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Status and trends of Germany's urban biodiversity: A nationwide assessment and identified knowledge gaps

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ABSTRACT

Knowledge on the status and trends of biodiversity in urban areas is scattered and biased towards a few taxonomic groups, despite the fact that cities are where most humans get in touch with nature today. As part of the German Biodiversity Assessment ('Faktencheck Artenvielfalt'), we conducted a nationwide review of published studies that recorded species occurrences in urban areas in Germany. We found that urban areas can host a large proportion of all plant, animal, and fungal species found in Germany, thus contributing to the nationwide conservation of biodiversity. However, compared to other habitat types outside of cities, the number of studies analysing the status and trends of urban biodiversity is relatively small. We could not identify a general trend over time for species diversity in German cities, based on the available studies. Even within individual species groups, there are combinations of declining, positive, and/or neutral trends. Information on population trends remains limited. Similarly, evidence of whether urbanisation promotes the homogenisation or differentiation of species groups is weak, with those groups investigated more thoroughly showing mixed patterns. With regard to biodiversity promotion, preserving the environmental heterogeneity that contributes to biodiversity is important,

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such as the maintenance of various habitat types (forests, parks, gardens, ponds, streams, etc.) that offer various food and nesting resources. Hence, the proportion of built-up impervious areas must remain limited, i.e. must not increase, and additional measures to promote biodiversity must be implemented. However, local authorities are largely ill-equipped to systematically monitor species occurrence across the variety of habitat types, or elements of green-blue infrastructure and taxonomic groups in cities. We discuss these findings, considering international urban biodiversity assessments and suggest key attributes of an effective national monitoring system to support urban biodiversity conservation and enhancement.

Introduction

Given the growing proportion of the world's urban population (United Nations, Department of Economic & Social Affairs, Population Division, 2019) and the related increase in soil sealing, biodiversity is threatened in cities (Seto et al., 2012). Nevertheless, urban areas can play an important role for biodiversity because of their environmental heterogeneity and mosaic landscape patterns (Secretariat of the Convention on Biological Diversity, 2012). In Germany, three-quarters of the human population live in cities, suggesting that human-nature relationships are (and will likely be) largely formed in urban areas. Protecting biodiversity in and around cities to also foster human-nature experience is therefore particularly important and constitutes one of the high-level policy targets of the Kunming-Montreal Global Biodiversity Framework (Target 12; Convention on Biological Diversity, 2025).

Many urban areas are located in regions with high primary natural site diversity (e.g., in river valleys, deltas, and areas of high geological diversity; Kühn et al., 2004). As a result, they often overlap with 'hot-spots' of local and regional biodiversity (Ives et al., 2016; Kühn et al., 2004; Seto et al., 2012). Urban areas are also special as a result of the site diversity created by humans. They form a spatially dense, heterogeneous mosaic of built, undeveloped, near-natural, and designed habitats (Kowarik, 1992; Sukopp, 1998). These habitats are further diversified by their variations in use and maintenance, and the preferences of urban dwellers for different species and landscaping elements (Williams et al., 2009). Site diversity results in a heterogeneity of soil properties, hydrological characteristics, and vegetation types. However, increasing pressure from urban development and densification for industrial, commercial, residential, and transportation uses induces a continuing loss of space for biodiversity.

Not every species can withstand urban environmental conditions, meaning that urbanisation induces the loss of maladapted species (called 'urban avoider' or 'urbanophobic species'), while other species are indifferent in their responses ('urban adapter' or 'urbanoneutral species'), whereas a third group even thrives with urbanisation ('urban exploiter' or 'urbanophilic species'; cf. Blair, 1996; Fischer et al., 2015; Wittig et al., 1985). Species found in urban areas consist of a subset of the regional species pool and species from elsewhere whose occurrence is facilitated by humans through trade, traffic, horticulture, and other means of species introduction (Aronson et al., 2016). While urban areas promote the occurrence of non-native (Li et al., 2025) and generalist species (Wenzel et al., 2020; Callaghan et al., 2021), specialist (Hahs et al., 2023) and rare species occur as well (Ives et al., 2016). Individual cities can host high biodiversity as compared to their surroundings (especially when the surroundings are shaped by intensive agriculture that are home to few species only), but species pools of different cities often overlap, even when far apart (e.g., Delgado-Baquerizo et al., 2021; Wittig & Becker, 2010). Still, evidence for urban biotic homogenisation - i.e., an increasing similarity of flora and fauna of cities over time and across the globe (McKinney, 2006) - is mixed and biased both spatially and taxonomically (Lokatis & Jeschke, 2022).

Despite the knowledge that has been gathered on urban biodiversity over the past centuries (Kowarik, 2023), the availability and accessibility of data on urban biodiversity is still limited, with few systematic monitoring systems in place (such as the monitoring of selected species in protected areas of the Natura 2000 Network, including in cities, based on the European Union's Bird and Habitat Directives; cf. Ellerbrok et al., 2025). Those that exist cover various urban habitat types and taxonomic groups, making it difficult to identify common trends across urban areas. Often, knowledge is scattered across different data sources, not all of which are publicly available, and is globally biased towards a few taxonomic groups, especially plants and birds (Rega-Brodsky et al., 2022). However, the protection, management, and enhancement of urban biodiversity requires in-depth knowledge of the status and trends of biodiversity across both taxonomic groups and habitat types, or types of green-blue infrastructure.

In light of the global biodiversity crisis and this fragmented data landscape, the German Federal Ministry of Education and Research (BMBF) commissioned an expert review to synthesise the state of knowledge on the status and trends of biodiversity in Germany, the so-called 'Faktencheck Artenvielfalt' (German Biodiversity Assessment; Wirth et al., 2024; 2025). The assessment was a collaborative effort of 145 authors from research institutions, public interest groups, and government agencies. It focused on Germany's five main habitat types (agricultural and open land, forests, inland waters and floodplains, coasts and coastal waters, urban areas), as well as on soil biodiversity and the overarching drivers of biodiversity change as cross-cutting topics. Most authors of the present paper served as experts for the habitat type of urban areas (with additional authors - CB, JMM, MSp, WERX - opting in for this paper specifically to share their expertise on soil organisms and the Weighted Vote Count analysis - cf. Methods).

Based on the assessment report's chapter on urban areas (Haase et al., 2024), we present main findings on the status and trends of urban biodiversity and its monitoring. The assessment of urban biodiversity was based on the combination of a systematic literature review of published studies with a Weighted Vote Count analysis of trends in species richness, total abundance or biomass, and effective number of species, as well as an assessment of urban Red Lists, and a questionnaire spread among German municipalities on the availability of biodiversity data and biodiversity monitoring efforts. Reflecting on the assessment's results, we ask in this paper:

1. What proportion of the species known to occur in Germany per taxonomic group are found in urban areas?
2. What are the temporal trends in the abundance and species richness of main taxonomic groups in the urban areas of Germany, and which groups show tendencies of biological homogenisation vs. differentiation in response to urbanisation?
3. What is the extent and future development of biodiversity monitoring at the municipal level (cf. Methods for a definition)?

We discuss our findings in the context of international urban biodiversity assessments and suggest key attributes of an effective national monitoring system to support urban biodiversity conservation and enhancement.

Methods

Literature review

Our systematic search in Scopus (Elsevier, 2025) and the Web of Science (WoS) Core Collection (Clarivate, 2025) covered both English and German language publications in scientific journals until 30 April 2022. After several preliminary tests, we developed a search string to identify literature on the status and trends of biodiversity in urban areas in Germany. The search string was composed of four major blocks of search terms, relating to: biodiversity, urban areas, trends, geographical scope (cf. Appendix A). The searches in Scopus and in WoS resulted in 2109 and 1366 publications, respectively. We compiled the results of both searches and removed duplicate records (based on title), obtaining a total of 2545 publications for further analysis. The titles and abstracts of those publications were pre-screened using the ASReview software (version 1.6; ASReview LAB ASReview, 2024). ASReview (van de Schoot et al., 2021) facilitates the pre-selection of publications from a systematic literature search using machine learning. To train ASReview's model, 50 publications were first manually classified as relevant or irrelevant by two members of the research team. Relevance was based on the following criteria:

- Study sites needed to be located completely or partially in Germany, meaning that we included studies that had study sites in Germany only, or across borders in Germany and a neighbouring country, or in several countries, including Germany (in the latter case, if possible, we extracted results specific to the German study sites);
- Study sites needed to be located in urban areas (the definition whether an area is urban was taken from the respective study. No universally valid definition of urban areas exists, but rather, the distinction between urban and rural areas depends on whether it is defined, for example, demographically, morphologically, or functionally; Rega-Brodsky et al., 2022);
- The study needed to deal with status and/or trends of biodiversity.

ASReview then sorted all publications not trained in the model from the highest to the lowest probability of relevance according to the prediction of the publications already considered. The software iteratively sorts publications after each subsequent classification of a publication as (not) relevant by the user.

Pre-screening was carried out until no more relevant publications were suggested; a minimum of 90 publications that were consistently flagged as not relevant was used as a cut-off. Publications considered relevant in the pre-screening were then screened by other members of the research team, based on their title and abstract and by applying the aforementioned criteria. In this step, a total of 1061 publications were selected for full-text screening. In this full-text screening, we identified 76 publications as relevant for our analysis, based on the same selection criteria.

To capture the full set of sources available on status and trends for the manifold taxa found in Germany, we supplemented the peer-reviewed literature covered by Scopus and WoS, and included search engines covering further literature (e.g., Zoological-Botanical Database; ZOBODAT, 2023; cf. Appendix A). Additionally, potentially relevant catalogues of technical and administrative reports or publication series of Germany's environmental agencies and federal research centres (e.g., 'BfN-Skripte' - a publication series of the German Federal Agency for Nature Conservation) and non-peer-reviewed journals (e.g., journal 'Stadt+Grün') were screened (including both publications available online and print-only). Lastly, further literature was added based on the expert knowledge of the authors and of external reviewers who commented on draft versions of the German Biodiversity Assessment report. This additional literature included, amongst others, Bachelor and Master theses, and PhD dissertations listed in public online university databases. Again, it included both digital as well as print-only publications.

From the selected publications, we extracted the following information: data on status (e.g., species numbers) and direction of trends of biodiversity (e.g., positive, neutral, or negative development of species numbers over time), taxonomic group for which status and/or trends were recorded, type of habitat/green-blue infrastructure for which status and/or trends were recorded, urban area(s) the data came from, and whether/what patterns of biotic homogenisation or differentiation were recorded.

Red List assessment concerning the status of urban biodiversity in Germany

In addition to the data on status taken from the reviewed publications, we made use of the Red Lists of endangered taxa specific to a city or metropolitan area. These lists are an important tool for assessing the status of biodiversity as well as monitoring its temporal development. However, they are not available and up to date for every city in Germany (cf. Tab. B.1 in Appendix B) because the respective data is collected at the level of federal states. Therefore, data cannot be clearly associated with a city in a federal state. Still, the two biggest cities in Germany, Berlin and Hamburg, each being a federal state of its own, have individual Red Lists, which provide comprehensive species presence data, not only for threatened species, but for all species recorded in the respective city. The urban areas in the central Ruhr Area, the largest conurbation in Germany, share a common Red List of vascular plants (Verbücheln et al., 2021). From both Red List data and data on status taken from the reviewed publications, we compiled an overview of how many species occur in a city as compared to the species that occur in Germany overall.

Trends in Germany's urban biodiversity

Weighted vote count

From the pool of publications identified as relevant in our literature review, we selected those that contained information on temporal trends of biodiversity. In addition, a call for biodiversity time series datasets was circulated among the 145 authors contributing to the German Biodiversity Assessment. We restricted the trend analyses to those publications that provided data for at least two time periods and to time series datasets with more than two years of data. Moreover, we only considered data (for both publications and time series) from the year 1900 onwards. The biodiversity metrics for which the trends were calculated include total abundance or biomass (TAB), number of species (S), and effective number of species (ENS). ENS is less affected by differences in sampling effort, size of the species pool, and spatial aggregation of individuals (Chase & Knight, 2013), and so is preferable when analysing species occurrence data from multiple sources. From the publications, trends were grouped into categories (i) change to increased numbers = 'positive', (ii) change from negative to positive = 'negative to positive', (iii) no change in numbers, absence of a significant trend = 'no trend', (iv) change from positive to negative = 'positive to negative', and (v) change to decreased numbers = 'negative'. Grouping was based on the statements found in the publications. From the time series, trends were calculated by regressing annual estimates of biodiversity against time. The respective data from both publications and the time series were then analysed using the Weighted Vote Count (WVC) method (Tannenbaum, 2022), which weighs biodiversity metrics by the number of years with data (which is not to be confused with the length of the study - e.g., in a study with a length of six years, where measurements took place in every second year, the number of years with data would equal three). For more details, see Marx et al. (2024).

Red List analysis

In addition to the WVC and data gained through the literature review, we again used the Red Lists of endangered taxa specific to a city or metropolitan area of Germany. We did so because these lists provide information on the long-term population trends of species - in this case, whether a species is categorised as near threatened, vulnerable, endangered, critically endangered, extinct, or data deficient or whether no data is available. We extracted this information to summarise the share of species in Germany's urban areas that belong to each of these categories.

Analysis of biotic homogenisation vs. differentiation

From the pool of publications identified as relevant in our literature review, we selected those that studied biotic homogenisation vs. differentiation. For each of these publications, we recorded: (i) the taxonomic group(s) analysed, (ii) the number of urban areas analysed per taxonomic group, and (iii) the study results, i.e., whether urbanisation was found to promote biotic homogenisation, differentiation, or to have no effect. Based on the number of urban areas analysed per taxonomic group across all relevant publications, we classified the quality of evidence as high (≥ 10 urban areas) or low (< 10 urban areas). In addition, we classified the analyses as comparing: (i) urban and rural areas, (ii) areas within cities, for example, across an urbanisation gradient, (iii) different cities, or (iv) the same city/cities over time. We did so owing to insights of Lokatis and Jeschke (2022).

Questionnaire about biodiversity data and monitoring in German municipalities

In addition to our assessment of the relevant literature, we distributed a questionnaire among the members of the 'Municipalities for Biodiversity' alliance (in German: 'Kommbio - Kommunen für biologische Vielfalt e.V.', Kommunen für biologische Vielfalt e.V, 2025). This network currently comprises >400 municipalities in Germany, and seeks to support its members in promoting biodiversity in urban areas. Municipalities in Germany are the administrative units subordinate to the level of the federal states. They include both urban municipalities (mainly large and medium-sized cities) and municipalities that combine a city (often small- or medium-sized) with their rural surroundings. The questionnaire focused on how well-equipped municipalities are in terms of biodiversity data and whether they plan (further) collection of biodiversity data. Specifically, we asked:

- 'To what extent does your municipality have data on biodiversity in settlement areas? Could you indicate this for the following species groups [plants, mammals, insects, fish, birds, amphibians and reptiles]?'
- 'Are (further) data collections on biodiversity in urban areas planned in your municipality?'

The questionnaire was emailed centrally to all member municipalities (397 at this time) and took place in April and May 2023.

Results

The status of urban biodiversity: share of species living in cities in Germany

Most cities with recorded urban biodiversity have >100,000 inhabitants (meaning that in Germany, they are classified as large cities – so-called 'Großstädte'), but altogether ranging from ~8500 (Ballenstedt) to ~3.6 million (Berlin) inhabitants. The cities with the lowest share still host between 14 % (reptiles in Dortmund; Münch, 2001) and 55 % (mussels in Cologne; Tappert, 1996) of the taxon-specific national species pool. Smaller cities are expected to host lower shares, as exemplified by vascular plant species in Ballenstedt. Here, only 6.5 % of the national species pool have been recorded (Klotz, 1990; cf. Tab. 7.2 in Haase et al., 2024). Overall, we found that across taxonomic groups, the highest share of species has been recorded in the two largest cities, i.e., Berlin and Hamburg (within their Red Lists). According to these Red Lists, individual cities in Germany can have percentages ranging from 15 % (lichens in Berlin) to 76 % (dragonflies in Hamburg) of the taxon-specific national species pool (Fig. 1; see Appendix C for a more detailed description and references). Focusing on the lower end of this range, we mainly find those groups with special habitat requirements, be it high moisture levels or clean air, like lichens and mosses, as well as those groups in which adult individuals are immobile, i.e., plants in general. At the upper end, we find species with water dependency and local area

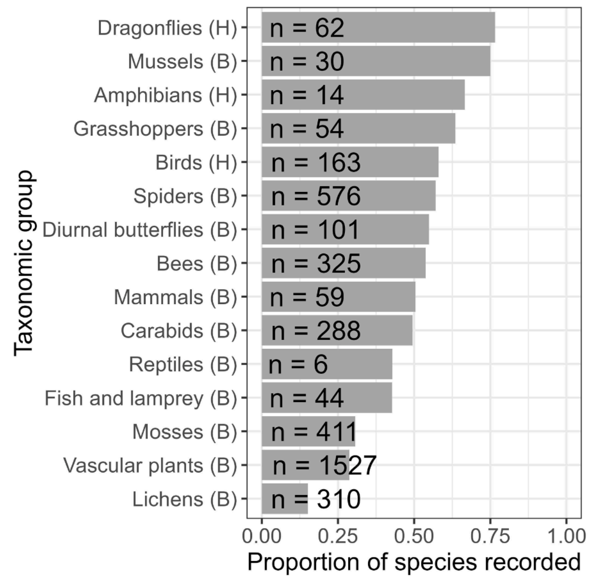


Fig. 1. Overview of selected species groups and their numbers (n) reported for the individual city with the highest species number known (H = Hamburg, B = Berlin, in parenthesis for each taxonomic group). Species are ordered from top to bottom, from highest to lowest proportion of species in the respective city, relative to all the species that are known to occur per taxonomic group in Germany overall. All information is based on species Red Lists (for references see Table D.1 in Appendix D).

requirements, like mussels, amphibians, and dragonflies (but fish and lamprey species are less abundant). Heat-tolerant insects like grasshoppers, bees, and carabids, as well as spiders and birds, form the groups where about 50 % of the species occurring in Germany overall can also be found in cities. Those groups profit from habitat diversity, are flexible generalists, and can cover large areas, like birds and mammals.

Trends in Germany's urban biodiversity

Weighted vote count

Out of a total of 14,901 individual biodiversity trends analysed within the German Biodiversity Assessment (Wirth et al., 2024; 2025), 624 (4.2 %) were related to urban areas. Of these, 510 were derived from time-series datasets and 114 from reviewed literature. Broken down by the main taxonomic groups, 589 trends were related to vertebrates, of which 522 were related to birds, 56 to mammals and 11 to amphibians. There were 21 trends for plants and 14 trends for invertebrates. Of the latter, all were arthropods. The number of years with data per study ranged from two to 39 years, with an average of 9.7 years. The earliest start year of a study was 1900 (few studies exist using even older data, e.g., Knapp et al., 2010b, but we only considered data from 1900 onwards - cf. Methods). The most recent study started in 2019, and the median start year was 2007 (Fig. 2). This means that most studies do not reflect biodiversity changes before 1980 (only 9 % of the studies), and even the beginning of the 1990s is only covered by 13 % of the studies. Remarkably, the duration of observation has an effect on the detection of trends, with an average of 10.2 years for stable/neutral trends, but an average of 15.2 years for both positive and negative trends.

As the number of trends in plants and invertebrates was small, conclusions on trends in these groups would be weak. Therefore, only vertebrate data were further analysed, showing that for roughly half of them, there was no trend (48 % for the number of species, 51 % for the abundance/biomass, and 55 % for the effective number of species; cf. Fig. 2). Negative trends were more frequent than positive trends in the number of species (34 % negative, 18 % positive) and in the effective number of species (27 % negative, 18 % positive), but equally frequent

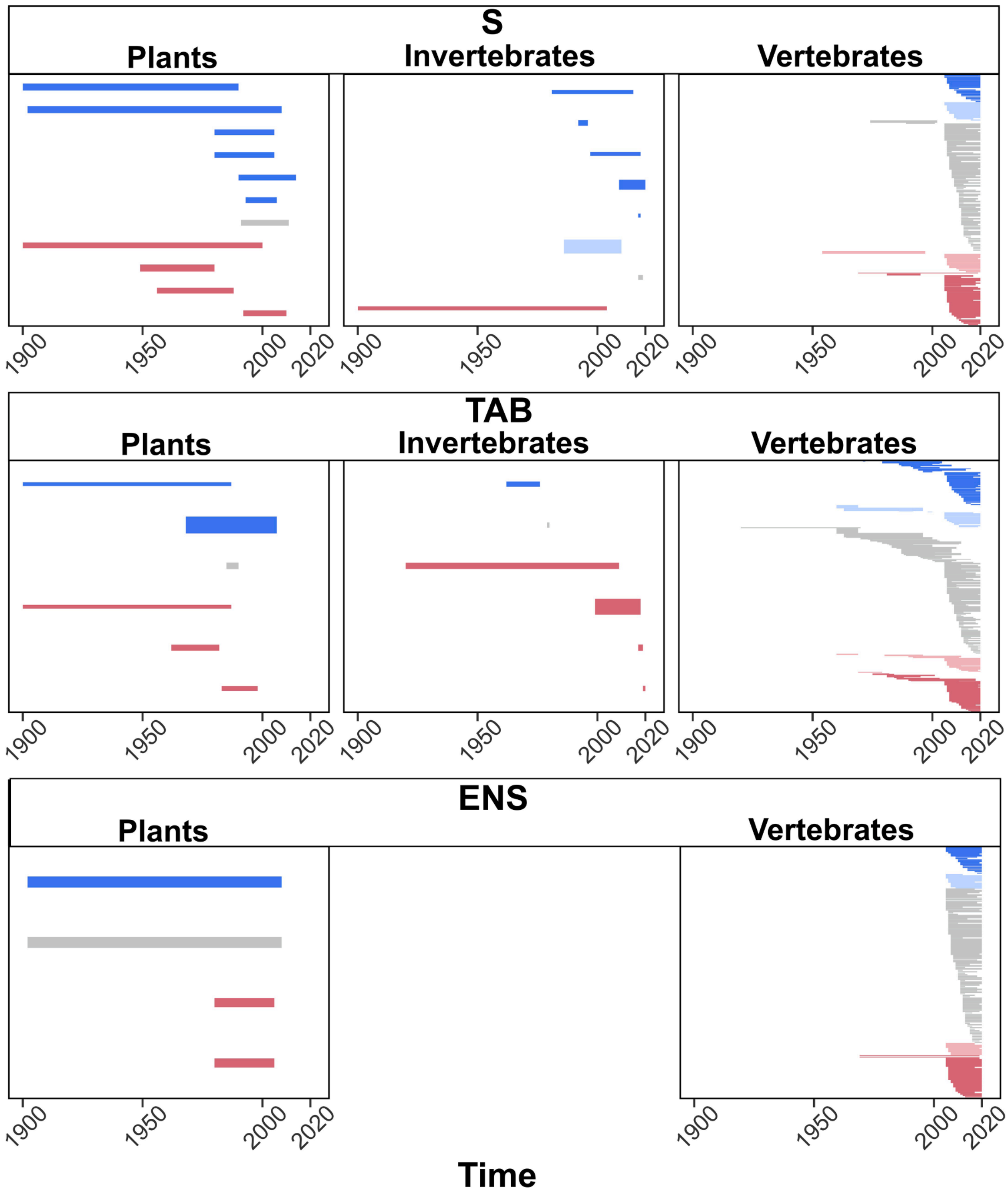


Fig. 2. Weighted trends of the measured biodiversity metrics - number of species (S), total abundance or biomass (TAB), effective number of species (ENS) - for the respective taxonomic group in urban areas. Each horizontal line, irrespective of colour, represents a study; the line thickness is the weighting according to the number of observation years (i.e., years with data; square root transformed). The extent of the line represents the duration of the study from the start year to the end year. The colours represent the trends: positive (blue), change from negative to positive (light blue), no trend (grey), change from positive to negative (light red), and negative (red). 'No trend' indicates the absence of a significant trend. No graph represents missing or insufficient data. The figure is a modified version of Fig. 7.9 in Haase et al. (2024). Colour is only shown in the online version of this article.

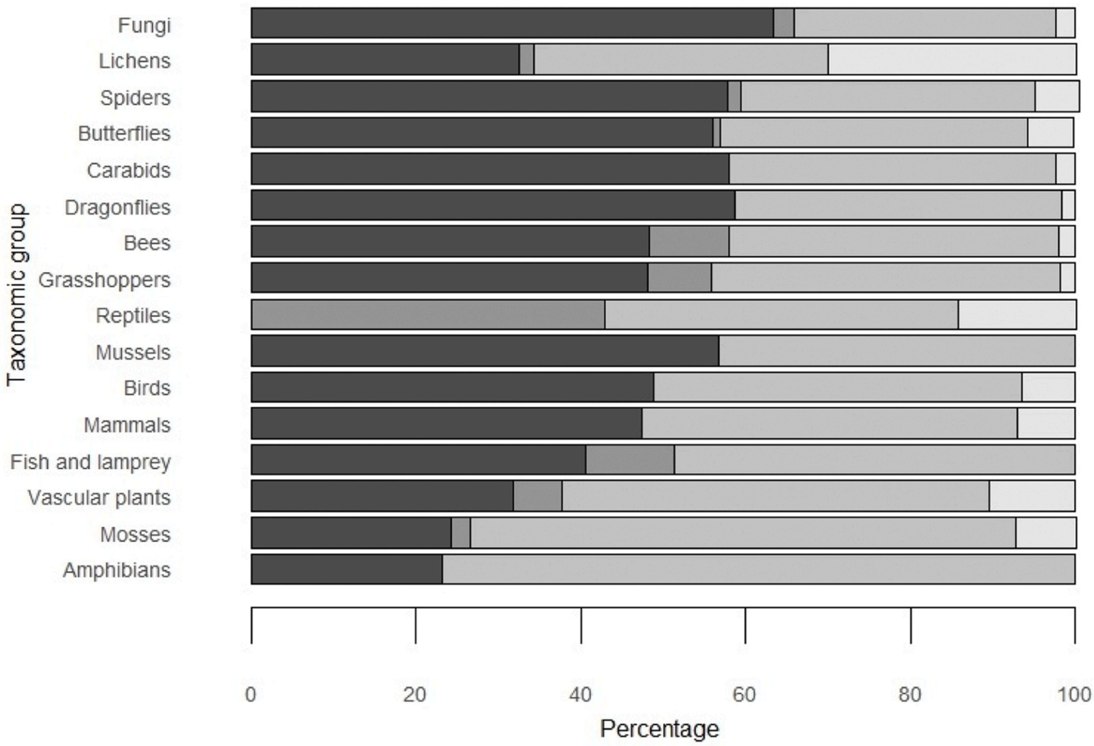
in abundance/biomass (25 % negative, 24 % positive).

Long-term population trends according to Red Lists and literature

Looking at the Red Lists of Berlin and Hamburg, many species populations have been declining, with the number of species being assigned a Red List status (including extinct, critically endangered, endangered, and vulnerable species), ranging from more than three-quarters in amphibians to less than one-third in fungi (c.f. Fig. 3 for trends from Berlin). Beyond Red Lists, data gathered in a consistent monitoring effort across Germany exists for birds. These data show that the population sizes of bird species associated with settlements decreased by 23 % between 1990 and 2018 (Kamp et al., 2021). Still, while bird species that use human buildings for nesting have slightly recovered since 2005 (Kamp et al., 2021), species that mainly nest in forest or scrub show decreasing population sizes in response to urbanisation (Planillo et al., 2021b).

Trends of biotic homogenisation vs. differentiation

Looking at the individual taxonomic groups we reviewed for



	Fungi	Lichens	Spiders	Butterflies	Carabids	Dragonflies	Bees	Grasshoppers	Reptiles	Mussels	Birds	Mammals	Fish and lamprey	Vascular plants	Mosses	Amphibians
Not threatened	63.4	32.4	57.7	56.0	58.0	58.6	48.3	48.1	0.0	56.7	48.8	47.4	40.5	31.7	24.3	23.1
Near threatened	2.4	1.9	1.7	0.9	0.0	0.0	9.7	7.7	42.9	0.0	0.0	0.0	10.8	6.0	2.2	0.0
Red List	31.7	35.6	35.7	37.2	39.6	39.7	39.9	42.3	42.9	43.3	44.6	45.6	48.6	51.8	66.2	76.9
Data deficient	2.4	30.2	5.3	5.7	2.4	1.7	2.0	1.9	14.3	0.0	6.6	7.0	0	10.5	7.4	0.0

Fig. 3. Overview of selected species groups and the percentage of species not threatened, near threatened, or with some threat category in the respective Red List (including extinct, critically endangered, endangered, and vulnerable species), and data deficient. All numbers were exemplarily taken from the respective Red Lists of the city of Berlin and do not include neobiota (see Table E.1 in Appendix E for references). Species are sorted by increasing percentage of red-listed species from top to bottom in the diagram, and from left to right in the accompanying table. Butterflies here refer to Macrolepidoptera.

Germany, most evidence (in terms of the number of urban areas investigated) has been accumulated for vascular plants, dragonflies, and land snails. Depending on the specific comparison, they display varying patterns: For both vascular plants and land snails, non-native species contribute to differentiation, while native species assemblages are more similar across cities (Horsák et al., 2016; Kühn & Klotz, 2006). For dragonflies, Goertzen and Suhling (2019) found that urban areas neither host more similar assemblages nor significantly fewer specialist species than other landscape types but rather tend towards differentiation (but see Willigalla & Fartmann, 2010). Within cities, there is no clear evidence whether highly urban sites promote homogenisation more strongly than less urbanised sites do – rather, different studies come to different conclusions (cf. Table 1).

The state of monitoring urban biodiversity in Germany

Eighty-four municipalities responded to our questionnaire assessing their capacity in terms of biodiversity data and plans for further data collection. Responses show that among the taxonomic groups listed in Fig. 4, data availability in the cities of the respondents is the lowest for fish, and the highest for amphibians and reptiles, birds, and vascular plants. The same pattern applies to data collection planned by these 84 municipalities (Fig. 4). Still, the majority of these municipalities do not plan any (further) data collection.

Discussion

Status and trends of biodiversity in urban areas of Germany

Biodiversity data for German cities is mixed in its breadth of taxonomic groups and species coverage. Nevertheless, we found that some taxonomic groups are well documented in urban areas, and German cities can harbour relatively high proportions of the regional-level or national-level species pool. For example, 93 % of dragonfly species recorded in Germany have been documented in German cities (Goertzen & Suhling, 2015), with up to 76 % of all species having been recorded in one city - Hamburg (Röbelen & Schütte, 2020).

A high number or proportion of species found within cities can be a

Table 1
Main pattern of homogenisation vs. differentiation per species group in urban areas of Germany. Shown are the main pattern and quality of evidence (based on the number of urban areas where patterns of biotic homogenisation have been investigated; cf. Methods), in a combined classification (arrows), type of evidence (i.e., studies are classified as comparing urban and rural areas or areas within cities, for example, across an urbanisation gradient, or different cities, or the same cities over time), and main references. (Goertzen & Suhling, 2019; Horsák et al., 2013, 2016, Knapp et al., 2008, 2010a; Kühn & Klotz, 2006; Lokatis & Jeschke, 2022; Lososová et al., 2012; Meffert & Dziock, 2013; Trentanovi et al., 2013; Werner & Zahner, 2009; Whitehead et al., 2022; Willigalla & Fartmann, 2010, 2012; Wolter, 2010) Upward-pointing arrows indicate differentiation, downward-pointing arrows indicate homogenisation, and arrows pointing to the right indicate a mixed pattern. Light-shaded arrows indicate that evidence is based on < 10 urban areas; darkly shaded arrows indicate that evidence is based on ≥ 10 urban areas.

Species group	**Main pattern/ Quality of Evidence**	**Type of evidence**	**Main references**
Birds	→	*Urban vs. rural; Within city*	Lokatis & Jeschke (2022); Meffert & Dziock (2013)
Mammals	↘	*Within city*	Lokatis & Jeschke (2022)
Fish	↘	*Within city*	Werner & Zahner (2009); Wolter (2010)
Carabid beetles	↗	*Urban vs. rural*	Knapp et al. (2008, 2010a)
Land snails	→	*Different cities; Urban vs. rural*	Horsák et al. (2013, 2016) Knapp et al. (2008, 2010a)
Dragonflies	→	*Urban vs. rural*	Willigalla & Fartmann (2010, 2012); Goertzen & Suhling (2019)
Vascular plants	→	*Different cities; Urban vs. Rural; Within cities (and villages); Temporal*	Kühn & Klotz (2006); Knapp et al. (2008, 2010a); Lososová et al. (2012); Lokatis & Jeschke (2022); Trentanovi et al. (2013)
Lichens and mosses	↘	*Urban vs. rural*	Knapp et al. (2008, 2010a)
Fungi	↗	*Within city*	Whitehead et al. (2022)

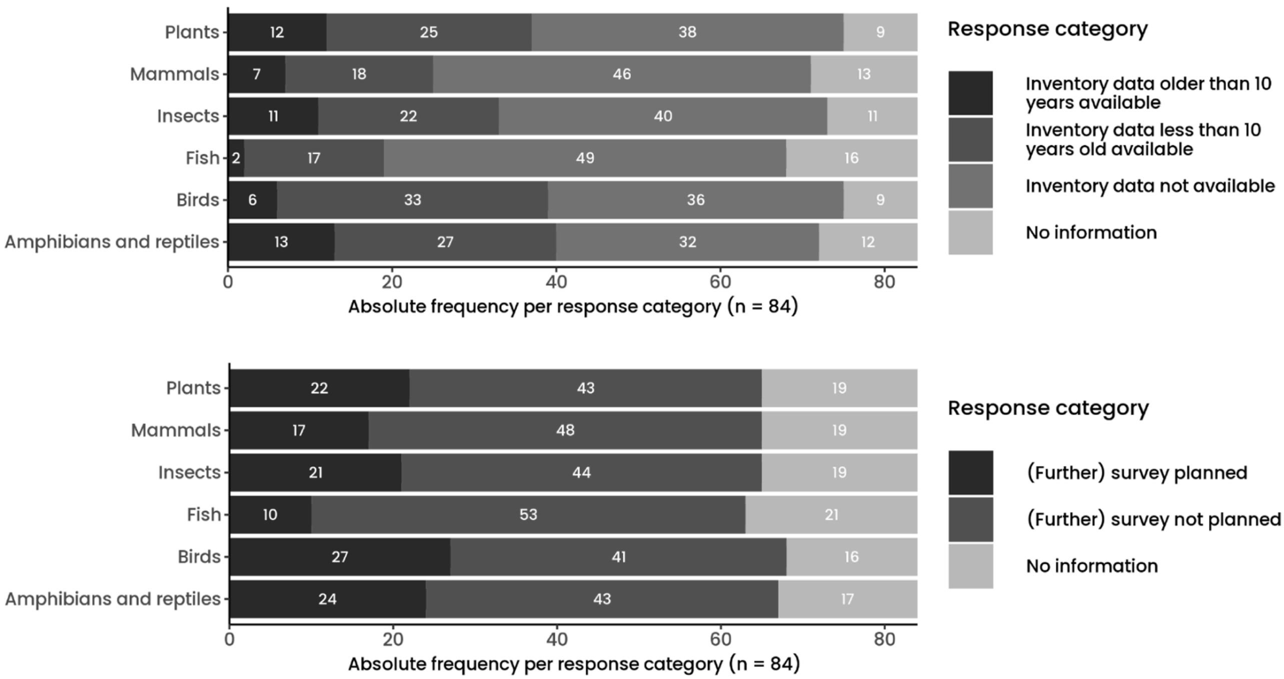


Fig. 4. Results of the questionnaire distributed among members of the 'Municipalities for Biodiversity' alliance regarding the questions 'To what extent does your municipality have data on biodiversity in settlement areas? Could you indicate this for the following species groups?' (top) and 'Are (further) data collections on biodiversity in urban areas planned in your municipality?' (bottom).

product of environmental heterogeneity that provides resources over time and space (e.g., abundant arthropods for birds, high richness and cover of flowering plant species for bees, high tree density, or nesting habitats; see e.g., Gathof et al., 2022; Hülsmann et al., 2015; Planillo et al., 2021a; Weber et al., 2024), but also due to the integration of remnant natural and human-made, horticultural, and urban-industrial ecosystems (Kowarik, 1992). This variety of ecosystems is important for supporting urban biodiversity by hosting a mix of species with diverging habitat requirements - for example, amphibians can inhabit artificial and natural ponds, small temporary water bodies forming in sinks, alluvial meadows and forests, parks, gardens, and wastelands (Holtmann et al., 2018a; Münch, 2001; Plesker & Glatfeld, 1998; Schulte, 2017). Dragonflies benefit from the high structural heterogeneity of urban areas, from many urban areas being located at rivers, and from the presence of semi-natural ponds (Goertzen & Suhling, 2013; Holtmann et al., 2018b). In contrast, a lack of connectivity among habitats caused by high shares of built-up areas, including migration barriers in blue infrastructure such as river damming, and increased loads of pollutants and nutrients in air, soil, and water are obstacles to a range of species groups (see e.g., Buchholz et al., 2018; Fuchs, 2013; Klawitter & Köstler, 2017; Kricke, 2002; Krause et al., 2017; Weber & Wolter, 2017). While there have been improvements in air and water quality that benefit, for example, fish and lamprey species, dragonflies, lichen, and moss (Weber, 2001; Kricke, 2002; Willigalla & Fartmann, 2010; Klawitter & Köstler, 2017; Krause et al., 2017), many of them remain threatened or extinct (for example, in Berlin, 66 % of the moss and 35.6 % of the lichen species; Klawitter & Köstler, 2017; Krause et al., 2017).

Thus, even though it has been widely claimed that urbanisation promotes biotic homogenisation (e.g., McKinney, 2006; Wittig & Becker, 2010), we did not find clear or strong evidence to support the urban biotic homogenisation theory and trend. Across cities in Germany, species diversity may be relatively high within various habitats across the city, and relatively high in comparison to rural counterparts. Goertzen and Suhling (2019) argue that homogenisation occurs in both rural and urban areas, and thus, when comparing the two, no clear distinctions can be found. While their study focused on dragonflies, this might also apply to other taxonomic groups.

Current gaps in knowledge of urban biodiversity in Germany

While we were able to document the share of species living in individual cities in Germany for a number of taxonomic groups, the majority of this data was taken from the Red Lists of Berlin and Hamburg. Data for other cities exists, but for the vast majority - especially small to medium-sized cities - we did not find any published biodiversity data. We acknowledge that our literature review focused mainly on data and publications available through online databases. Therefore, we missed e.g., recent and historic literature published by local and regional natural history (e.g., ornithological or entomological) associations. Moreover, municipalities in Germany are responsible for monitoring selected species within protected areas according to the European Union's Habitats and Birds Directive (European Commission: Directorate-General for Environment, Ecosystems Ltd & Sundseth, 2015), but this does not cover all species across a city, and data is not shared in public databases (Ellerbrok et al., 2025; Moersberger et al., 2024). Better data availability in larger cities might also be driven by the potentially higher density of citizens interested in biodiversity that may participate in citizen science initiatives that contribute to public biodiversity databases (e.g., GBIF).

Urban biodiversity data beyond species Red Lists of cities mainly consist of case studies or observations made at one point in time or over short time periods. Long-term data that could inform about the stability versus dynamics of species populations and assemblages is scarce (but see Kowarik & von der Lippe, 2018; Kamp et al., 2021). Data bias further reduces the informative value of the available time series: For example, almost 90 % of the vertebrate data that we included in the WVC was bird data, reflecting patterns in the international urban ecology literature (Rega-Brodsky et al. 2022) and in the biodiversity monitoring data at European scale (Moersberger et al. 2024). Interestingly, the majority of the trends we identified for the groups with a relatively high amount of data were neither strictly positive nor negative (birds in WVC, dragonflies, snails, and vascular plants in terms of homogenisation vs. differentiation). More long-term data is needed across cities and taxonomic groups to reliably identify trends in urban biodiversity, to conclude on strengths, weaknesses, and gaps in species conservation, and to derive targeted conservation measures.

While a number of conservation measures have been implemented in the urban areas of Germany (e.g., protected areas, wildflower strips in parks and along streets, extensive meadows in parks, nest boxes; Haase et al., 2024), and several municipalities in the 'Municipalities for Biodiversity' alliance (Kommunen für biologische Vielfalt e.V, 2025) regularly share best-practice conservation measures among their members, the effectiveness of these measures is rarely monitored (as shown by the replies to our questionnaire distributed among 'Municipalities for Biodiversity'; Fig. 4). Expert and volunteer observations provide some evidence, but this is restricted to selected conservation measures. For example, different green roof types have been tested for their effects on biodiversity (Köhler, 2006; Köhler & Poll, 2010; Ksiazek-Mikenas et al., 2018; Schrader & Böning, 2006), and the effectiveness of extensive mowing, as well as the expansion of protected areas for biodiversity conservation have been well documented (Watson et al., 2020). While species inventories exist for old cemeteries (Buchholz et al., 2016; Buch et al., 2025), private (Müller, 2009) and community gardens (Neumann et al., 2024), allotments (Cabral et al., 2017), parks (Kümmerling & Müller, 2012; Matthies et al., 2015), industrial brownfields (Keil, 2019), and more urban habitat types, these are often restricted to individual urban areas (i.e., one city) and taxonomic groups. Also, comparisons of the effectiveness of conservation measures among urban habitat types are lacking (e.g., urban grasslands, Fekete et al., 2024). Currently, municipalities in Germany strive to adapt to climate change through various policies, planning, and practical measures (Lebrun et al., 2021), including enhancing or managing blue and green infrastructure for climate change at its (forecasted) extremes (Schubert et al., 2023). However, biodiversity conservation usually is not in the focus of climate adaptation, and potential synergies might be missed (Hansen et al., 2023; but see e.g., Bruchmann et al., 2024; Röseler et al., 2024), i.e., designing climate-proof blue and green infrastructure in the most biodiversity-friendly way and explicitly promoting biodiversity where its positive effects on climate adaptation are known.

Towards a nationwide monitoring of urban biodiversity

In summary, our assessment of the status and trends of biodiversity in Germany's urban areas reveals a lack of systematic, standardised monitoring procedures for many taxonomic groups within diverse urban ecosystems. In particular, baseline data and continuous monitoring and observation are needed to identify patterns and trends in biodiversity. To date, existing databases, reports, and studies are fragmented, often operate at different scales, use different recording methods, and cover different time periods. Much of the data is inaccessible or only partially accessible in online public databases to scientists. This provides an insufficient foundation for addressing the global biodiversity crisis at local and national levels, and for evaluating the effectiveness of conservation efforts (Moersberger et al., 2024).

To enhance scientific understanding of the state and trends of urban biodiversity and to collect more evidence of the impact of urban conservation measures, we suggest to follow the guidelines proposed for the European scale, namely '[…] improving coordination and collaboration, standardising data collection and sharing, employing novel technologies, increasing financial resources, and enhancing capacity building and stakeholder engagement.' (Moersberger et al., 2024: 8). This is particularly true in a federal system such as Germany, where the 16 federal states sometimes have significantly different monitoring systems and varying levels of data availability.

Better coordination and collaboration include identifying synergies among existing monitoring programmes that involve urban areas. It also involves strengthening these programmes by connecting biodiversity data collected by different societal groups - administration, associations, planning offices, (natural history) museums, science, citizen science, and the general public (e.g., through the use of species identification apps) from the local to the national scale. Scientists can facilitate stakeholder involvement and co-design data sharing standards, e.g., through a data portal where all biodiversity data can be stored. Ideally, the results of all biodiversity monitoring efforts (including urban and other monitoring programmes) should become openly available in one data portal. Recently, the National Monitoring Centre for Biodiversity (Bundesamt für Naturschutz (BfN), 2025a) was established in Germany, aiming, amongst others, to better connect different stakeholders and to bundle monitoring data. Moreover, new online data portals were launched that could become central hubs for biodiversity data, in particular umwelt.info (Umweltbundesamt, 2025) and with GBIF, an international biodiversity data portal exists (GBIF.org, 2025). Initiatives such as NFDI4Biodiversity (GFBio e.V., 2024) aim to train and connect scientists and other actors that are involved in biodiversity research and monitoring in data management and data literacy. FAIR data principles (Findable, Accessible, Interoperable, and Reusable) should be promoted and mainstreamed across municipalities. Data created by, for example, scientists should be easily accessible, but also data collected by governmental agencies for administration should be easily accessible by scientists for synthesis analyses. Evidence on the status and trends of biodiversity, as well as on the impacts and effectiveness of conservation measures would be strengthened through such a combination of data from different sources. Also, collaboration among societal groups, including practitioners, should be strengthened.

In addition to synergistically combining existing data, urban biodiversity should be monitored on a regular, long-term, standardised basis. This should include monitoring essential biodiversity variables, i.e., variables informing about genetic composition, species populations, species traits, community composition, and ideally also ecosystem functioning and ecosystem structure (Pereira et al., 2013). Additionally, drivers of biodiversity (both direct - e.g., degree of sealing, management intensity, green space visitor density, light pollution, climate - and indirect drivers - e.g., urban land-use planning and development) should be monitored. Monitoring should cover a broad range of taxa, including soil organisms, as well as the full range of ecosystems occurring in urban areas (remnant natural and human-made, horticultural, and urban-industrial; Kowarik, 1992). A first step in creating such monitoring should be to bring representatives of the societal groups mentioned above together, to identify their needs in terms of urban biodiversity monitoring (cf. Moersberger et al., 2024), and to co-create a harmonised monitoring programme. Standardisation can build on experience gained in 'Stadtbiotopkartierung' ('Biotope Mapping in Populated Areas'), which was introduced in the 1970s as guidance for monitoring, even though its implementation was not completely harmonised across Germany (Müller & Werner, 2024). Tools to support monitoring could include automated monitoring techniques (e.g., passive acoustic monitoring, camera traps, remote sensing, and DNA barcoding). For example, species-specific passive acoustic bird-monitoring has been tested in the federal state of Baden-Wuerttemberg in southwestern Germany (Holderried et al., 2025). However, with the increasing amount of data that can be collected through automated and affordable monitoring techniques, analytical approaches must also keep pace to effectively process and analyse this data for biodiversity assessments and conservation planning. In this respect, deep learning tools offer promising options (e.g., for the identification of indicator species; Basavegowda et al., 2024). Similarly, DNA barcoding has been successfully applied in the identification of invasive alien plant species of European Union concern from cut lawn grass in an urban setting in Italy (Frigerio et al., 2024), and it supported the identification of native and non-native amphipods in urban freshwater systems in the Ruhr Area (Grabner et al., 2015). In terms of capacity building, science in cooperation with (e.g., ornithological or entomological) associations, nature conservation administration, and planning offices could offer training in taxonomic knowledge and in the application of (innovative) monitoring technologies (Silbernagl, 2022).

Some biodiversity monitoring programmes already exist in

Germany. For example, the majority of the bird data we analysed in the WVC originates from the monitoring of common breeding bird species, which is done annually on 2637 plots of 1 km^2 size distributed across the country (Dachverband Deutscher Avifaunisten (DDA) e.V., Dachverband Deutscher Avifaunisten DDA e.V. 2025). These plots are not restricted to, but do include, urban areas. Similarly, vascular plant species have been monitored within a nationwide grid (including urban areas), resulting in the database FLORKART (Bundesamt für Naturschutz (BfN), 2025b) hosted by the German Federal Agency for Nature Conservation. However, within FLORKART, temporal data is scarce and spatial resolution is too coarse for detailed research on inner-urban biodiversity. Butterflies have been monitored within the citizen science project 'Tagfalter-Monitoring Deutschland' (Helmholtz-Zentrum für Umweltforschung GmbH - UFZ, 2025; Feldmann et al., 2005) since 2005, with monitoring transects covering different types of landscapes, both outside and inside urban areas. A national insect monitoring scheme is in preparation (Bundesamt für Naturschutz (BfN), 2025) , as for bats (https://batlas.info/), and a national assessment of soil biodiversity has been suggested (Guerra et al., 2024). At the scale of federal states, species from a range of groups are monitored regularly to update Red Lists (cf. Methods). For urban areas, existing Red Lists should be updated regularly, and they should be extended to more cities of diverse climates, sizes, and urbanisation histories and patterns, as well as more taxonomic groups (cf. Table B.1 in Appendix B). The existing monitoring schemes should be integrated when designing an urban biodiversity monitoring scheme in order to learn from them, to create synergies, and to combine so-far fragmented data.

It is clear that the proposed efforts require adequate funding. However, if the societal groups involved in biodiversity monitoring join forces and make use of synergies, partly, existing funds can be involved.

Conclusions

The current state of knowledge on urban biodiversity in Germany is mixed: while some taxonomic groups are well-documented and show that cities can host a significant proportion of the national species pool, many taxonomic groups and cities remain insufficiently studied. A major challenge is the lack of systematic and standardised long-term monitoring programmes across a broad range of cities, including smaller settlements, to reliably capture urban biodiversity trends across a variety of urban landscapes and habitat types. Another critical gap is the limited accessibility and standardisation of already existing biodiversity data. Improved coordination and collaboration between the federal government, the federal states and municipalities, as well as different groups such as scientific institutions, governmental agencies, conservation organisations, and citizen science initiatives, are essential to address this issue. Furthermore, fostering modern technologies, such as remote sensing, DNA barcoding, and acoustic monitoring, alongside the establishment of a central data platform following the FAIR principles, would significantly enhance data collection and the monitoring of urban biodiversity trends across Germany. Additionally, existing national and local monitoring programmes should be better aligned and supported by adequate funding to guarantee long-term monitoring. By enhancing monitoring efforts, improving coordination and cooperation, and ensuring sufficient funding, it is possible to build a more robust and evidence-based foundation for informed biodiversity conservation and policy-making for German cities and settlements.

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Data availability

All literature selected for the German Biodiversity Assessment (Wirth et al., 2024; 2025) will be made available online in a literature database (work in progress; FEdA, 2025). The database includes the references to the selected literature, and, if applicable, information on type of habitat, ecosystem, and land use, location, climate, taxonomic group, type of biodiversity measure, related ecosystem services, direct and indirect drivers of change in biodiversity, measures to protect biodiversity, type of study, type of method, spatial grain/ extent, and study period. When searching the literature database for studies on urban areas, a filter for 'Lebensräume' = 'Urbane Räume' should be used.

CRediT authorship contribution statement

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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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Supplementary materials

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