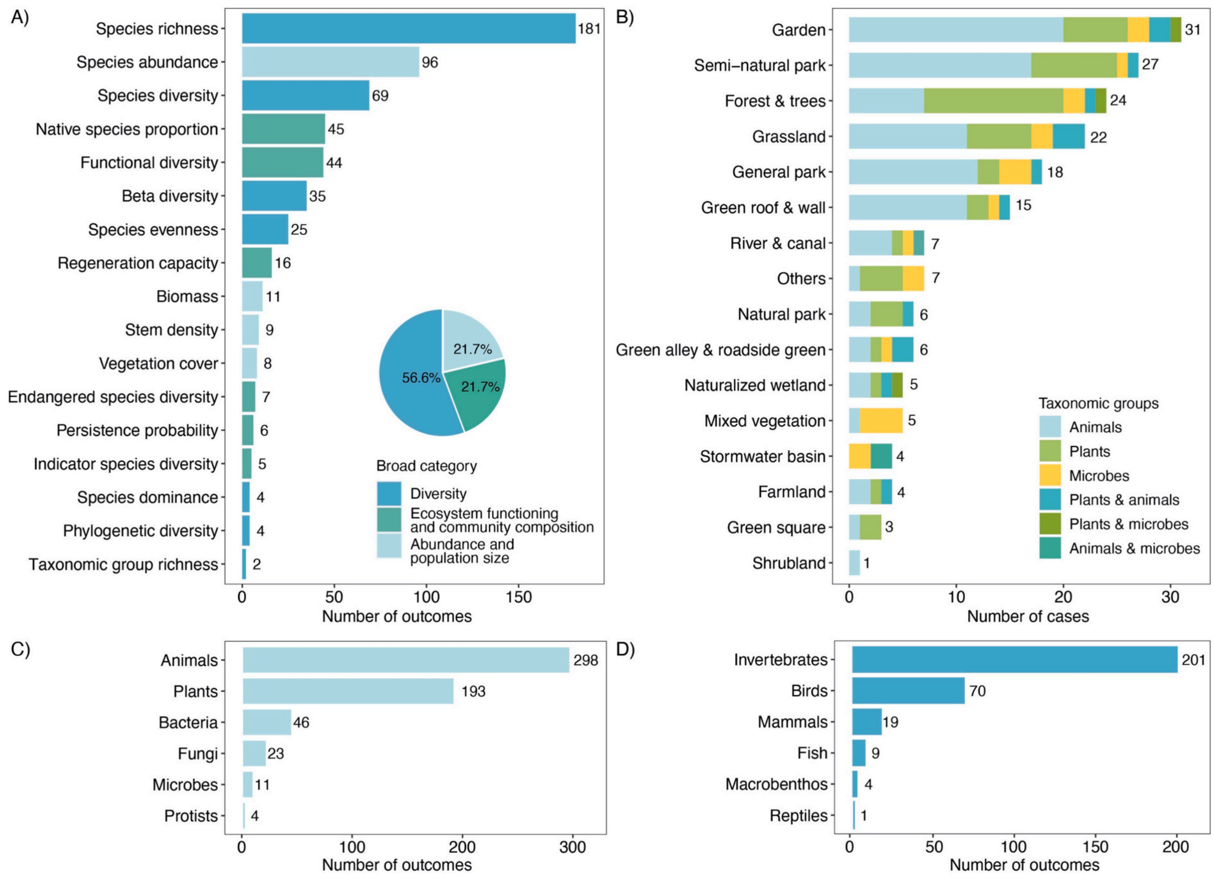

Fig. 3. Frequency of A) Metrics used to assess biodiversity outcomes; B) Taxonomic coverage per unit type at the case level; C) Biodiversity outcomes across different kingdoms; and D) Biodiversity outcomes assessed per taxonomic group of animals. The sum of categories in C) and D) exceeds the total number of included outcomes, as multiple taxonomic groups were included to assess a single biodiversity outcome.

of which 79 % of the outcomes were positive. Increased species richness was mostly found in grasslands (11 out of 38 outcomes), forests and trees (5), and green roofs and walls (5). Overall, most positive outcomes were found in grasslands, which were primarily the result of extensive mowing (20 out of 26 outcomes), leading to increased diversity, abundance, and functional diversity, particularly for plants and invertebrates. Similarly, the positive outcomes found in rivers and canals (18 of 23 outcomes) mainly resulted from combined measures (14), mostly measured through enhanced species diversity. Negative effects were mostly reported from forests & trees (5 out of 13 outcomes), all involving measures taken within the NbS, i.e., soil rehabilitation and revegetation/replanting. Negative effects were also often related to farmland (4 out of 13 outcomes). Measures of native species proportion resulted in the most neutral outcomes, mostly related to naturalized wetlands (4 out of 11 outcomes).

At the NbS case level, 78 % demonstrated positive overall outcomes for biodiversity when compared to non-NbS (Fig. 5A). For instance, cases of green roofs consistently yielded positive biodiversity outcomes compared to grey roofs. NbS cases reporting at least one negative outcome, shown as mixed or negative in Fig. 5A, primarily involved specific measures applied (9 out of 10 cases) and were exclusively related to plants and animals (Fig. 5A and B). For instance, soil rehabilitation in the forests decreased the ratio of native to non-native saplings and seedlings recruiting while co-planting with nurse shrubs also decreased the seedling and sapling abundance and native to non-native ratio of saplings (Doroski et al., 2018).

Few NbS resulted in comparable or better outcomes than their natural reference. For 75 % of the 55 outcomes, lower biodiversity was reported compared to natural references, while 18 % reported comparable effects to the natural reference and 5 % reported higher effects.

3.3.2. Differential performance between nature-based solution types

82 NbS cases, studied in 26 publications, involved comparisons to other NbS unit types. Across the three selected comparisons, neutral outcomes were commonly observed related to species richness, diversity, and abundance (Fig. 6). For instance, 45 % of comparisons between gardens and grasslands and 41 % of comparisons for general parks and gardens showed no difference. The results of comparisons for each metric type showed a mixed pattern, particularly in species richness, species diversity, and beta diversity. For example, comparisons between general parks and gardens in species richness exhibited four instances where general parks had higher biodiversity and four where gardens had higher biodiversity.

When examining specific metric types and taxonomic groups, general parks demonstrated higher biodiversity outcomes than gardens for bird richness, soil bacterial abundance, and beta diversity. Conversely, gardens showed higher biodiversity outcomes for invertebrate richness. Predominantly higher biodiversity outcomes were observed in grasslands compared to general parks, indicated by the diversity of soil bacteria, bees, and small mammals. In comparisons between garden and grassland, grassland generally had a higher biodiversity for soil bacteria and invertebrates. Conflicting results were observed as well; for instance, some cases found that general parks had higher bee richness and diversity outcomes compared to grasslands, although reverse results were also reported.

Fig. 4. Performance assessed by comparing biodiversity outcomes of nature-based solutions (NbS) to those of a non-NbS, indicated for NbS types and metric types. The analysis encompassed 189 outcomes from 59 NbS cases, with 38 cases involving measures applied in units (119 outcomes).

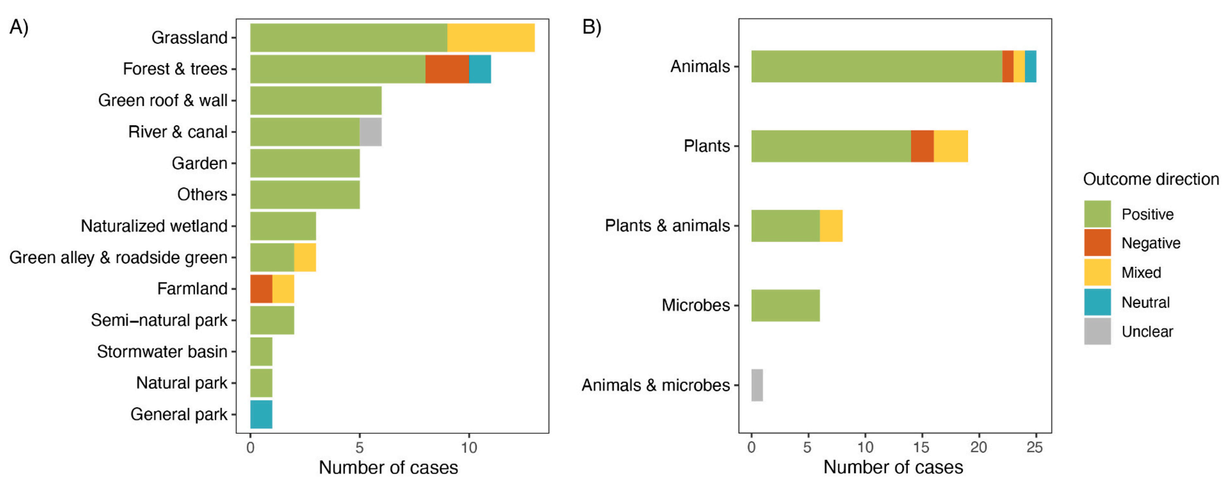

Fig. 5. Performance of nature-based solutions compared to non-NbS by assessing the general biodiversity outcomes at the case level across unit types (A), and associated with different taxonomic groups (B). The analysis encompassed 59 NbS cases.

3.4. Identifying win–win solutions for biodiversity and human well-being

15 % of the NbS cases reported other outcomes in addition to biodiversity outcomes. These studies addressed a wide variety of NbS types, with forests & trees (4 out of 28 cases), stormwater basins (3), and naturalized wetlands (3) most frequently reported. 11 out of the 28 cases only applied one biodiversity metric in the evaluation. Species richness (31 %), species diversity (24 %), and biomass (13 %) were the most often used metrics within these integrative evaluations of NbS (54 metrics in total). 51 distinct non-biodiversity outcomes were identified within these cases and categorized based on indicator clusters (Fig. 7B).

In addition, we examined the combined performance of biodiversity outcomes and human well-being outcomes. 12 NbS cases included a comparison to non-NbS cases to reveal win–win and win-lose scenarios (Fig. 7A). These cases reported 15 relationships between biodiversity and non-biodiversity outcomes, with one case contributing three distinct non-biodiversity outcomes. The cases exclusively reported positive effects on biodiversity (12) and consistently reported positive effects on non-biodiversity outcomes (14 out of 15). Based on this, the relationships identified are predominantly win–win (14), stemming from 11 out

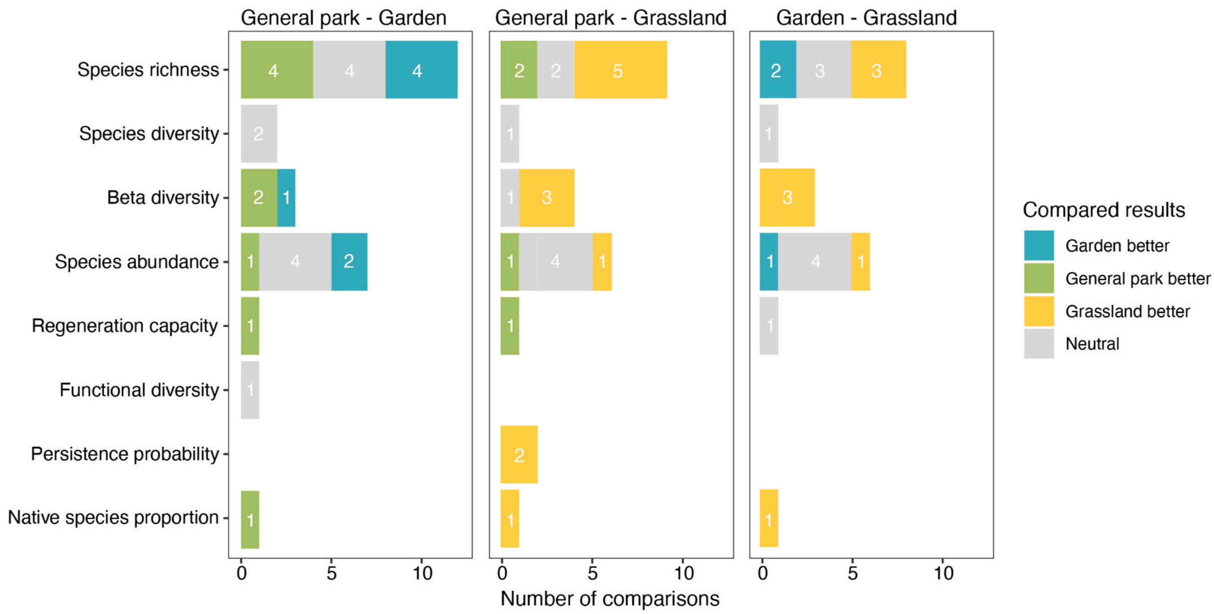

Fig. 6. Results of the three most commonly studied comparisons between two NbS types. They involve general parks compared to gardens (n = 27) as well as grasslands (n = 24), and gardens compared to grasslands (n = 20).

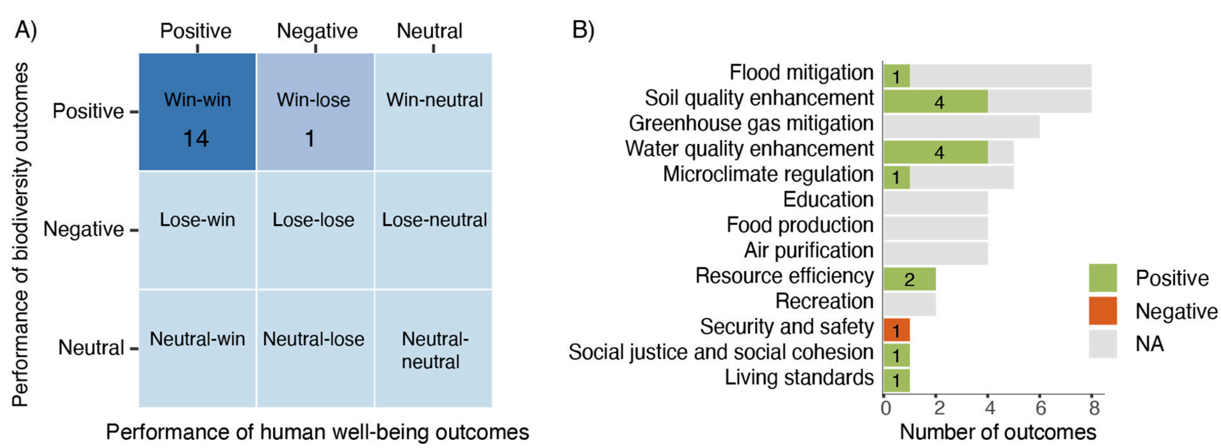

Fig. 7. A) Relationships between the performance of biodiversity outcomes and human well-being outcomes. B) Human well-being outcomes and their performance. Data was based on 12 case studies, which included 15 non-biodiversity outcomes, with one case contributing three non-biodiversity outcomes.

of 12 cases. Win-win scenarios predominantly occurred between biodiversity outcomes and outcomes measured by indicators of water and soil quality enhancement (4 for each; Fig. 7B), primarily associated with NbS that apply specific measures to restore rivers, forests and wetlands. Secondary win–win scenarios were observed in relation to outcomes measured by resource efficiency indicators, as evidenced by reduced maintenance cost by applying green roof and wildflower meadows compared to more engineered solutions. Notably, one case reported quadruple wins associated with a semi-natural park, achieving a primary outcome in flood mitigation while simultaneously contributing to improved water quality, social justice and social cohesion, living standards, and increased plant and animal richness (Kim, 2018). A win-lose scenario was only reported once, where extensive mowing of grasslands increased plant biodiversity but also heightened fire risk (Winkler et al., 2021). Other types of relationships, such as neutral-win, were not found.

4. Discussion

4.1. Interpretation of results

We provided the first systematic global analysis on how NbS contribute to biodiversity, analyzing 185 case studies across 87 cities worldwide. The majority of NbS contribute positively to urban biodiversity. Moreover, NbS that also reported non-biodiversity outcomes predominantly demonstrated win–win solutions, i.e. they contributed positively to both biodiversity and human well-being. Underlining these overarching findings, we offer a more nuanced understanding of these outcomes considering specific NbS types, taxa studied, and different dimensions of biodiversity measured. This nuance is essential as urban biodiversity outcomes related to NbS remain limited to a few NbS types, taxa, and metrics, and are understudied compared to other NbS outcomes (Li et al., 2025).

The data considered in our study reveals an emphasis on a limited range of NbS types, specifically gardens, forests, and grasslands, which is consistent with previous reviews on urban NbS and urban biodiversity research (Li et al., 2025; Rega-Brodsky et al., 2022). However, unlike

Rega-Brodsky et al. (2022), who found that urban biodiversity studies predominantly focus on forests, followed by grasslands and gardens, our study found a major focus on gardens. This discrepancy may be attributed to our study's focus on biodiversity as an outcome rather than a feature of NbS. This may have led to the exclusion of broader studies on urban ecology, such as species distribution patterns in urban areas. Compared to Li et al. (2025), parks received less attention in our research, possibly because biodiversity assessments often survey site characteristics such as vegetation coverage, which park-related studies may not specify. Naturalized wetlands and stormwater basins received the least focus on biodiversity, likely because these areas are primarily designed for water-related issues such as flood risks and water pollution (Li et al., 2025). To strengthen the evidence of NbS as multifunctional solutions, and to secure the inclusion of a broader range of NbS in urban planning and policy, further research on NbS for biodiversity is needed on less-studied ecosystem types, such as naturalized wetlands, stormwater basins, and green alleys.

We find that biodiversity outcomes are skewed toward animal biodiversity, a trend consistent with previous studies on urban biodiversity research (Rega-Brodsky et al., 2022) and global species monitoring programs (Moussy et al., 2022). This trend contrasts with studies that assess biodiversity outcomes of NbS addressing climate change (Key et al., 2022), possibly due to their interest in ecosystem services that reduce climate impacts. Moreover, specific animal taxa such as birds, bees, and butterflies received more attention in both science and practice, likely due to their widely recognized roles in ecosystem functioning (e.g., pollination) and social benefits (e.g., recreation, mental health) (Dicks et al., 2016; Kremen et al., 2002; Methorst, 2024).

The relatively limited focus on plants in our database may be attributed to the urban management of ecosystems where vegetation is directly controlled, and most research subsequently evaluates how these changes in vegetation impact various other communities (Faeth et al., 2011; Fig. 3B). In our database, plant-based measurements, such as plant composition, structure, and vegetation coverage, were often used to characterize NbS, rather than analyzing their outcome. Monitoring changes in plant biodiversity is particularly valuable for ensuring long-term effective NbS in sustaining ecosystems and delivering related ecosystem services for people (Seddon et al., 2021), including regulating services such as carbon sequestration and air purification, as well as cultural services such as recreational and aesthetic value in urban green areas.

Our study showed that biodiversity outcomes are predominantly measured on a species level, particularly species richness and abundance. While our research focuses on biodiversity as an endpoint related to specific interventions, habitat attributes or landscape characteristics have been often investigated in ecological studies as influencing factors on species (Beninde et al., 2015). This discrepancy is also revealed in a disconnect in NbS planning, where biodiversity target is often measured based on simplistic and ecosystem-level indicators (Xie & Bulkeley, 2020), in contrast to more comprehensive measurements in outcome evaluations (Marshall et al., 2020; Pierce et al., 2020). Finally, the prevailing use of simple species counts also reflects the greater data availability and the relative ease with which these metrics can be collected and analyzed. This is especially true compared to complex ecological or population phenomena such as mammal persistence probability and regeneration capacity or intermediately complex metrics like functional diversity.

4.2. Multiple outcome metrics for assessing nature-based solutions: biodiversity and beyond

Our findings underscore the critical importance of using multiple outcome metrics to effectively assess NbS performance, specifically for biodiversity. First, biodiversity is inherently multidimensional (Díaz & Malhi, 2022), and multiple metrics are more likely to estimate a complete picture of biodiversity changes (Lyashevska & Farnsworth, 2012; Vereecken et al., 2021). This is evidenced by our data, where most NbS cases used multiple metrics to assess biodiversity, providing a fuller picture and revealing more mixed effects compared to cases relying on a single metric. Potential negative effects might be overlooked if fewer biodiversity dimensions were assessed. Second, evaluating NbS performance requires a broad set of metrics considering the multiple outcomes provided, not just for biodiversity but also for human well-being. Our study reveals that such evidence remains scarce but provides examples of win–win and win-lose relationships between both outcome domains. Measuring a broad range of metrics can be time-consuming and costly, making it critical to select the most efficient ones for biodiversity and beyond.

The three key attributes of biodiversity proposed by Franklin (1988) and Noss (1990), i.e., composition, structure, and function, have been widely used in studies to develop metrics. As suggested by Lyashevska & Farnsworth (2012), selecting one indicator from each of these three key attributes may provide a sufficient approximation of biodiversity with minimum data collection. Furthermore, researchers can rely on finer-scale knowledge on specific taxa and ecosystems to develop metrics tailored to NbS contexts. For instance, Vereecken et al. (2021) cautioned against the limitations of monitoring biodiversity through insect biomass for the conservation of wild bees and Molina et al. (2023) suggested measuring spontaneous plants as indicators of soil functionality and ecosystem functioning. Our study suggests that metrics reflecting the community structure and ecosystem function need further integration in the assessment, alongside the species-level metrics, consistent with previous suggestions (Díaz & Malhi, 2022; Lyashevska & Farnsworth, 2012).

Research should also consider measuring biodiversity within an integrated indicator system to effectively evaluate multifunctional NbS that benefit human well-being. To advance the efficient evaluation of win–win scenarios, developing indicators that connect the values of biodiversity to its broader contributions to people is essential. Particularly, assessing functional trait indicators of studied taxa deserves more attention, as they provide accurate predictions of ecosystem functioning and associated ecosystem services (Cadotte et al., 2011; Yu et al., 2017). Additionally, social valuations of biodiversity need further attention as proxy indicators for well-being benefits; for example, using social value indicators to assess the effects of improved plant diversity on mental health. However, performance of win–win scenarios in NbS depends on multiple contextual factors, particularly the scale of measurements (both spatial and temporal), and geographical climates (Dumitru and Wendling, 2021; Li et al., 2025). For instance, the appropriate time frame for assessing different NbS outcomes varies by indicator (Hutchins et al., 2021): cooling effects are often monitored during the hottest months to capture the peak temperature reductions, while pollinator abundance is commonly assessed in flowering seasons when pollination activity is highest. These phenomena may or may not overlap in time, depending on local contexts. Additionally, assessing an increase of species that produce a high amount of biomass can indicate the risk of fire, although this is only applicable to warm climatic regions (Winkler et al., 2021). Evaluating the successful win–win solutions thus requires a refined understanding of the relations between indicators of biodiversity and its contributions to people while accounting for these contextual factors (Díaz & Malhi, 2022).

These considerations necessitate collaboration between decision-makers, urban planners, ecologists, and local communities to propose context-specific metrics and enable subsequent knowledge sharing. Such integration could lead to the improvement of biodiversity assessment and extend it to the many different facets of biodiversity that are important to biodiversity and human well-being (Pollock et al., 2020).

4.3. Evaluating the performance of nature-based solutions to benefit biodiversity

Our findings reveal that NbS generally contribute to improving biodiversity over non-NbS, and in some cases, NbS performance was comparable to that of natural reference sites, in line with previous studies (Filazzola et al., 2019; Wang et al., 2022). Evaluating biodiversity changes is crucial for determining the success of NbS. In the broader context of NbS, there has been a common thread that creating more habitats is beneficial for urban biodiversity (Beninde et al., 2015). Consequently, urban planning often considers the increasing amount of green in the cities as a major strategy for NbS, such as planting a specific number of trees, and tends to consider such projects as a general success (Seddon et al., 2021). However, simply increasing the amount and extent of greenery does not always translate into positive biodiversity outcomes. The performance of these actions depends on how the addition of green is integrated into the urban settings (Knapp & MacIvor, 2023; Lepczyk et al., 2017). Our study provides a more nuanced assessment of the effects on biodiversity across different NbS.

When comparing the performance on biodiversity and other outcomes across different NbS, it is essential to consider the baseline to accurately inform their success in achieving relevant goals (Maron et al., 2018). In NbS research, non-NbS controls are commonly used to evaluate performance. Compared to a previous study on NbS outcomes, we found that NbS produce less positive effects on biodiversity than on human well-being (Li et al., 2025). The overwhelmingly positive effects of these human well-being outcomes could be explained by the fact that studies focusing on ecosystem services, such as local temperature regulation and flood mitigation, commonly use a baseline that is less likely to provide higher values (Esraz-Ul-Zannat et al., 2024; Veerkamp et al., 2021). Such baselines include unvegetated control sites such as grey roofs and built areas. From the perspective of NbS, such comparisons provide insights into their effectiveness compared to engineered solutions in providing essential ecosystem services (Anderson & Renaud, 2021; Dick et al., 2020). Our findings also indicate that NbS, such as green roofs, constantly present higher biodiversity than engineered solutions or built areas (Fig. 4; Wang et al., 2022).

In contrast to NbS assessments on ecosystem services, studies on biodiversity outcomes often use non-NbS controls with inherent biodiversity value, such as existing forests or vacant lots. This partially explains the trend that negative effects are frequently observed for NbS involving measures taken to manage existing forests. These existing ecosystems are also likely to have had higher biodiversity values before the intervention. Furthermore, studies on biodiversity outcomes also frequently use natural references as baselines for evaluating the performance of NbS, particularly for the restoration of degraded ecosystems that target remnant habitats. When comparing NbS cases to natural reference situations, their biodiversity is generally lower than that of relatively healthier habitats.

While choosing an appropriate baseline is important, choosing one at all maybe even more important. Our study reveals that 61 % of cases did not quantify the outcomes against a baseline situation in their biodiversity assessment, hindering further analysis of their performance. Biodiversity outcomes are more frequently assessed without baselines compared to other outcomes (Li et al., 2025). Future studies should adopt rigorous experimental frameworks that integrate the baseline data to quantify biodiversity outcomes, thereby improving the integration of these findings into NbS strategies and urban planning.

4.4. Implications

When properly designed, NbS can support biodiversity while delivering multiple human well-being outcomes (Seddon et al., 2021). Our research complements previous syntheses of NbS evaluation with a human-centered focus in urban areas. Our focus on biodiversity outcomes contributes to a more balanced understanding of the multifunctional potential of NbS. Our findings indicate that NbS generally reported positive effects on biodiversity, with few instances of negative effects or win-lose situations with non-biodiversity outcomes. However, true multifunctionality studies assessing both biodiversity and human well-being outcomes remain scarce (Li et al., 2025). With the field of NbS assessment expanding, future exploration of relationships between biodiversity and human well-being benefits or ecosystem services would benefit from broader evidence of multifunctionality assessments (Key et al., 2022; Li et al., 2025; Viti et al., 2022). Such research would advance our comprehension of the full potential of NbS as multifunctional and integrative solutions to benefit both biodiversity and people, enabling more effective NbS planning and design (McPhearson et al., 2022).

Our evidence-based research provides valuable insights to formulate more effective urban strategies, with information tailored to their specific interests in biodiversity. Specifically, our findings can guide the selection of NbS that align with their priorities regarding biodiversity dimensions and targeted taxa. For example, gardens and grasslands contribute to the conservation of pollinators such as bees and butterflies. Additionally, extensive mowing of existing ecosystems consistently enhances biodiversity, while soil rehabilitation, in some cases, negatively impacts native species. Such information offers insights into refining the strategies to manage existing ecosystems, particularly important in areas with limited space. Estimates of plant communities are particularly informative in shaping urban greening or re-naturing strategies that rely mostly on planting activities (Threlfall et al., 2016). We recommend that practitioners report specific plant features within their interventions, and researchers to evaluate changes in plant communities over time and assess their cascading effects on non-plant species.

Robust NbS evaluation, which incorporates metrics that reflect diverse values of biodiversity is needed to support urban planning and decision-making (Pascual et al., 2023). This entails consideration of broader social-ecological contexts and the interests of the relevant stakeholders. When developing evaluation frameworks, researchers should be conscious of potential mismatches between the specificity of indicators required for concrete impact evaluation and the openness required for gathering stakeholder support when advocating for an NbS project (Geukes et al., 2024; van Oudenhoven et al., 2018). When biodiversity is included in NbS planning, the goals are often vague and generic, focusing on ecosystem-level indicators, such as the number of green spaces to be created (Pierce et al., 2020; Xie & Bulkeley, 2020). This contrasts with ecological evaluation in urban systems, which often provides concrete information. To prevent mismatches, researchers are advised to utilize metrics that correspond to a wide range of stakeholder interests, including those related to local communities, legislation and policy aims (Geukes et al., 2024). Moreover, this would enable the more optimal alignment of urban NbS evaluation and global frameworks referring to NbS, such as the Global Biodiversity Framework (GBF, target 12; Convention on Biological Diversity, 2024) and comprehensive tools linked to global commitments, like the Urban Nature Indexes (UNI) recently proposed by Pierce et al. (2024). Urban NbS have gained considerable momentum in recent years. Our research provides a way to ensure that biodiversity will continue to be considered in NbS assessment.

5. Conclusion

Our systematic analysis demonstrates that NbS can enhance multiple aspects of urban biodiversity and hold the potential to offer win–win solutions for both biodiversity and human well-being. Current evidence for biodiversity outcomes of NbS in urban areas is limited in terms of NbS types, taxa assessed, and metrics used. Future attention should be given to plant communities, and neglected types such as naturalized wetlands, stormwater basins, and green alleys.

Evaluating NbS performance in delivering desirable biodiversity outcomes and win–win solutions that simultaneously benefit human well-being requires consideration of broader social-ecological contexts and the interests of the relevant stakeholders. This necessitates strong interdisciplinary collaboration to propose context-specific and comprehensive indicators. To capture a more complete picture of biodiversity, metrics reflecting the community structure and ecosystem function need further integration in the assessment, alongside the commonly used species-level metrics. Additionally, developing indicators that bridge the values of biodiversity with its broader contribution to people is efficient to advance the evaluation of win–win solutions. Yet, evaluating the performance of win–win solutions requires refined understanding of relations between these indicators, accounting for varying scales and geographical climates. Future studies should adopt more rigorous experimental frameworks that integrate baseline data to quantify biodiversity outcomes, helping to identify the success of such interventions. Our comprehensive analysis will help to capitalize on the benefits of NbS for both biodiversity and human well-being and guide evaluations to provide actionable insights and information accessible to decision-making and policy.

CRediT authorship contribution statement

Meng Li: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Roy P. Remme:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **Peter M. van Bodegom:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **Alexander P.E. van Oudenhoven:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2025.113523.

Data availability

The data supporting this study are available in the supplementary data.

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