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Review Article

Status of urban ecology in Africa: A systematic review

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HIGHLIGHTS

- African urban ecology is understudied.
- There are important geographic, ecological and scientific biases.
- Urban ecology is significantly more studied in wealthier African countries.
- More urbanized areas (now or in the future) are not the main focus of study.
- We need to redirect our priorities regarding urban ecology in Africa.

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ABSTRACT

Urbanization is an extreme human activity and is expanding worldwide, consequently increasing the attention of scientists across research areas of urban ecology. Recent studies have warned of the lack of information from certain regions, particularly Africa, which is rapidly urbanizing. Thus, we did a detailed literature search to determine the state of knowledge in African urban ecology in the last century. We found 795 relevant papers from where data were collected and tested to understand geographic and ecological mismatches in research effort, allowing us to identify important knowledge gaps (e.g., taxonomy and scientific fields). We also tested the effect of current and future urbanization intensity, human population density, size and conservation status of ecoregions and Gross Domestic Product (GDP) on research effort. Our results suggest a low turnout of papers and a dearth of knowledge about African urban ecology. Studies were conducted in 72% of African countries, with South Africa alone accounting for almost 40% of all published papers. The studies were either conducted at the city (55%) or local/country (34%) level, suggesting the lack of transnational research collaboration. Interestingly, only country GDP and the size and conservation status of ecoregions significantly predicted the number of publications, suggesting that research effort is driven by economic reasons and the relevance of conservation in African urban ecology. We need to account for these biases to advance our understanding of the impacts of urbanization on African biodiversity.

1. Introduction

Rapidly expanding urbanization is a major threat to nature worldwide, leading to the reduction of biodiversity and alteration of species interactions and ecosystem services (Gaston, 2010; McDonald, Kareiva, & Forman, 2008; McKinney, 2006; United Nations, 2016). The impacts of urbanization could be even worse in the near future due to the geometric progression of human population. According to the United Nations (2019), the global human population density will increase from 60 humans/km^2 in 2020 to 78 humans/km^2 in 2050, while the global urban land cover will increase from 824,200 km^2 to 1,145,698 km^2 during the same period (Angel et al., 2011). Thus, research on urban ecology is imperative to achieve sustainable development, allowing for the understanding of ecological processes in urban areas and providing necessary data for urban planning, landscape design, policy formulation and biodiversity conservation (Corbyn, 2010; Moragues-Faus & Carroll, 2018).

Given the availability of various definitions of urban ecology, we follow the scientific proposition that incorporates the 'interaction of organisms, built structures and the physical environment where people

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are concentrated' (Forman, 2014). Due to the transformative potential of urbanization, the concept of social and ecological integration (inclusiveness) has been proposed to enhance biodiversity in urban areas (e.g., Haase et al., 2017). For instance, Ferketic et al., (2010) demonstrated the usefulness of inclusiveness in promoting conservation justice in Cape Town (South Africa), thereby influencing the ecology of the city, and an understanding of such a nexus is useful to design resilient and sustainable urban areas (Childers et al., 2015; Grimm et al., 2008).

The globally recognized multi-disciplinary fields and the embedded scientific topics in urban ecology have attracted increasing attention from researchers (e.g., Anderson et al., 2013; Cilliers et al., 2013; Girma et al., 2019). However, several papers have highlighted important knowledge gaps across regions, taxa and scientific topics (e.g., Magle et al., 2012; Tóth et al., 2020; van der Walt et al., 2015). Probably, one of the most important mismatches between urban ecology research effort and the urbanization process is the lack of knowledge on the topic from the most rapidly urbanizing continents of South America, Asia and Africa (Ibáñez-Álamo et al., 2017; Seto et al., 2012; Shackleton et al., 2021). As identified in these studies, geographic biases impede the full comprehension of the real impacts of urbanization on nature. Future studies conducted in appropriate areas will therefore be useful to determine ameliorative strategies needed to promote the co-existence of humans with nature, thereby enhancing urban habitats and the associated biodiversity, which is in line with the 11th Sustainable Development Goal of the United Nations (2021).

Literature reviews provide an opportunity for summarizing the state of evidence-based knowledge applied in many fields (e.g., Ibáñez-Álamo et al., 2017; Magle et al., 2012). Broadly, this involves the incorporation of published literature in any given field (Garousi et al., 2019). However, the generalization and application of findings from literature reviews in decision-making have been a subject for debate, mainly due to transparency, objectivity, repeatability and credibility (Sánchez-Tójar et al., 2020). Since traditional approaches to literature reviews are prone to errors (Grant & Booth, 2009), rigorous methodological approaches have been developed and applied more recently in the field of urban ecology (e.g., Cilliers et al., 2018; Kendal et al., 2020; Ibáñez-Álamo et al., 2017), allowing for an important advancement in our understanding of the effect of urban areas on organisms.

In the present study, we conducted a systematic literature review to determine trends in urban ecological research conducted in Africa. Relative to other regions such as Asia, Europe and North America (Forman, 2016; Lin & Grimm, 2015; Magle et al., 2012; Wu et al., 2014), there have been few attempts aimed at synthesizing the state of knowledge in African urban ecology (e.g., Cilliers et al., 2013; Shackleton et al., 2017; Lindley et al., 2018; du Toit et al., 2018). Our aims were to (i) analyze the current status of research effort on urban ecology in this continent, (ii) identify research gaps (geographic, taxonomic and ecological) and (iii) provide recommendations and insights on future prospects. Additionally, (iv) we investigated the potential association of urban ecology research effort with some factors previously associated with the number of scientific publications. On the one hand, we tested whether the number of publications in the field (i.e., urban ecology) per country could be influenced by human population density, economic wealth, as well as the current or future urbanization prospects. Given the positive association between human population density and the degree of urbanization (e.g., Gao & O'Neill, 2021; Qizhi et al., 2016), we would expect that countries with high human population density would hold the majority of studies in urban ecology. Furthermore, if urban ecology research effort is driven by the intensity of urbanization, based on the scientific reasoning of geographic focus areas of particular interest, we could predict a positive association of the number of publications on this topic in those countries currently more urbanized or with the highest rate of urban expansion (i.e., future urbanization). Although the relationship between urbanization and economic growth is often contested (e.g., Chen et al., 2014; Moomaw & Shatter, 1996), we would expect that wealthier countries (i.e., higher Gross Domestic Product –GDP–) are those concentrating the majority of urban ecological studies as increased funding positively influences publication rates (Man et al., 2004). On the other hand, we also tested whether the number of publications in the field could be influenced by the conservation status and size of African ecoregions. Previous reviews have pointed out the positive association between the conservation status of study sites and research effort (e.g., de Lima et al., 2011). Thus, if research effort is based on conservation-oriented reasons, we would expect that threatened ecoregions will be more studied. In addition, since smaller areas generally support lower species richness (see Rantalainen et al., 2005), we would expect that larger ecoregions will provide more study opportunities for researchers specializing in different species and scientific topics, and will therefore be more studied. Considering the marked differences between Global North and Global South urban settings (Shackleton et al., 2021), we acknowledge that there could be other factors (e.g., climate severity, colonial history or high diversity in human-nature interactions) shaping the urban ecology research effort in Africa, which is considered part of the Global South. However, we did not include them because of the difficulty of extracting such information and to avoid over-parameterization of models. Findings of this study will provide additional information about African urban landscapes that should generate interest among researchers, conservation practitioners and policy-makers.

2. Methods

2.1. Bibliographic search and paper screening

We performed a literature search in Web of Science, Google Scholar and Scopus on 8 March 2021 using different combinations of 89 relevant keywords within the article titles, abstracts and keywords, covering the period 1920–2020. The search string containing research focus (23 keywords; e.g., ecology, biodiversity and wellbeing) and urban terms (5 keywords; e.g., urban, city and town) were matched with region (Africa and country name). We performed independent searches for each of the 58 countries and autonomous territories in the continent. A detailed description of these search terms, and the relevant Web of Science categories (41) and Scopus study fields (10) selected can be found in Table S1. The relevance of the use of such comprehensive keywords has been demonstrated by previous studies (e.g., Raji & Downs, 2021; Roy et al., 2012; Tan & bin Abdul Hamid, 2014).

We then uploaded all detected papers on Rayyan (https://www.rayyan.ai/) for screening. Rayyan is a web-based App that uses a semi-automation process to screen paper's preliminary pages with a high degree of precision (Olofsson et al., 2017; Ouzzani et al., 2016). Its adaptability and many functions allow the detection of duplicates, verification, collaboration and decisions in systematic reviews (Abreha, 2019; de Keijzer et al., 2016). In the present study, both authors independently performed the paper selection process by activating the "blind function" in Rayyan and reached a consensus thereafter.

Our selection process followed the Preferred Reporting Items for Systematic Reviews and meta-analyses (PRISMA Statement) (Abreha, 2019; Moher et al., 2009), which is presented in Fig. 1. Based on article titles and abstracts, we first excluded duplicates, non-African studies and investigations carried out outside urban settings. We also excluded papers on human diseases, climate change, pollution and agriculture when they were exclusively focused on clear different disciplines, such as malaria studies exclusively focused on the medical science (e.g., Kigozi et al., 2020) or agricultural papers investigating different crop varieties without any socio-ecological, biodiversity or human dimensions focus (e.g., Kent et al., 2001). Several systematic reviews already exist on these disciplines (e.g., Fayiga et al., 2018; Hulme et al., 2001; Orsini et al., 2013). The remaining articles were then screened and those that met the following criteria were retained for data extraction: (1) urban landscape, ecological and sociological studies, (2) journal articles

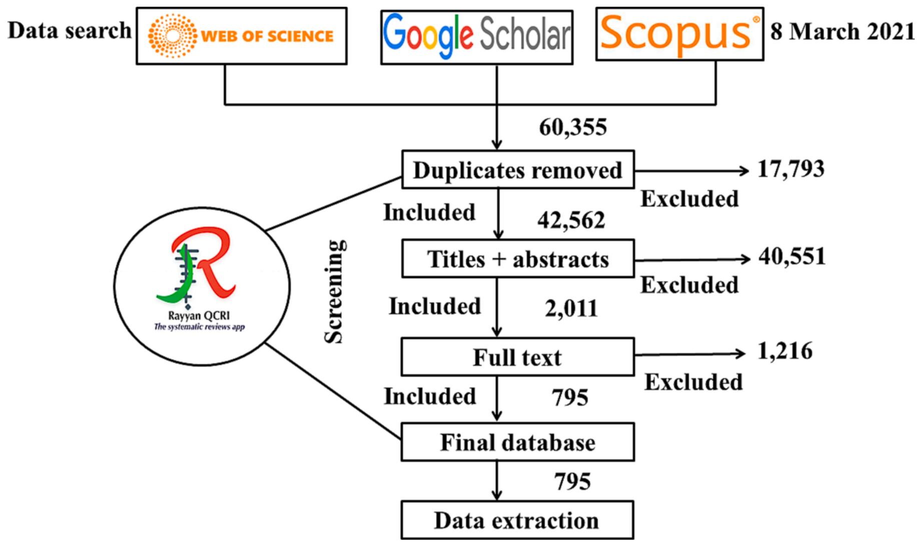

Fig. 1. PRISMA flow diagram for determining the state of urban ecology in Africa using the Rayyan Software.

published in English, (3) peer-reviewed as a first step towards quality control (Beninde et al., 2015; Raji & Downs, 2021), and (4) biodiversity conservation studies (including pet animals and introduced species).

2.2. Data extraction and categorization

We extracted the following data from each included paper: title, year of publication, journal, country of study and study sites. We then classified each paper based on type (field study, review or perspective) and scale, which included city (conducted in a single city), local (involving more than one city in a country), regional (involving more than one African country) and global (involving more than the African continent). Further, we followed the classification of Magle et al. (2012) to allocate each paper to one of the following scientific fields, including animal behavior, community ecology, conservation, human dimensions, human-wildlife conflict, landscape ecology, population ecology, wildlife disease and wildlife management. For taxonomic studies, we extracted information on the kingdoms and classes of focal species based on the classification of the Global Biodiversity Information Facility (GBIF) (GBIF, 2021; accessed May 2022).

With the exception of reviews and perspectives, we obtained the coordinates of all 1405 African study sites included in the selected papers by using Google Earth. This ensured conformity and completion given that the coordinates of some sites were either not originally provided in the papers or were presented in different formats. We then obtained information on all terrestrial ecoregions found in Africa from the World Wildlife Fund for Nature (WWF: Olson et al., 2001). Further data on the ecoregions, including size, conservation status and the biome they are located in, were also collected (Burgess et al., 2004). In addition, we obtained data on urbanization intensity and urban land cover (2015) across the continent, as well as the total population (2015) and total land area of each studied country from Africapolis (OECD/SWAC, 2020; accessed 9th June 2021). Urban land cover was used as a proxy for country urbanization intensity, while the total population was divided by the total land area to obtain the population density of each country. We then overlaid the study sites across ecoregions and urbanization intensity, as well as urbanization intensity across ecoregions, using QGIS (version 3.24 Tisler). Africapolis is the single most important and comprehensive geospatial database on cities and urbanization dynamics in Africa, which incorporates data on demography, satellite and aerial imagery and other cartographic sources (OECD/SWAC, 2020). To investigate urbanization prospect based on the urban land cover, data on the average annual rate of change of the percentage urban expansion by country (2015–2050) were integrated (United Nations, 2018). The Gross Domestic Product (GDP 2020; US$) of each studied country was also extracted from the National Accounts Section of the United Nations Statistics Division (accessed 6th May 2022).

2.3. Statistical analyses

All analyses were carried out using R Version 1.4.1717 (R Core Team, 2016). We performed descriptive statistics using the number of published urban ecological studies to determine temporal and spatial trends in urban ecological knowledge across years, countries, study scales, scientific fields, journals, and taxonomic kingdoms and classes.

We first used the number of published urban ecological studies (hereafter: research effort) per country as the response variable to test the effect of urbanization intensity, urbanization prospect, human population density and GDP using general linear models (LM). We used the "performance" package to check for multi-collinearity among the independent variables (Bernat-Ponce et al., 2021; Lüdeck et al., 2021) and tested the normality (Shapiro & Wilk, 1965) of the dependent variable ($p < 0.05$). The independent variables had low correlation (Variance Inflation Factor < 5) and, consequently, were all included in the models, but research effort was log-transformed to obtain reasonably normally distributed residuals from final models, and models that did not violate LM assumptions when examined visually as diagnostic plots (Crawley, 2013). Using the stepwise backward selection method (Crawley, 2013), variables with the highest p values were removed and the procedure repeated until the best model was selected as the one with the lowest Akaike Information Criterion value (Burnham & Anderson, 2002). Statistical significance was set at p value < 0.05. We also conducted a sensitivity analysis (Moher et al., 2009) due to the disproportionate weight of South African studies in our database, causing outliers. Of the overall 710 field studies that mentioned the 42 African countries represented here, 313 (44 %) were from South Africa. The second model therefore incorporated the same variables as the first but without South African papers.

Secondly, we tested for mismatches in the distribution of research effort across ecoregions. Note that this information could not be combined with the one collected at the country level and thus requires for an additional model to be tested. Given that research effort was not normally distributed ($p < 0.05$) even after log-transformation, we built a separate model using Poisson Logistic Regression to test if the size and conservation status of ecoregions (factor: Critical, Endangered, Vulnerable, Relatively Stable or Relatively Intact) influence research effort. We then conducted a Tukey post-hoc test for a pairwise comparison across the different categories of conservation status using the package "emmeans" (Manley et al., 2015; Yvoz et al., 2020).

3. Results

Our search string detected a total of 60,355 papers out of which 17,793 duplicates were removed. The output of the remaining processes of Rayyan screening led to the retention of 795 papers considered in this review (Fig. 1). Out of them, 691 (87 %) were field studies, 90 (11 %) reviews and 14 (2 %) perspectives, all of which were published in 377 journals (Table S2). The first urban ecology studies focused on Africa date back from the 1970s (Okpala, 1978; Hugo, 1979), but the publication rate on the topic was slow (<10 papers/year) until 2006 when an exponential growth started, culminating in 126 papers published in 2020 (Fig. 2). From a geographical point of view, we found studies from 72 % of the countries that make up the African continent (42 out of 58 countries and autonomous territories; Fig. 3). However, a single country (South Africa) published 4 out of every 10 papers on the topic (N = 313), with the highly-urbanized and biodiversity-rich countries of tropical regions of the continent recording little (<40 papers; e.g., Democratic Republic of the Congo and Kenya) or even no urban studies (e.g., Angola and Liberia; Figs. 3 and 4) for the period of study (1920–2020). Furthermore, papers found in our literature search showed that most urban ecological research in Africa (89 %) was performed within countries, either focused on a single city (N = 434; 55 %) or conducted locally (N = 270; 34 %). We identified very few international research as only 4 % of the studies were carried out regionally (i.e., including more than one African country; N = 29) and only 8 % were coordinated at a global scale (i.e., including data from other continents too; N = 62).

The result of the LM analysis for all countries shows that research effort significantly increased with higher GDP, but not according to any other predictors (Table 2; Fig. 5). Contrary to our expectation, countries with higher human density and current or future urbanization prospects (up to 2050) have not been more studied (Table 1). In contrast, wealthier African countries have significantly investigated more on urban ecology (Table 1; Fig. 5). The same significant pattern was found for the sensitivity analysis (i.e., when South Africa was removed; Table S3).

Regarding ecoregions, we found information from 75 out of the 119 ecologically relevant regions in Africa (Fig. 6a-b; Table S4). This implies 37 % of ecoregions without a single urban ecology study. The research effort at this respect is not homogeneously distributed and varies

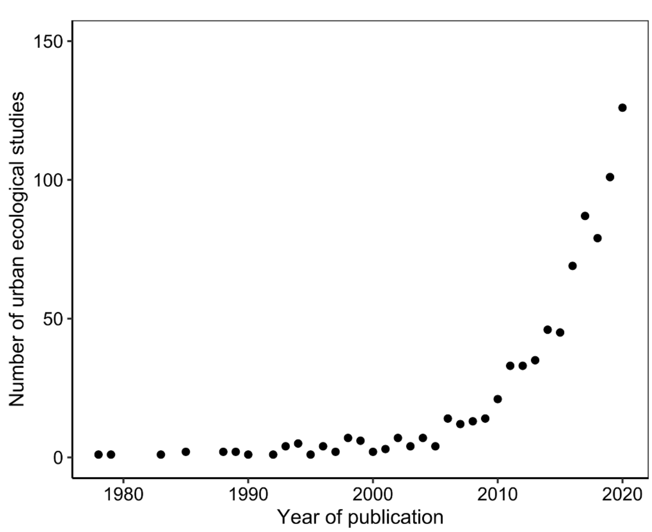

Fig. 2. Urban ecology research effort (number of urban ecological studies) across years.

considerably depending on the biome (Table 2). Furthermore, 22 out of the 44 African ecoregions without urban ecology studies are classified as threatened (Table S4) (Burgess et al., 2004). The Poisson Logistic Regression shows that research effort significantly increased in larger and more threatened ecoregions (Table 3). Urban areas in critical, endangered and vulnerable ecoregions have been more intensively studied (Fig. 7).

Our review also showed important taxonomic biases in the study of urban ecology in Africa. We found information on studies focusing on seven kingdoms, with Animalia and Plantae being the most studied so far (Fig. 8). This result also highlights our limited understanding of other organisms, including Archaea, Bacteria, Chromista, Fungi and Protozoa, which when combined accounted only for 5 % of the studies. The number of studied classes was considerably higher in Animalia (27) than Plantae (9), with Aves (N = 138; 34 %) and Mammalia (N = 95; 23 %) accounting for the majority of studied animal groups (Fig. 9). Regarding plants, the most commonly studied classes were Magnoliopsida (N = 253; 66 %) and Liliopsida (N = 94; 24 %).

From a more conceptual point of view, we found variation in research effort among scientific fields (Fig. 10). The main focus of urban ecology in Africa seems to be applied studies given that conservation and human dimensions studies were the two most commonly investigated fields, with 41 % of all papers falling into these two categories. The scientific fields of wildlife management, wildlife disease and human-wildlife conflict were the least studied, accounting for merely 6 % of the total publications represented in this review. Our data showed that pattern approaches (e.g., Population, Community or Landscape Ecology) are more common than mechanistic studies (e.g., Animal Behavior) in Africa (Fig. 10). The first animal behaviour studies were published in the early 1990s, investigating insects (Paillette et al., 1993) and birds (Van Zyl, 1994). But the focus on this discipline has considerably increased since 2015, with 64 % of all Africa urban ecology studies on animal behavior published after this year (Table S2). Despite this increasing interest, there is still an important taxonomic bias, and only 44 % of the 27 animal classes were represented in animal behaviour studies, including Mammalia (38), Aves (47), Reptilia (7), Amphibia (6), Insecta (5), Gastropoda (2), Actinopterygii (2), Arachnida (1), Clitellata (1), Entognatha (1), Malacostraca (1) and Sarcopterygii (1).

4. Discussion

4.1. Spatio-temporal patterns in knowledge

Our literature search shows almost 800 urban ecology papers for the entire African continent. According to a recent review investigating the top 20 countries publishing on urban ecology (Shackleton et al., 2021), this number is lower than the number of publications from medium-sized European countries, such as Germany (2,479) or Spain (1,864), and much lower than the research effort identified for the United States (12,728), China (6,655) or Australia (2,900). This suggests that urban ecology research in Africa is still considerably low compared to other regions of the World (e.g., Europe, North America, Asia or Australia), matching previous findings that already indicated the African continent was the least studied regarding urban ecology (e.g., Magle et al., 2012 stated that Africa accounted for 2.8 % of published papers on urban wildlife ecology in 2010). It is interesting to note that despite the exponential growth in research effort during the last 15 years, mimicking the global trend on the topic (Lin & Grimm, 2015), Africa has not increased its relative contribution to the field like other regions (e.g., Asia) that were also underrepresented a decade ago (Magle et al., 2012; Wu et al., 2014; Shackleton et al., 2021). The overall number of urban ecology papers in Africa does not seem to be associated with a delayed start in the discipline. Our review shows that African urban ecology started at the end of 1970s around the same time that this discipline started in other regions of the World (McDonnel, 2011; Wu, Xiang, & Zhao, 2014). We cannot be completely sure that there have not been

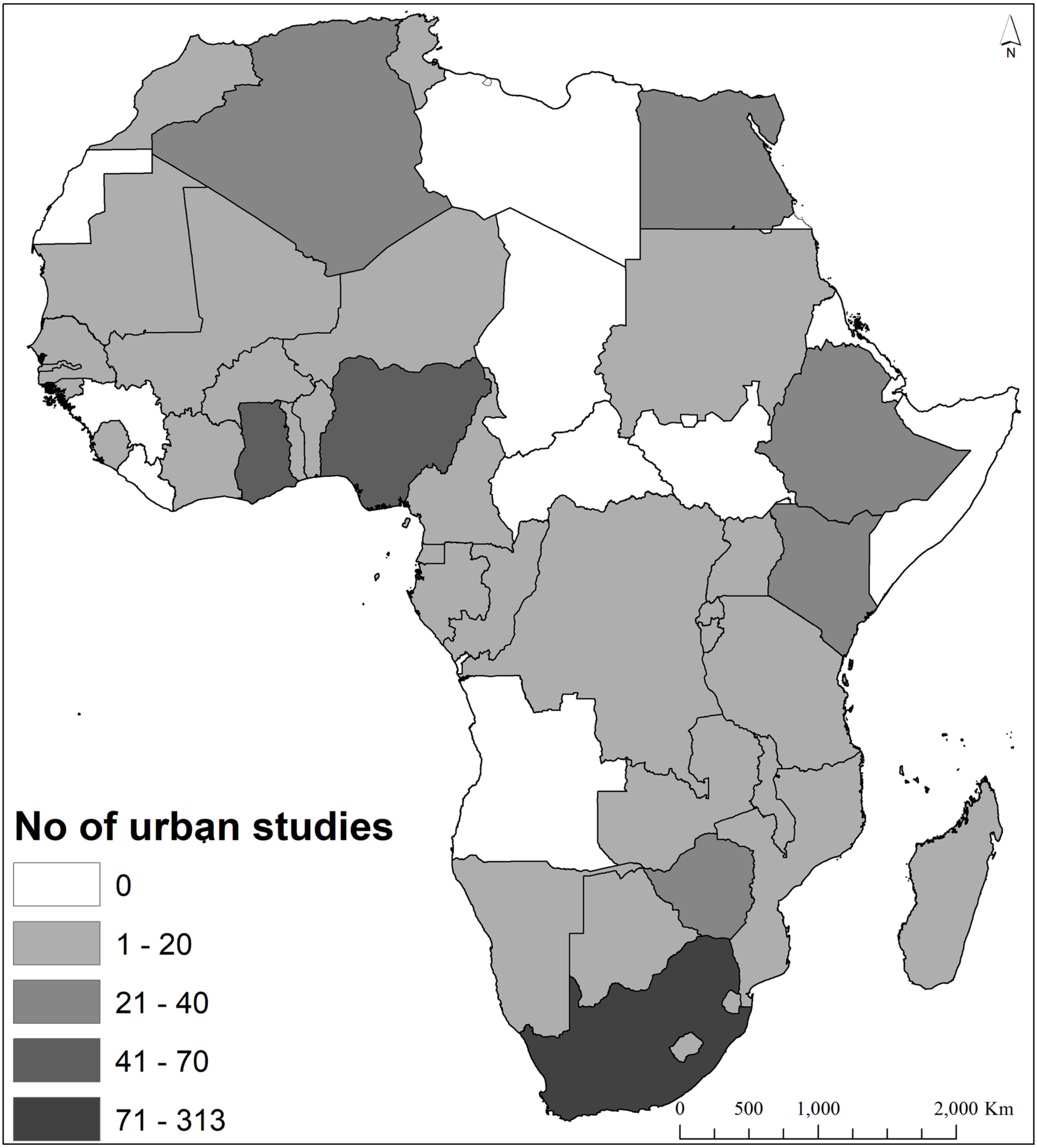

Fig. 3. The distribution of urban ecological studies across African countries.

earlier publications in non-English languages, but probably the first African paper explicitly mentioning the concept of urban ecology corresponded to Okpala's study (1978). This pioneering investigation focused on socio-economic aspects from Lagos (Nigeria), already highlighting the potential conflict of trying to apply European or American urban ecology theory to the African case, an argument that is still valid within the Global North and Global South framework (Shackleton et al., 2021). The current underrepresentation of African urban ecology is particularly worrying as most African urban settings are considered as clear representatives of the Global South urban settings, integrating particular biophysical and socio-economic contexts (Shackleton et al., 2021). Thus, the lack of knowledge at this respect impedes us to complement our understanding of urban ecology, which is based on the more traditional Global North perspective.

There could be other different reasons explaining the low number of publications from Africa. The lack of local capacity/experts in the field is

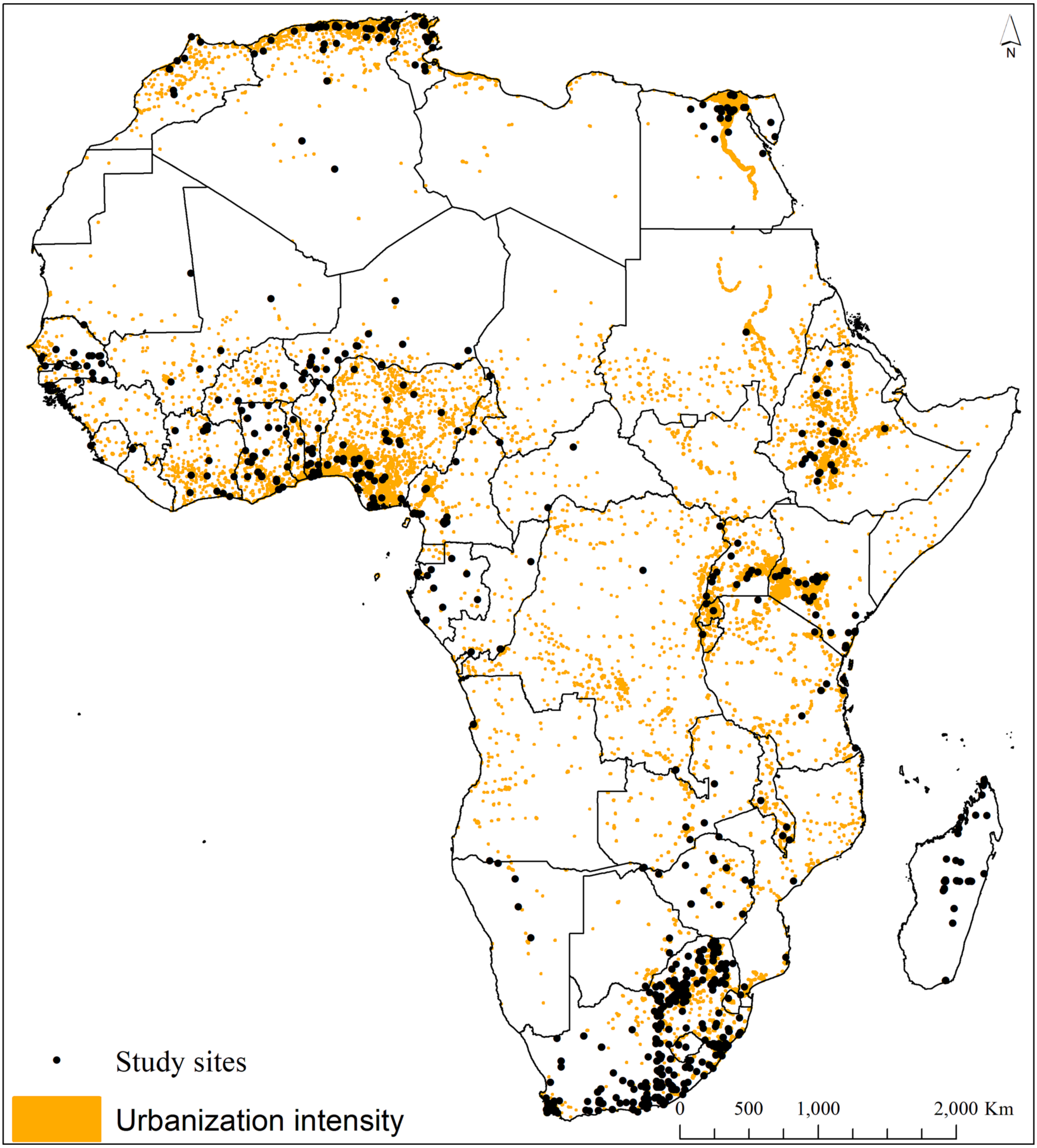

Fig. 4. The distribution of urban ecological study sites superimposed on urbanization intensity.

one of them. This factor has been previously highlighted as a key difference between the Global North and Global South urban settings that could influence the lower level of urban ecology research effort in the latter (Shackleton et al., 2021). According to the UNESCO's database for the period 2015–2020 (UNESCO, 2020; accessed 30 Oct 2022), the number of researchers per million of inhabitants in Northern (732.4) and, particularly, Sub-Saharan Africa (97.4), is considerably lower than in other regions of the planet, such as North America (4,544.8), Europe (3,010.4) or Oceania (3,510.5). This low ratio of skilled people has been demonstrated to influence research effort in Africa regarding other fields such as ornithology (Cresswell, 2018). Therefore, we encourage funding bodies to finance the education of local urban ecologists and researchers to overcome this potential restriction. Another potential reason explaining the low research effort is partially linked to the previous one: the lack of investment in Research and Development (R&D) in Africa compared to other continents. Despite the African Union aims at

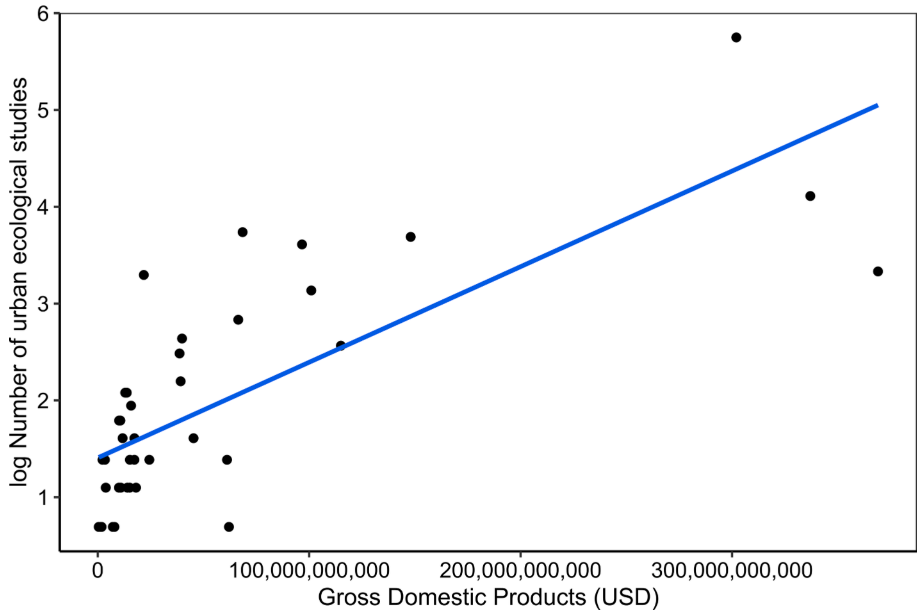

Fig. 5. Relationship between urban ecology research effort (number of urban ecological studies) across all countries and Gross Domestic Products (USD). Note that the y-axis is on a logarithmic scale and that there are several overlapping points.

Table 1
Results of a GLM exploring the predictors of the number of urban ecological studies published across all countries. The number of urban studies +1 was log-transformed to achieve a normal distribution of residuals. The last model (F_{40} = 51.9, P < 0.001; AIC = 100.57) incorporated only the significant variable and had an adjusted R^2 = 0.55.

	Estimate	SE	*t-value*	*p-value*
Intercept	1.41E + 00	1.38E-01	10.22	<0.001
Gross Domestic Product	9.88E-12	1.37E-12	7.203	<0.001
Rejected variables				
Urbanization intensity	1.07E-01	1.20E-01	0.892	0.378
Human population density	−9.24E-04	9.68E-04	−0.955	0.346
Urbanization prospect	5.19E-02	3.69E-02	1.4	0.167

Table 2
Urban ecology research effort (i.e., studied ecoregion/total ecoregion %) across African biomes and ecoregions.

Biome	Total ecoregion	Studied ecoregion	Research effort (%)
Temperate Coniferous Forests	1	1	100
Mangroves	5	4	80
Tropical and Subtropical Moist Broadleaf Forests	30	23	77
Mediterranean Forests, Woodlands, and Scrub	7	5	71
Tropical and Subtropical Grasslands, Savannas, Shrublands, and Woodlands	24	16	67
Montane Grasslands and Shrublands	16	10	63
Flooded Grasslands and Savannas	10	6	60
Deserts and Xeric Shrublands	23	9	39
Tropical and Subtropical Dry Broadleaf Forests	3	1	33

reaching to the 1 % of GDP invested in R&D (United Nations. Economic Commission for Africa 2018), current data indicate that it is 0.64 % and 0.34 % for northern and sub-Saharan Africa, respectively. This is quite far from the values of North American, European or Eastern Asian countries that reached a mean of 2.6 % in 2020. Matching the target proposed by the African Union will certainly help to increase the focus on multiple topics, including urban ecology. However, there are ways to improve knowledge on urban ecology in Africa even without the need of large economic investments. For example, the use of available databases, such as the various atlas projects, which have been successfully implemented in the continent (Botts et al., 2011; Lee & Nel, 2020). Other repositories, such as the Global Biodiversity Information Facility, laboratories, herbaria and museums in and outside of Africa are also useful tools to advance our understanding of the ecology of African urban areas and biodiversity as some recent studies have already shown (e.g., Cohen et al., 2021; Fishpool & Collar, 2018). This approach could also be implemented in collaboration with inhabitants of African urban areas through citizen science projects (e.g., iNaturalist or the Southern African Bird Atlas Project) that can serve to improve information on certain urban questions (e.g., animal distribution) as well as promote the connection between citizens and nature (Reynolds et al., 2021). Engaging citizens could also be instrumental to help increase the urban governance in the Global South, including Africa (Shackleton et al., 2021), and ultimately promote additional support for urban ecology studies in this continent.

Our review also shows that research effort is not homogeneously distributed within the African continent. From a political point of view, there is an important variation among African countries in their urban ecology research effort. One single country (South Africa) stands out as it is responsible for almost 40 % of published papers on the topic. This is so despite only representing 4 % of African territory and 1.02 % of all urban areas in the region (OECD/SWAC, 2020). This high rate of urban ecology publications matches previous information indicating that South Africa is very active in the field at the global level (Shackleton et al., 2021). This does not seem to depend on its number of researchers per million of inhabitants (411.6) or its R&D investment (0.62 % of GDP), which is lower than the mean for Northern Africa (UNESCO, 2020), an area that not even combining all its countries reaches half the number of papers published in South Africa. This country started publishing urban ecology papers at the earliest stages in Africa (Hugo, 1979), so it is possible that this long-term publication period is behind its uniqueness. Another possibility could be that several South African cities (e.g., Cape Town and Durban) are located in biodiversity hotspots of global importance (Cilliers & Siebert, 2012). Alternatively, given that

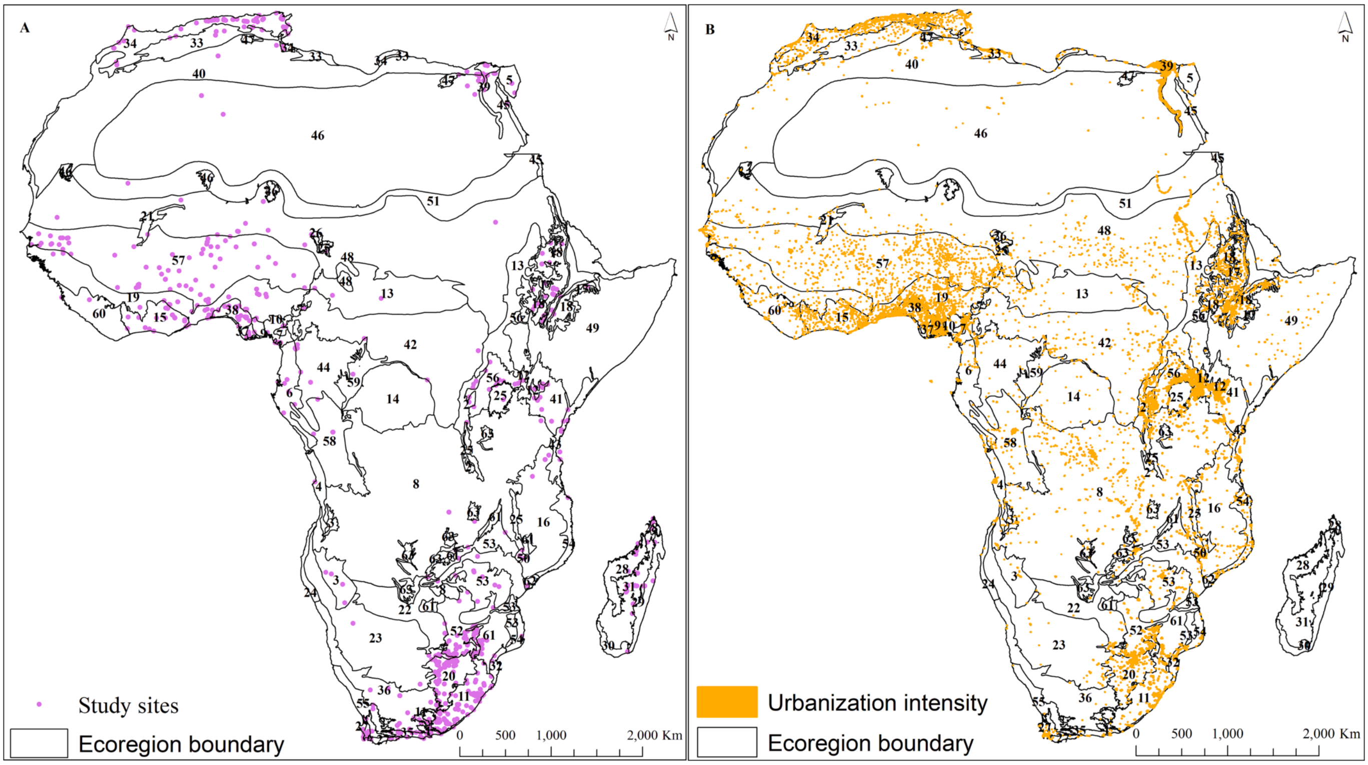

Fig. 6. Map of the African terrestrial ecoregions showing the distribution of urban ecological study sites (a) and urbanization intensity (b). The maps were simplified to facilitate interpretation. Thus, we retain outlines of relatively large ecoregions >10,000 km^2 and those including study sites. However, the names of all ecoregions, their corresponding numbers in the map and additional details (e.g., size) are included in Table S4.

Table 3
Results of a Poisson Logistic Regression exploring the relationship between the number of published urban studies and the conservation status and size of ecoregions. Conservation status is a factor with 5 levels (Critical, Endangered, Relatively Intact, Relatively Stable, Vulnerable) and size is a continuous variable. Critical has been set as the intercept in the model.

	Estimate	SE	z-value	*p-value*
Intercept	2.99E + 00	4.50E-02	66.467	**<0.001**
Endangered	2.44E-01	6.46E-02	3.782	**<0.001**
Relatively Intact	−2.33E + 00	2.13E-01	−10.971	**<0.001**
Relatively Stable	−1.13E + 00	9.02E-02	−12.524	**<0.001**
Vulnerable	−2.62E-02	1.10E-01	−0.239	0.811
Size	5.45E-07	4.69E-08	11.609	**<0.001**

Global North urban principles do not always apply to Global South urban areas (Okpala, 1978; Shackleton et al., 2021), there could be a special interest by funders and/or researchers from this country to acquire first-hand knowledge of direct application to South-African urban settings. For instance, some universities from this country (e.g., Witwatersrand) have strategically focused on global change research, including urban ecology (Scholes et al., 2013) or have developed specific institutes for the study of 'urbanism from an African perspective' (e.g., The African Centre for Cities, from the University of Cape Town; <https://www.africancentreforcities.net/about/acc-at-uct/>). Independently of the reasons for this important outlier, urban ecology research effort varies considerably within African countries. We identified that 28 % of these countries did not publish a single urban ecology study and thus, they completely depend on urban knowledge obtained elsewhere that sometimes might not be really useful for their local situations.

Our analyses show that the number of publications per country on the topic is not associated with current or future urbanization. This result contradicts our initial prediction; however, it could be well understood from a Global South perspective. African countries, like other countries from this group, have several particularities compared to those from the Global North (Shackleton et al., 2021). One of them is the extremely high urbanization rate. Africa is the continent of the World with the most intense urbanization (Cohen, 2006; Seto et al., 2012), with many African countries experiencing urbanization rates above 4 % (e.g., Mali, Nigeria, Angola or Mozambique), an order of magnitude higher than those from other regions of the planet (World Bank, 2021). This factor leads to unplanned urbanization (Zhang, 2016) and compromises sustainable urban development in the continent by impeding the implementation of ecologically-sound practices (Cohen, 2006) and hence potentially explaining the mismatch between urbanization and urban ecology research effort.

Furthermore, we found that the human population density of a country was not significantly associated with the number of publications on urban ecology either. The reasons for this lack of association could be the same as explained before for the current and future urbanization prospects as these are positively correlated with human population density (e.g., Gao & O'Neill, 2021; Qizhi et al., 2016). However, this predictor could also be associated with other potential factors that might prevent investing resources and effort in investigating about urban ecology. For example, there is an increase in people living in extreme poverty in Africa, with more than half of the urban population living in slums and informal settlements (World Cities Report, 2016). Highly populated areas also require a higher infrastructure investment, which is particularly needed in Africa (Zhang, 2016). Thus, socio-economic priorities combined with an insufficient capacity of urban governance (Zhang, 2016; Shackleton et al., 2021) could prevent finding the initially expected effect of human population density. Considering all these results and factors, particularly the uncoupled distribution between urban ecology knowledge and future urban prospects, we would recommend local authorities, funding bodies and researchers to make an effort in the study of the areas that soon will be transformed into urban landscapes.

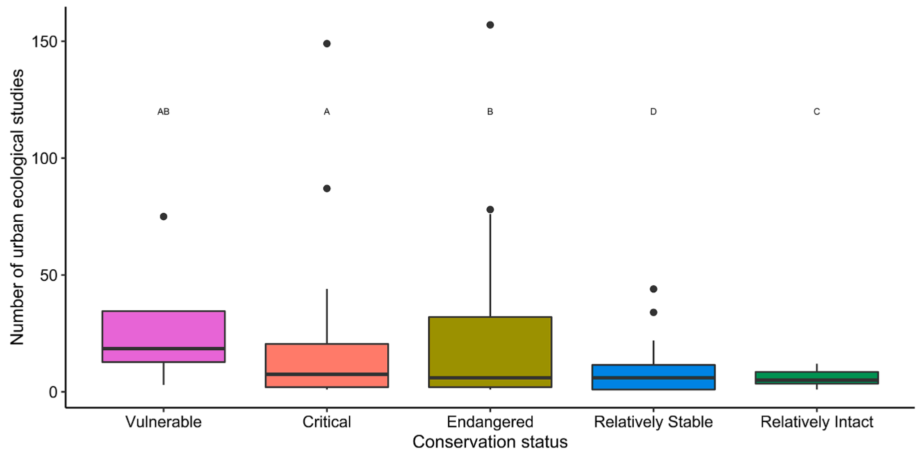

Fig. 7. Urban ecology research effort (number of urban ecology studies) across the conservation categories of ecoregions. Box-plots show median, quartiles, 5- and 95- percentiles and extreme values. Different letters indicate significant differences ($P < 0.01$) between conservation status according to Tukey post-hoc tests using the package "emmeans" (Manley et al., 2015; Yvoz et al., 2020).

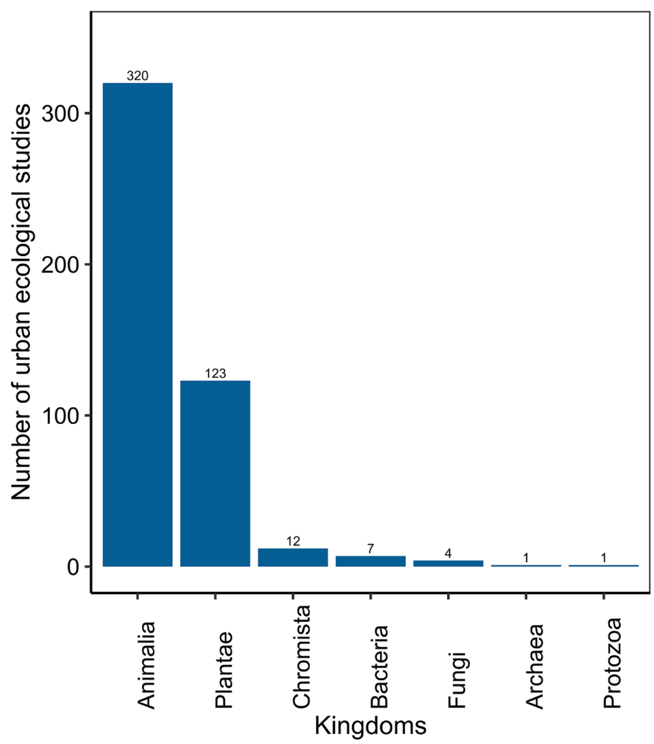

Fig. 8. Urban ecology research effort (number of urban ecological studies) across taxonomic kingdoms.

This is particularly important in the tropical African belt given that it will concentrate the greatest urban expansion in the future (Seto et al., 2012), but also holds the largest biodiversity of the continent (Cazzolla Gatti et al., 2015).

Interestingly, our results indicate that the number of published urban ecological studies depended on economic factors (i.e., GDP). This association has been found in other cross-sectional (e.g., (Doi & Takahara, 2016; Fisher et al., 2011) and longitudinal studies (Vinkler, 2008). This economic indicator is in addition significantly associated with a higher rate of influential publications within their subject area (Bornmann et al., 2014). However, other investigations showed that R&D investment rather than per capita GDP is positively associated with research productivity in different continents (Meo et al., 2013, 2014). It is possible that GDP is a better predictor of R&D in Africa than in other regions, thus potentially explaining the obtained finding. This influence of economic factors on urban ecology research effort is crucial given the link between cities and economic wealth (Zhang, 2016), which could lead us to think that as urbanization progresses in Africa, the better their economies will be and consequently more research on urban ecology could be made. This scenario seems unlikely as this association between economic and urban growth is decoupled in the African continent (Cohen, 2004), which does not warrant this increasing research effort in the future. Other factors not considered in our analyses could also explain the country-wide variation in urban ecology research. For example, political instability could play an important role for the lack of studies on the topic in certain countries such as Western Sahara, South Sudan or Libya.

The fact that the majority of published studies were conducted locally within a single city or country (e.g., Koricho et al., 2020; Lindley et al., 2018; Muleya & Campbell, 2020) suggests the need for investigation of local/national cases for the application of specific solutions. However, it also highlights the lack of transnational collaboration among African countries. This low level of international research both within Africa and with countries from other continents is particularly important considering that: (1) it impedes the generalization of findings at the continental and global scale, and (2) reduces the number of substantive contributions to scientific progress (Bornmann et al., 2014). Therefore, we recommend funders and researchers alike to strengthen or promote the creation of new international networks or institutes on African urban ecology as well as encourage urban ecologists of the continent to participate in other global actions, networks (e.g., the Urban Biodiversity Research Coordination Network) or societies (e.g., Society for Urban Ecology) that are already running.

The geographic variation in research effort could also be linked to conservation aspects. Conservation research in Africa is particularly relevant and prolific in the global context (Doi & Takahara, 2016). There are still some controversies on whether conservation status is significantly and positively associated with research effort at the species level (e.g., Brooke et al., 2014; Ducatez & Lefebvre, 2014; Ibáñez-Álamo et al., 2017), but countries with a higher level of environmental protection activity investigate more in ecology (Doi & Takahara, 2016). Our results match this finding given that urban ecology research effort is significantly associated with the conservation status of African ecoregions. The ecologically relevant regions belonging to the most threatened categories (Critical, Endangered and Vulnerable) showed the highest number of publications on the topic. This is logical considering the previously described restricted R&D investment in Africa that would divert the current available resources towards areas of conservation concern. Despite this, we found that about half (50 %) of African

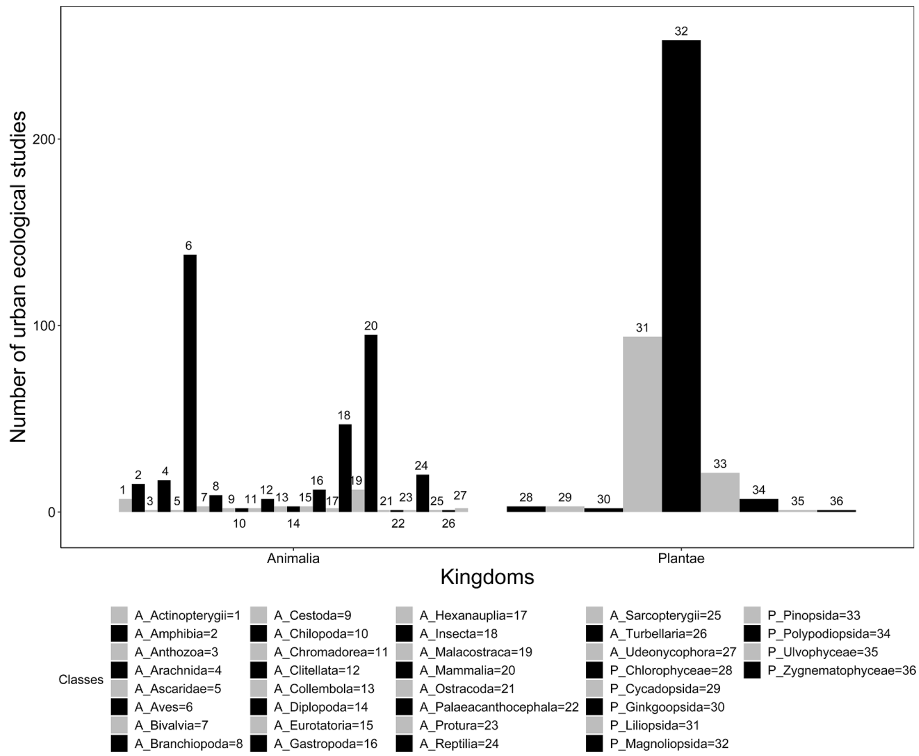

Fig. 9. Urban ecology research effort (number of urban ecological studies) per class of the two most studied kingdoms (Animals and Plants). Each number on/below the bars corresponds with the number and class in the legend.

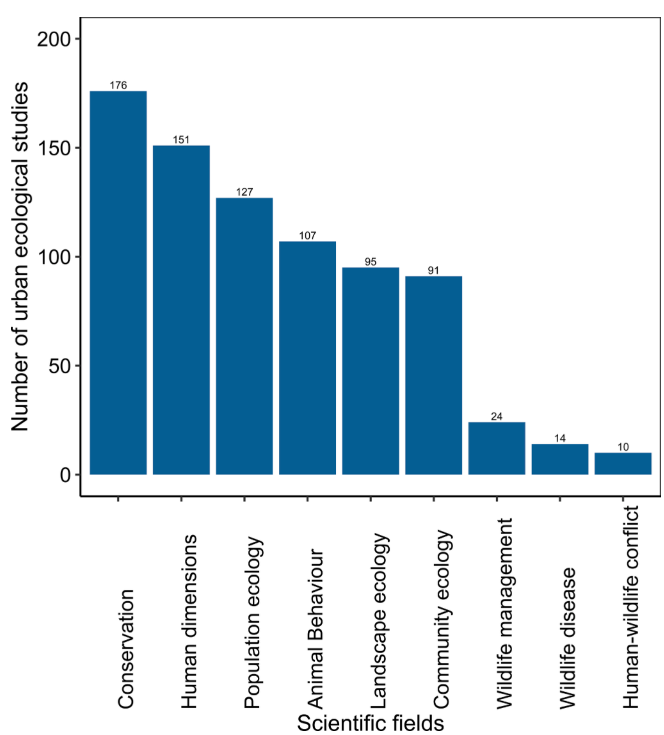

Fig. 10. Urban ecology research effort (number of urban ecological studies) across scientific fields.

ecoregions without a single published study on the topic are classified as threatened, and urbanization is considered a leading threat in the area (Burgess et al., 2004), suggesting the need for additional studies to determine the ecological effects of urbanization and propose suitable conservation actions. On the other side, the significant effect of ecoregion size fitted our initial expectations as larger ecoregions would support higher biodiversity levels (Rantalainen et al., 2005) and consequently a higher likelihood of being investigated. As larger and more threatened ecoregions were significantly more studied in the continent, there is a need to expend greater research effort on smaller and relatively stable ecoregions (e.g., East African Montane Moorlands and Lake Chad Flooded Savanna), which are more likely to suffer unnoticed fragmentation from urbanization and other anthropogenic land-use changes as also indicated by previous studies (e.g., Beyer, Venter, Grantham, & Watson, 2020; Burgess, Hales, Ricketts, & Dinerstein, 2006; McDonald et al., 2008). Particularly surprising is the lack of studies from the majority (77 %) of ecoregions from the Tropical and Subtropical Dry Broadleaf Forests biome. These ecoregions mainly correspond with large areas of Madagascar, a megadiverse country (<https://www.biodiversitya-z.org/content/megadiverse-countries> accessed 30 October 2022) with the lowest percentage of urban land-cover in the whole continent (0.04 %; OECD/SWAC, 2020). In contrast, other forested biomes are quite well represented, which makes sense considering that forests, especially those from Western Africa, support higher biodiversity and endangered species, thus promoting a more intense ecological research effort (Doi & Takahara, 2016).

4.2. Gaps in knowledge according to taxonomy and scientific fields

Our review also offers interesting information on the current methodological and conceptual orientation of urban ecological research in Africa. From a methodological point of view, we found an important taxonomic bias in the study of urban ecology in Africa similar to those previously reported (e.g., Callaghan et al., 2020; Shwartz et al., 2014). This taxonomic bias has a strong effect in our urban ecology knowledge given that the impact of urbanization varies considerably depending on the type of organisms considered (McKinney 2008; Paul & Meyer, 2001). Our literature search offered studies focused on organisms belonging to seven kingdoms, although the majority of urban ecology research used either animals or plants as model systems. This result highlights our limited understanding of other organisms in the African urban context, including Archaea, Bacteria, Chromista, Fungi and Protozoa, which should be prioritized for future studies. This is justified by current literature highlighting their relevance in natural environments (e.g., Epp Schmidt et al., 2019; Kartzinel et al., 2019; Thompson et al., 2017). The uneven distribution of urban ecology research effort went down to lower taxonomic levels (e.g., classes). Among animals, birds and mammals were the two most studied groups. The publication bias towards these two classes in urban ecology is not restricted to Africa alone (Donaldson et al., 2017; Shwartz et al., 2014), and has also been identified in other study fields such as conservation biology (Lawler et al., 2006) and invasion ecology (Pyšek et al., 2008). Several reasons have been proposed to explain this bias for birds and mammals, such as body size (Brodie 2009) or conservation status of focal species (Donaldson et al., 2017). Regarding plants, flowering plants (Magnoliopsida and Liliopsida) dominate urban ecology research effort in Africa, replicating the patterns found by other research effort studies on plants (Richardson & Rejmanek, 2011; Stranga & Katsanevakis, 2021). In contrast with plants, with the richly diverse Magnoliopsida (Tracheophyta) relatively well studied (Cilliers & Bredenkampl, 1999; Moussa et al., 2020; van der Walt et al., 2015), the most diverse animal group of Arthropoda is clearly underrepresented in urban ecology and calling for additional scientific attention (reviewed here; McIntyre, 2000).

Urban ecology research effort in Africa also varied in terms of scientific disciplines. Conservation was the most studied scientific field. This result is in agreement with previous findings already highlighting the relevance of Africa in the study of environmental conservation and ecology (Doi & Takahara, 2016), and matches also with our initial result that indicates preference for ecoregions of conservation concern. Interestingly, a handful of such African conservation studies diagnosed different socio-environmental issues in urban areas and developed useful frameworks or plans for promoting nature conservation and sustainable urban development in the continent (e.g., Boon et al., 2016; Cilliers et al., 2004; Goosen & Cilliers, 2020; Rebelo et al., 2011). While these findings imply the availability of data that could be useful for promoting conservation actions, they are mostly restricted to South Africa. For an effective implementation of conservation actions, more studies are needed from unrepresented areas as they may help to discover local issues such as environmental injustice (Ernstson, 2013). The human dimension field is well-represented within African urban ecological research, which points to the relevance of multifaceted approaches in Africa, particularly regarding ecosystem services that complements conservation or ecological studies (e.g., population ecology or animal behavior). For instance, the majority of human dimension studies in our review indicate that people in African urban areas appreciate the socio-ecological services (Dipeolu et al., 2020; Rogerson & Rogerson, 2020) and economic benefits provided by urban biodiversity (Babalola et al., 2013; King & Shackleton, 2020). In a study by Popoola and Ajewole (2002), most Nigerian respondents were even willing to support the conservation of urban nature through personal funds. The conservation of urban biodiversity is tightly linked to public support (Miller & Hobbs, 2002), and thus, human dimension studies could be useful educational tools to reconcile urban development and nature preservation in the continent (McDuff, 2000). In addition, unlike in other regions where the important roles of urban biodiversity in enhancing ecosystem services and human well-being have been well-documented (Brown & Grant, 2005; Dallimer et al., 2012; O'Sullivan et al., 2017), this interplay is much more complex in the African case (Wangai et al., 2016) usually not considering the ecosystem disservices that could be of critical importance in areas of the Global South (Davoren & Shackleton, 2021). In general, ecosystem services in Africa have been poorly studied (du Toit et al., 2018), although there is a clear effort in recent years to overcome this important gap (e.g., Dobbs et al., 2021; Escobedo, 2021; Shackleton et al., 2021; Wangai et al., 2016), including the evaluation of how different frameworks are applied to African urban settings (Lindley et al., 2018).

We identified that many urban ecology papers focused on Africa used pattern approaches either at the species or community level. Several reviews on urban ecology or specific aspects of urban ecology (e.g., urban ornithology) have also found similar results at the global level (Magle et al., 2012; Marzluff, 2016; Wu et al., 2014). As we have stated before, Africa is understudied in urban ecology, and we lack many basic information on even the presence/absence of certain organisms in cities of this continent. Some of the studies in these categories describe new species (e.g., Malonza et al., 2016; Smales et al., 2017), provide information on potentially problematic organisms (e.g., invasive species; Bigirimana et al., 2011; Hima et al., 2019) or provide much needed information on the distribution of organisms in African urban settings (e.g., Moussa et al., 2020; Muchayi et al., 2017). But some of these articles also used applied approaches by integrating human-nature interaction aspects. For example, Chamberlain et al. (2019) found evidence supporting the luxury effect in South Africa. This effect states that there is a positive correlation between wealth and biodiversity, and thus relates to environmental injustice issues (Reynolds et al., 2021). These pattern-approach studies that also consider applied aspects and the particularities of Global South urban areas are excellent examples on how we can advance in our understanding of African urban ecology. Some researchers have highlighted the lack of urban ecology mechanistic studies in countries of the Global South compared to those from the Global North (Marzluff, 2016). Mechanistic studies would, for example, include animal behavior papers that could explain the observed patterns (e.g., feeding behavior explaining the presence of certain animals in cities). Africa has produced quite a lot of animal behavior studies centered in urban areas but most of them were observational (e.g., McPherson et al., 2016; Widdows & Downs, 2016), with only a handful of experimental manipulations (Cronk & Pillay, 2018; Patterson et al., 2016) that are much more powerful to identify cause-effect associations. Future studies should try to put more emphasis on experimental manipulations to fill in this important gap in our urban ecology knowledge.

Landscape ecology is still not as well studied as in other regions regarding urban areas (Magle et al., 2012; Wu et al., 2014), but it offers unique opportunities for the development of this field in Africa. On the one hand, landscape ecology studies in our database extensively utilized the Geographic Information System (GIS) for estimating land cover and habitat heterogeneity (e.g., Benza et al., 2016; Kowe et al., 2020). The use of GIS techniques could enhance better coverage of study sites (e.g., conflicting/dangerous/remote areas), helping to complete the missing geographic areas in urban ecology research detected in our review. These techniques require highly qualified personnel but provide useful information at minimal time and cost (Langat et al., 2019), thus, offering a good opportunity for capacity building in the continent while considering the economic restrictions in R&D of the region (see above). On the other hand, landscape ecology is an integrative discipline merging geospatial patterns, ecological and socio-economic processes and ecosystem services/disservices, thus favoring the interdisciplinary collaborations between sociologists, ecologists and geographers among others (Wu et al., 2014), thereby facilitating the establishment of much needed interdisciplinary collaborations in African urban ecology. For all these reasons, we expect that the field of urban landscape ecology will continue to increase as it has happened at the global scale (Magle et al., 2012).

5. Conclusions

This review shows that research effort on urban ecology is still low in Africa, with the exception of South Africa, particularly in the highly urbanized and biodiversity-rich areas of the continent. This continent is an important representative of the Global South, and thus the lack of information on the topic is an important impediment to try to overcome the traditional Global North perspective on urban ecology (Shackleton et al., 2021). In addition, the information presented here could be crucial to achieve the 11th Sustainable Development Goal in the rapidly urbanizing African continent (Cobbinah et al., 2015). Urban areas, if well-planned, can still provide substantial benefits for biodiversity, act as hotspots and habitat corridors for some threatened species (Ives et al., 2016; Kumdet et al., 2021) and serve important socio-ecological (Dipeolu et al., 2020; Rogerson & Rogerson, 2020) and economic benefits (Babalola et al., 2013; King & Shackleton, 2020). To our knowledge, this is the first general literature review of urban ecological studies for the entire African continent that follows rigorous, verifiable and repeatable methodological approaches recommended in recent times (Ibáñez-Álamo et al., 2017; Magle et al., 2012; Moher et al., 2009; Sánchez-Tójar et al., 2020). Previous methodologically-similar reviews of African urban ecology, though interesting and useful, either focused mainly on socio-ecological systems (e.g., Cilliers, 2019; Lindley et al., 2018) or specific aspects of African urban biodiversity (e.g., Güneralp et al., 2018; Roets et al., 2019; Trimble & van Aarde, 2014). The low research effort in African urban ecology seems to point to socio-economic factors such as the low level of skilled people and reduced investment in R&D typical from this continent (e.g., Cresswell, 2018). We believe that this situation could be partially reverted if African countries follow the African Union recommendation of investing 1 % of their GDP in R&D, although other socio-economic needs (e.g., infrastructure, security, health issues) could make this change very difficult (Zhang, 2016).

Economic factors (GDP) rather than other urban indicators (e.g., urbanization intensity, human population density) are also crucial to explain urban ecology research effort within the continent. South Africa congregates many of the papers on the topic, while there are 16 African countries without urban ecology studies, providing clear targets for future investigations. The South African case could be useful to identify specific aspects that could be reproduced in other neighboring countries to try to boost urban ecology research. Thus, studies comparing different urban ecology aspects between South Africa and other African countries would be particularly interesting at this respect. In addition, it is especially worrisome the uncoupled nature between future urbanization prospects and urban ecology knowledge as local authorities will not count with valuable information to take scientifically-based actions. This lack of information has already been suggested as an important impediment to achieve sustainable urban development in Africa (Cobbinah et al., 2015; Patel et al., 2017).

In addition, greater research effort is expended on larger and threatened ecoregions. Threatened sites and species are usually prioritized for conservation actions (Brooks et al., 2006), and could influence research effort (e.g., de Lima et al., 2011). However, relatively stable ecoregions could suffer unnoticed effects of urbanization, which could be detrimental to certain biodiversity that may suffer regional extinction before being identified. This pattern has been previously reported in Africa (Ahrends et al., 2011), and could even be more severe in the future given the mismatches in the allocation of research effort across regions. This research bias towards threatened areas is partially linked to the fact that conservation studies dominate the urban ecology literature produced in the African continent. Our literature search also indicated that African urban ecology research is multidimensional with an important contribution to human dimension studies including those on ecosystem services and disservices. These studies have increased in recent years providing much needed information for the urban settings of this continent and ultimately helping to improve our understanding of the complex urban environment in which many different components interact (e.g., sociological, ecological, economical…).

6. Recommendations and future prospects

We argue that for African urban ecology to provide more useful information for decision-making and promote sustainable development, future research should try to overcome the detected geographic, taxonomic and ecological biases. To help in this endeavor, we provide a list of the articles reviewed here as well as the journals of publication, where key stakeholders or researchers could obtain relevant data on the topic (Table S2).

Based on our review, we propose the following recommendations to promote urban ecology research in this continent: (1) strengthening collaboration and networking among researchers across regions and countries, as previously suggested in a more general context (McPhearson et al., 2016). This will allow for larger scale studies that will provide an additional and complementary perspective to city/local studies that tackle more specific problems. (2) Helping the education of local experts on urban ecological studies can be also instrumental to overcome some of the previously described publication biases on the topic (Shackleton et al., 2021). (3) Engaging with the citizenship through citizen science projects. This will allow the acquisition of additional scientific information at the same time as it promotes a better urban governance through participation of urban inhabitants. (4) Use of low-cost techniques like GIS or available databases (e.g., museums) to maximize the scientific outcome considering the economic restrictions of the region. We hope that this review will help to re-orientate our research effort on the topic and fill in some important knowledge gaps highlighted here to grant a balanced strategy between urban development and nature conservation in this unique continent.

CRediT authorship contribution statement

Adewale G. Awoyemi: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Juan Diego Ibáñez-Álamo:** Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2023.104707.

References

Abreha, S. K. (2019). Model-based cost-effectiveness analysis of external beam radiation therapy for the treatment of localized prostate cancer: A systematic review. *Cost Effectiveness and Resource Allocation, 17*(1), 1–12. https://doi.org/10.1186/s12962-019-0178-3

Ahrends, A., Burgess, N. D., Gereau, R. E., Marchant, R., Bulling, M. T., Lovett, J. C., Platts, P. J., Wilkins Kindemba, V., Owen, N., Fanning, E., & Rahbek, C. (2011). Funding begets biodiversity. *Diversity and Distributions, 17*(2), 191–200. https://doi.org/10.1111/j.1472-4642.2010.00737.x

Anderson, P. M. L., Brown-Luthango, M., Cartwright, A., Farouk, I., & Smit, W. (2013). Brokering communities of knowledge and practice: Reflections on the African Centre for Cities' CityLab programme. *Cities, 32*, 1–10. https://doi.org/10.1016/j.cities.2013.02.002

Angel, S., Parent, J., Civco, D. L., Blei, A., & Potere, D. (2011). The dimensions of global urban expansion: Estimates and projections for all countries, 2000–2050. *Progress in Planning, 75*(2), 53–107. https://doi.org/10.1016/j.progress.2011.04.001

Dipeolu, A. A., Aluko, R. O., Omoniyi, S. S., & Oyinloye, A. M. (2020). Assessment of residents' socio-demographic factors associated with visit to green infrastructure facilities in Lagos Metropolis, Nigeria. *International Journal of Built Environment and Sustainability, 7*(2), 45–55. https://doi.org/10.11113/ijbes.v7.n2.489

Babalola, F. D., Borokini, T. I., Onefeli, A. O., & Muchie, M. (2013). Socio-economic contributions of an indigenous tree in urban areas of Southwest Nigeria. *African Journal of Science, Technology, Innovation and Development, 5*(6), 479–489. https://doi.org/10.1080/20421338.2013.820449

Beninde, J., Veith, M., & Hochkirch, A. (2015). Biodiversity in cities needs space: A meta-analysis of factors determining intra-urban biodiversity variation. *Ecology Letters, 18* (6), 581–592. https://doi.org/10.1111/ele.12427

Benza, M., Weeks, J. R., Stow, D. A., López-Carr, D., & Clarke, K. C. (2016). A pattern-based definition of urban context using remote sensing and GIS. *Remote Sensing of Environment, 183*, 250–264. https://doi.org/10.1016/j.rse.2016.06.011

Bernat-Ponce, E., Ferrer, D., Gil-Delgado, J. A., & López-Iborra, G. M. (2021). Effect of replacing surface with underground rubbish containers on urban House Sparrows *Passer domesticus*. *Urban Ecosystems*. https://doi.org/10.1007/s11252-021-01138-y

Beyer, H. L., Venter, O., Grantham, H. S., & Watson, J. E. M. (2020). Substantial losses in ecoregion intactness highlight urgency of globally coordinated action. *Conservation Letters, 13*, e12692.

Bigirimana, J., Bogaert, J., de Canniere Charles, C., Lejoly, J., & Parmentier, I. (2011). Alien plant species dominate the vegetation in a city of Sub-Saharan Africa. *Landscape and Urban Planning, 100*(3), 251–267. https://doi.org/10.1016/j.landurbplan.2010.12.012

Boon, R., Cockburn, J., Douwes, E., Govender, N., Ground, L., McLean, C., Roberts, D., Rouget, M., & Slotow, R. (2016). Managing a threatened savanna ecosystem (KwaZuluNatal Sandstone Sourveld) in an urban biodiversity hotspot: Durban, South Africa. *Bothalia, 46*(2). https://doi.org/10.4102/abc.v46i2.2112

Bornmann, L., Stefaner, M., de Moya Anegón, F., & Mutz, R. (2014). What is the effect of country-specific characteristics on the research performance of scientific institutions? Using multi-level statistical models to rank and map universities and research-focused institutions worldwide. *Journal of Informetrics, 8*(3), 581–593. https://doi.org/10.1016/j.joi.2014.04.008

Botts, E. A., Erasmus, B. F. N., & Alexander, G. J. (2011). Geographic sampling bias in the South African Frog Atlas Project: Implications for conservation planning. *Biodiversity and Conservation, 20*(1), 119–139. https://doi.org/10.1007/s10531-010-9950-6

Brodie, J. F. (2009). Is research effort allocated efficiently for Conservation? Felidae as a global case study. *Biodiversity and Conservation, 18*(11), 2927–2939. https://doi.org/10.1007/s10531-009-9617-3

Brooke, Z. M., Bielby, J., Nambiar, K., & Carbone, C. (2014). Correlates of research effort in carnivores: Body size, range size and diet matter. *PLoS ONE, 9*(4). https://doi.org/10.1371/journal.pone.0093195

Brooks, T. M., Mittermeier, R. A., da Fonseca, G. A. B., Gerlach, J., Hoffmann, M., Lamoreux, J. F., Mittermeier, C. G., Pilgrim, J. D., & Rodrigues, A. S. L. (2006). Global biodiversity conservation priorities. *Science, 313*(5783), 58–61. https://www.science.org.

Brown, C., & Grant, M. (2005). Biodiversity and human health: What role for nature in healthy urban planning? *Built Environment, 31*(4), 326–338.

Burgess, N. D., Hales, J. D. A., Ricketts, T. H., & Dinerstein, E. (2006). Factoring species, non-species values and threats into biodiversity prioritisation across the ecoregions of Africa and its islands. *Biological Conservation, 127*(4), 383–401. https://doi.org/10.1016/j.biocon.2005.08.018

Burgess, N., D'Amico Hales, J., Underwood, E., Dinerstein, E., Olson, D., Itoua, I., Schipper, J., Ricketts, T., & Newman, K. (2004). *Terrestrial eco-regions of Africa and Madagascar: A conservation assessment*. Washington, DC: Island Press. https://www.researchgate.net/publication/292588815.

Burnham, K. P., & Anderson, D. R. (2002). *Model selection and multimodel inference: A practical information-theoretic approach* (2nd Ed.). Springer.

Callaghan, C. T., Ozeroff, I., Hitchcock, C., & Chandler, M. (2020). Capitalizing on opportunistic citizen science data to monitor urban biodiversity: A multi-taxa framework. *Biological Conservation, 251*. https://doi.org/10.1016/j.biocon.2020.108753

Cazzolla Gatti, R., Castaldi, S., Lindsell, J. A., Coomes, D. A., Marchetti, M., Maesano, M., di Paola, A., Paparella, F., & Valentini, R. (2015). The impact of selective logging and clearcutting on forest structure, tree diversity and above-ground biomass of African tropical forests. *Ecological Research, 30*(1), 119–132. https://doi.org/10.1007/s11284-014-1217-3

Chamberlain, D. E., Henry, D. A. W., Reynolds, C., Caprio, E., & Amar, A. (2019). The relationship between wealth and biodiversity: A test of the Luxury Effect on bird species richness in the developing world. *Global Change Biology, 25*(9), 3045–3055. https://doi.org/10.1111/gcb.14682

Chen, M., Huang, Y., Tang, Z., Lu, D., Liu, H., & Ma, L. (2014). The provincial pattern of the relationship between urbanization and economic development in China. *Journal of Geographical Sciences, 24*(1), 33–45. https://doi.org/10.1007/s11442-014-1071-9

Childers, D. L., Cadenasso, M. L., Morgan Grove, J., Marshall, V., McGrath, B., & Pickett, S. T. A. (2015). An ecology for cities: A transformational nexus of design and ecology to advance climate change resilience and urban sustainability. *Sustainability, 7*(4), 3774–3791. https://doi.org/10.3390/su7043774

Cilliers, E. J. (2019). Reflecting on green infrastructure and spatial planning in Africa: The complexities, perceptions, and way forward. *Sustainability, 11*(2). https://doi.org/10.3390/su11020455

Cilliers, S., Cilliers, J., Lubbe, R., & Siebert, S. (2013). Ecosystem services of urban green spaces in African countries-perspectives and challenges. *Urban Ecosystems, 16*(4), 681–702. https://doi.org/10.1007/s11252-012-0254-3

Cilliers, S. S., & Bredenkampl, G. J. (1999). Analysis of the spontaneous vegetation of intensively managed urban open spaces in the Potchefstroom Municipal Area, North West Province, South Africa. *South African Journal of Botany, 65*(1), 59–68.

Cilliers, S. S., Müller, N., & Drewes, E. (2004). Overview on urban nature conservation: Situation in the western-grassland biome of South Africa. *Urban Forestry and Urban Greening, 3*(1), 49–62. https://doi.org/10.1016/j.ufug.2004.04.003

Cilliers, S. S., & Siebert, S. J. (2012). Urban ecology in Cape Town: South African comparisons and reflections. *Ecology and Society, 17*(3). https://doi.org/10.5751/ES-05146-170333

Cilliers, S. S., Siebert, S. J., du Toit, M. J., Barthel, S., Mishra, S., Cornelius, S. F., & Davoren, E. (2018). Garden ecosystem services of Sub-Saharan Africa and the role of health clinic gardens as social-ecological systems. *Landscape and Urban Planning, 180*, 294–307. https://doi.org/10.1016/j.landurbplan.2017.01.011

Cobbinah, P. B., Erdiaw-Kwasie, M. O., & Amoateng, P. (2015). Africa's urbanisation: Implications for sustainable development. *Cities, 47*, 62–72. https://doi.org/10.1016/j.cities.2015.03.013

Cohen, B. (2004). Urban growth in developing countries: A review of current trends and a caution regarding existing forecasts. *World Development, 32*(1), 23–51. https://doi.org/10.1016/j.worlddev.2003.04.008

Cohen, B. (2006). Urbanization in developing countries: Current trends, future projections, and key challenges for sustainability. *Technology in Society, 28*(1–2), 63–80. https://doi.org/10.1016/j.techsoc.2005.10.005

Cohen, C., Collar, N. J., Dagne, A., Fishpool, L. D. C., Marsden, S. J., Spottiswoode, C. N., & Wotton, S. R. (2021). Status of Taita Falcon Falco fasciinucha in Ethiopia and the identification problem posed by African Hobby F. cuvierii. *ABC Bulletin, 28* (2), 225–233.

Corbyn, Z. (2010). Urban ecosystems research joins mainstream ecology. *Nature, 467* (September), 153. https://doi.org/10.1038/news.2010.359

Crawley, M. J. (2013). *The R book* (2nd Ed.). John Wiley & Sons Ltd.

Cresswell, W. (2018). The continuing lack of ornithological research capacity in almost all of West Africa. *Ostrich, 89*(2), 123–129. https://doi.org/10.2989/00306525.2017.1388301

Cronk, N. E., & Pillay, N. (2018). Food choice and feeding on carrion in two African mongoose species in an urban environment. *Acta Ethologica, 21*(2), 127–136. https://doi.org/10.1007/s10211-018-0291-x

Dallimer, M., Irvine, K. N., Skinner, A. M. J., Davies, Z. G., Rouquette, J. R., Maltby, L. L., Warren, P. H., Armsworth, P. R., & Gaston, K. J. (2012). Biodiversity and the feel-good factor: Understanding associations between self-reported human well-being and species richness. *BioScience, 62*(1), 47–55. https://doi.org/10.1525/bio.2012.62.1.9

Davoren, E., & Shackleton, C. M. (2021). Urban ecosystem disservices in the global South. In C.M. Shackleton, S.S. Cilliers, E. Davoren, & M.J. du Toit (Eds.), *Urban ecology in the global South, cities and nature* (pp. 265–292). Springer Nature.

de Keijzer, C., Gascon, M., Nieuwenhuijsen, M. J., & Dadvand, P. (2016). Long-term green space exposure and cognition across the life course: A systematic review. *Current Environmental Health Reports, 3*(4), 468–477. https://doi.org/10.1007/s40572-016-0116-x

de Lima, R. F., Bird, J. P., & Barlow, J. (2011). Research effort allocation and the conservation of restricted-range island bird species. *Biological Conservation, 144*(1), 627–632. https://doi.org/10.1016/j.biocon.2010.10.021

Dobbs, C., Vasquez, A., Olave, P., & Olave, M. (2021). Cultural urban ecosystem services. In C.M. Shackleton, S.S. Cilliers, E. Davoren, & M.J. du Toit (Eds.), *Urban ecology in the global South, cities and nature* (pp. 245–264). Springer Nature.

Doi, H., & Takahara, T. (2016). Global patterns of conservation research importance in different countries of the world. *PeerJ, 4*(e2173). https://doi.org/10.7717/peerj.2173

Donaldson, M. R., Burnett, N. J., Braun, D. C., Suski, C. D., Hinch, S. G., Cooke, S. J., & Kerr, J. T. (2017). Taxonomic bias and international biodiversity conservation research. *FACETS, 1*(1), 105–113. https://doi.org/10.1139/facets-2016-0011

du Toit, M. J., Cilliers, S. S., Dallimer, M., Goddard, M., Guenat, S., & Cornelius, S. F. (2018). Urban green infrastructure and ecosystem services in sub-Saharan Africa. *Landscape and Urban Planning, 180*, 249–261. https://doi.org/10.1016/j.landurbplan.2018.06.001

Ducatez, S., & Lefebvre, L. (2014). Patterns of research effort in birds. *PLoS ONE, 9*(2). https://doi.org/10.1371/journal.pone.0089955

Epp Schmidt, D. J., Kotze, D. J., Hornung, E., Setälä, H., Yesilonis, I., Szlavecz, K., Dombos, M., Pouyat, R., Cilliers, S., Tóth, Z., & Yarwood, S. (2019). Metagenomics reveals bacterial and archaeal adaptation to urban land-use: N catabolism, methanogenesis, and nutrient acquisition. *Frontiers in Microbiology, 10*. https://doi.org/10.3389/fmicb.2019.02330

Ernstson, H. (2013). The social production of ecosystem services: A framework for studying environmental justice and ecological complexity in urbanized landscapes. *Landscape and Urban Planning, 109*(1), 7–17. https://doi.org/10.1016/j.landurbplan.2012.10.005

Escobedo, F. J. (2021). Understanding urban regulating ecosystem services in the global South. In C.M. Shackleton, S.S. Cilliers, E. Davoren, & M.J. du Toit (Eds.), *Urban ecology in the global South, cities and nature* (pp. 227–244). Springer Nature.

Fayiga, A. O., Ipinmoroti, M. O., & Chirenje, T. (2018). Environmental pollution in Africa. In *Environment, development and sustainability*, 20 (1), 41–73. Springer Netherlands. https://doi.org/10.1007/s10668-016-9894-4.

Ferketic, J. S., Latimer, A. M., & Silander, J. A. (2010). Conservation justice in metropolitan Cape Town: A study at the Macassar Dunes Conservation Area. *Biological Conservation, 143*(5), 1168–1174. https://doi.org/10.1016/j.biocon.2010.02.024

Fisher, R., Radford, B. T., Knowlton, N., Brainard, R. E., Michaelis, F. B., & Caley, M. J. (2011). Global mismatch between research effort and conservation needs of tropical coral reefs. *Conservation Letters, 4*, 64–72.

Fishpool, L. D. C., & Collar, N. J. (2018). On the validity of the Golden-naped Weaver Ploceus aureonucha and the Yellow-legged Weaver *P. flavipes*, with comments on forest "nuthatch-weavers." *ABC Bulletin*, *25* (2), 159–179.

Forman, R. T. T. (2014). *Urban ecology: Science of cities* (1st Ed.). Cambridge University Press.

Forman, R. T. T. (2016). Urban ecology principles: Are urban ecology and natural area ecology really different? *Landscape Ecology, 31*(8), 1653–1662. https://doi.org/10.1007/s10980-016-0424-4

Gao, J., & O'Neill, B. (2021). Different spatiotemporal patterns in global human population and built-up land. *Earth's Future, 9*(8). https://doi.org/10.1029/2020EF001920

Garousi, V., Felderer, M., & Mäntylä, M. V. (2019). Guidelines for including grey literature and conducting multivocal literature reviews in software engineering. *Information and Software Technology, 106*, 101–121. https://doi.org/10.1016/j.infsof.2018.09.006

Gaston, K. (2010). *Urban ecology*. Cambridge: Cambridge University Press.

GBIF: The global biodiversity information facility. (2021). *What is GBIF? Available from* https://www.gbif.org/what-is-gbif *[22—28 December 2021]*.

Girma, Y., Terefe, H., & Pauleit, S. (2019). Urban green spaces use and management in rapidly urbanizing countries: The case of emerging towns of Oromia special zone surrounding Finfinne, Ethiopia. *Urban Forestry and Urban Greening, 43*. https://doi.org/10.1016/j.ufug.2019.05.019

Goosen, Z., & Cilliers, E. J. (2020). Enhancing social sustainability through the planning of third places: A theory-based framework. *Social Indicators Research, 150*(3), 835–866. https://doi.org/10.1007/s11205-020-02350-7

Grant, M. J., & Booth, A. (2009). A typology of reviews: An analysis of 14 review types and associated methodologies. *Health Information and Libraries Journal, 26*(2), 91–108. https://doi.org/10.1111/j.1471-1842.2009.00848.x

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008). Global change and the ecology of cities. *Science, 319*(5864), 756–760. https://www.science.org.

Güneralp, B., Lwasa, S., Masundire, H., Parnell, S., & Seto, K. C. (2018). Urbanization in Africa: Challenges and opportunities for conservation. *Environmental Research Letters, 13*(1), Article 015002. https://doi.org/10.1088/1748-9326/aa94fe

Haase, D., Kabisch, S., Haase, A., Andersson, E., Banzhaf, E., Baró, F., Brenck, M., Fischer, L. K., Frantzeskaki, N., Kabisch, N., Krellenberg, K., Kremer, P., Kronenberg, J., Larondelle, N., Mathey, J., Pauleit, S., Ring, I., Rink, D., Schwarz, N., & Wolff, M. (2017). Greening cities – To be socially inclusive? About the alleged paradox of society and ecology in cities. *Habitat International, 64*, 41–48. https://doi.org/10.1016/j.habitatint.2017.04.005

Hima, K., Houémenou, G., Badou, S., Garba, M., Dossou, H. J., Etougbétché, J., Gauthier, P., Artige, E., Fossati-Gaschignard, O., Gagaré, S., Dobigny, G., & Dalecky, A. (2019). Native and invasive small mammals in urban habitats along the commercial axis connecting Benin and Niger, West Africa. *Diversity, 11*(12), 1–20. https://doi.org/10.3390/d11120238

Hugo, M. L. (1979). A note on ethnicity and outdoor recreation: A South African Experience. *South African Journal of Sociology, 19*, 62–70.

Hulme, M., Doherty, R., Ngara, T., New, M., & Lister, D. (2001). African climate change: 1900–2100. *Climate Research, 17*, 145–168. http://www.cru.uea.ac.uk.

Ibáñez-Álamo, J. D., Rubio, E., Benedetti, Y., & Morelli, F. (2017). Global loss of avian evolutionary uniqueness in urban areas. *Global Change Biology, 23*(8), 2990–2998. https://doi.org/10.1111/gcb.13567

Ives, C. D., Lentini, P. E., Threlfall, C. G., Ikin, K., Shanahan, D. F., Garrard, G. E., Bekessy, S. A., Fuller, R. A., Mumaw, L., Rayner, L., Rowe, R., Valentine, L., & Kendal, D. (2016). Cities are hotspots for threatened species. *Global Ecology and Biogeography, 25*, 117–126.

Kartzinel, T.R., Hsing, J. C., Musili, P. M., Brown, B. R. P., & Pringle, R. M. (2019). Covariation of diet and gut microbiome in African megafauna. *Proceedings of the National Academy of Sciences*, *116* (47), 23588–23593. https://doi.org/10.5061/dryad.c119gm5.

Kendal, D., Egerer, M., Byrne, J. A., Jones, P. J., Marsh, P., Threlfall, C. G., Allegretto, G., Kaplan, H., Nguyen, H. K. D., Pearson, S., Wright, A., & Flies, E. J. (2020). City-size bias in knowledge on the effects of urban nature on people and biodiversity. *Environmental Research Letters, 15*(12). https://doi.org/10.1088/1748-9326/abc5e4

Kent, R., Johnson, D. E., & Becker, M. (2001). The influences of cropping system on weed communities of rice in Côte d'Ivoire, West Africa. *Agriculture, Ecosystems and Environment, 87*, 299–307. https://doi.org/10.1016/S0167-8809(01)00153-0

Kigozi, S. P., Kigozi, R. N., Sebuguzi, C. M., Cano, J., Rutazaana, D., Opigo, J., Bousema, T., Yeka, A., Gasasira, A., Sartorius, B., & Pullan, R. L. (2020). Spatial-temporal patterns of malaria incidence in Uganda using HMIS data from 2015 to 2019. *BMC Public Health, 20*, 1913. https://doi.org/10.1186/s12889-020-10007-w

King, A., & Shackleton, C. M. (2020). Maintenance of public and private urban green infrastructure provides significant employment in Eastern Cape towns, South Africa. *Urban Forestry and Urban Greening, 54*. https://doi.org/10.1016/j.ufug.2020.126740

Koricho, H. H., Seboka, A. D., & Song, S. (2020). Assessment of the structure, diversity, and composition of woody species of urban forests of Adama city, Central Ethiopia. *Arboricultural Journal*. https://doi.org/10.1080/03071375.2020.1798702.

Kowe, P., Mutanga, O., Odindi, J., & Dube, T. (2020). A quantitative framework for analysing long term spatial clustering and vegetation fragmentation in an urban landscape using multi-temporal landsat data. *International Journal of Applied Earth Observation and Geoinformation, 88*(102057). https://doi.org/10.1016/j.jag.2020.102057

Kumdet, P. S., Ivande, S. T., & Dami, F. D. (2021). Key drivers of avifauna in greenspace of institutional campuses in a state in Western Africa. *Urban Forestry and Urban Greening, 61*(March), Article 127092. https://doi.org/10.1016/j.ufug.2021.127092

Langat, P. K., Kumar, L., & Koech, R. (2019). Monitoring river channel dynamics using remote sensing and GIS techniques. *Geomorphology, 325*, 92–102. https://doi.org/10.1016/j.geomorph.2018.10.007

Lawler, J. J., Aukema, J. E., Grant, J. B., Halpern, B. S., Kareiva, P., Nelson, C. R., Ohleth, K., Olden, J. D., Schlaepfer, M. A., Silliman, B. R., & Zaradic, P. (2006). Conservation science: A 20-year report card. *Frontiers in Ecology and the Environment, 4*(9), 473–480. https://doi.org/10.1890/1540-9295(2006)4[473:CSAYRC]2.0.CO;2

Lin, T., & Grimm, N. B. (2015). Comparative study of urban ecology development in the U.S. and China: Opportunity and challenge. *Urban Ecosystems, 18*(2), 599–611. https://doi.org/10.1007/s11252-014-0413-9

Lindley, S., Pauleit, S., Yeshitela, K., Cilliers, S., & Shackleton, C. (2018). Rethinking urban green infrastructure and ecosystem services from the perspective of sub-Saharan African cities. *Landscape and Urban Planning, 180*, 328–338. https://doi.org/10.1016/j.landurbplan.2018.08.016

Lüdeck, D., Makowski, M. S., Ben-Shachar, D., Patil, I., Waggoner, P., Wiernik, B. M., Arel-Bundock, V., & Jullum, M. (2021). *Assessment of regression models performance. Accessed 10 Jan 2022*.

Magle, S. B., Hunt, V. M., Vernon, M., & Crooks, K. R. (2012). Urban wildlife research: Past, present, and future. *Biological Conservation, 155*, 23–32. https://doi.org/10.1016/j.biocon.2012.06.018

Malonza, P. K., Granthon, C., & Williams, D. A. (2016). A new species of dwarf gecko in the genus Lygodactylus (squamata: Gekkonidae) from central Kenya. *Zootaxa, 4061* (4), 418–428. https://doi.org/10.11646/zootaxa.4061.4.6

Man, M. P., Weinkauf, J. G., Tsang, M., & Sin, D. D. (2004). Why do some countries publish more than others? An international comparison of research funding, English proficiency and publication output in highly ranked general medical journals. *European Journal of Epidemiology, 19*, 811–817.

Manley, C. B., Rakocinski, C. F., Lee, P. G., & Blaylock, R. B. (2015). Feeding frequency mediates aggression and cannibalism in larval hatchery-reared spotted seatrout, *Cynoscion nebulosus*. *Aquaculture, 437*, 155–160. https://doi.org/10.1016/j.aquaculture.2014.11.012

Marzluff, J. M. (2016). A decadal review of urban ornithology and a prospectus for the future. *Ibis, 159*, 1–13. https://doi.org/10.1111/ibi.12430

McDonald, R. I., Kareiva, P., & Forman, R. T. T. (2008). The implications of current and future urbanization for global protected areas and biodiversity conservation. *Biological Conservation, 141*(6), 1695–1703. https://doi.org/10.1016/j.biocon.2008.04.025

McDonnel, M. (2011). The history of urban ecology: An ecologist perspective. *Urban Ecology: Patterns, Processes and Applications, 9*, 5–13.

McDuff, M. (2000). Thirty years of environmental education in Africa: The role of the wildlife clubs of Kenya. *Environmental Education Research, 6*(4), 383–396. https://doi.org/10.1080/713664697

McIntyre, N. E. (2000). Ecology of urban arthropods: A review and a call to action. *Annals of the Entomological Society of America, 93*(4), 825–835. https://academic.oup.com/aesa/article/93/4/825/22659.

McKinney, M. L. (2006). Urbanization as a major cause of biotic homogenization. *Biological Conservation, 127*(3), 247–260. https://doi.org/10.1016/j.biocon.2005.09.005

McKinney, M. L. (2008). Effects of urbanization on species richness: A review of plants and animals. *Urban Ecosystems, 11*, 161–176.

McPhearson, T., Pickett, S. T. A., Grimm, N. B., Niemelä, J., Alberti, M., Elmqvist, T., Weber, C., Haase, D., Breuste, J., & Qureshi, S. (2016). Advancing urban ecology toward a science of cities. *BioScience, 66*(3), 198–212. https://doi.org/10.1093/biosci/biw002

McPherson, S. C., Brown, M., & Downs, C. T. (2016). Crowned eagle nest sites in an urban landscape: Requirements of a large eagle in the Durban Metropolitan Open Space System. *Landscape and Urban Planning, 146*, 43–50. https://doi.org/10.1016/j.landurbplan.2015.10.004

Meo, S. A., Al Masri, A. A., Usmani, A. M., Memon, A. N., & Zaidi, S. Z. (2013). Impact of GDP, spending on R&D, number of universities and scientific journals on research publications among Asian countries. *PLoS ONE, 8*(6), e66449. https://doi.org/10.1371/journal.pone.0066449

Meo, S. A., Usmani, A. M., & Meo, A. (2014). Impact of R&D expenditures on research publications, patents and high-tech exports among European countries. *Europe Review for Medical and Pharmacological Science, 18*, 1–9.

Miller, J. R., & Hobbs, R. J. (2002). Conservation where people live and work. *Conservation Biology, 16*(2).

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & P.g.. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *BMJ, 339* (7716), 332–336. https://doi.org/10.1136/bmj.b2535

Moomaw, R. L., & Shatter, A. M. (1996). Urbanization and economic development: A bias toward large cities? *Journal of Urban Economics, 40*(21), 13–37.

Moragues-Faus, A., & Carroll, B. (2018). Reshaping urban political ecologies: An analysis of policy trajectories to deliver food security. *Food Security, 10*(6), 1337–1351. https://doi.org/10.1007/s12571-018-0855-7

Moussa, S., Kuyah, S., Kyereh, B., Tougiani, A., & Mahamane, S. (2020). Diversity and structure of urban forests of Sahel cities in Niger. *Urban Ecosystems, 23*(4), 851–864. https://doi.org/10.1007/s11252-020-00984-6

Muchayi, G. K., Gandiwa, E., & Muboko, N. (2017). Composition and structure of woody vegetation in an urban environment in northern Zimbabwe. *Tropical Ecology, 58*(2), 347–356. www.tropecol.com.

Muleya, N., & Campbell, M. (2020). A multisensory approach to measure public space quality in the city of Bulawayo, Zimbabwe. *Town and Regional Planning, 76*, 56–71. https://doi.org/10.18820/2415-0495/trp76i1.5

OECD/SWAC. (2020). Africapolis (database), www.africapolis.org (accessed 11 February 2020).

Okpala, D. C. I. (1978). Urban ecology and residential location theories: Application in Nigeria's socio-cultural milieu. *Socio-Economic Planning Sciences, 12*, 177–183.

Olofsson, H., Brolund, A., Hellberg, C., Silverstein, R., Stenström, K., Österberg, M., & Dagerhamn, J. (2017). Can abstract screening workload be reduced using text mining? User experiences of the tool Rayyan. *Research Synthesis Methods, 8*(3), 275–280. https://doi.org/10.1002/jrsm.1237

Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V. N., Underwood, E. C., D'Amico, J. A., Itoua, I., Strand, H. E., Morrison, J. C., Loucks, C. J., Allnutt, T. F., Ricketts, T. H., Kura, Y., Lamoreux, J. F., Wettengel, W. W., Hedao, P., & Ka, K. R. (2001). Terrestrial ecoregions of the world: A new map of life on Earth. *Bioscience, 51*(11), 933–938.

Orsini, F., Kahane, R., Nono-Womdim, R., & Gianquinto, G. (2013). Urban agriculture in the developing world: A review. *Agronomy for Sustainable Development, 33*(4), 695–720. https://doi.org/10.1007/s13593-013-0143-z

O'Sullivan, O. S., Holt, A. R., Warren, P. H., & Evans, K. L. (2017). Optimising UK urban road verge contributions to biodiversity and ecosystem services with cost-effective management. *Journal of Environmental Management, 191*, 162–171. https://doi.org/10.1016/j.jenvman.2016.12.062

Ouzzani, M., Hammady, H., Fedorowicz, Z., & Elmagarmid, A. (2016). Rayyan-a web and mobile app for systematic reviews. *Systematic Reviews, 5*(1), 1–10. https://doi.org/10.1186/s13643-016-0384-4

Paillette, M., Capy, P., Pla, E., & David, J. R. (1993). Reproductive isolation through homogamy in 2 sympatric habitat races of *Drosophila melanosgaster*. *Revue D Ecologie-La Terre Et La Vie, 48*(2), 229–238.

Patel, Z., Greyling, S., Simon, D., Arfvidsson, H., Moodley, N., Primo, N., & Wright, C. (2017). Local responses to global sustainability agendas: Learning from experimenting with the urban sustainable development goal in Cape Town. *Sustainability Science, 12*(5), 785–797. https://doi.org/10.1007/s11625-017-0500-y

Patterson, L., Kalle, R., & Downs, C. (2016). Predation of artificial bird nests in suburban gardens of KwaZulu-Natal, South Africa. *Urban Ecosystems, 19*(2), 615–630. https://doi.org/10.1007/s11252-016-0526-4

Paul, M. J., & Meyer, J. L. (2001). Streams in the urban landscape. *Annual Review of Ecology and Systematics, 32*, 333–365.

Popoola, L., & Ajewole, O. (2002). Willingness to pay for rehabilitation of Ibadan urban environment through reforestation projects. *International Journal of Sustainable Development and World Ecology, 9*(3), 256–268. https://doi.org/10.1080/13504500209470121

Pyšek, P., Richardson, D. M., Pergl, J., Jarošík, V., Sixtová, Z., & Weber, E. (2008). Geographical and taxonomic biases in invasion ecology. *Trends in Ecology and Evolution, 23*(5), 237–244. https://doi.org/10.1016/j.tree.2008.02.002

Qizhi, M., Long, Y., Wu, K., Ying, L., & Kang, W. (2016). Spatio-temporal changes of population density and urbanization pattern in China (2000–2010). *China City Planning Review, 25*(4), 8–14. https://www.researchgate.net/publication/311707586.

R Core Team. (2016). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

Raji, I. A., & Downs, C. T. (2021). Ficus-frugivore interactions, especially in areas of land-use change, in Africa: A systematic review. *Acta Oecologica, 113*(103774). https://doi.org/10.1016/j.actao.2021.103774

Rantalainen, M. L., Fritze, H., Haimi, J., Pennanen, T., & Setala, H. (2005). Species richness and food web structure of soil decomposer community as affected by the size of habitat fragment and habitat corridors. *Global Change Biology, 11*, 1614–1627. https://doi.org/10.1111/j.1365-2486.2005.00999.x

Rebelo, A. G., Holmes, P. M., Dorse, C., & Wood, J. (2011). Impacts of urbanization in a biodiversity hotspot: Conservation challenges in Metropolitan Cape Town. *South African Journal of Botany, 77*(1), 20–35. https://doi.org/10.1016/j.sajb.2010.04.006

Reynolds, C., Byrne, M. J., Chamberlain, D. E., Howes, C. G., Seymour, C.L., Sumasgutner, P., & Taylor, P. J. (2021). Urban animal diversity in the global South. In C.M. Shackleton, S.S. Cilliers, E. Davoren, & M.J. du Toit (Eds.), *Urban ecology in the global South, cities and nature* (pp. 169–202). Springer Nature.

Richardson, D. M., & Rejmanek, M. (2011). Trees and shrubs as invasive alien species - a global review. *Diversity and Distributions, 17*, 788–809.

Roets, F., Allison, J. D., & Basson, R. J. (2019). Recent records of fruit chafers (Scarabaeidae: Cetoniinae: Cetoniini) in the Southwestern Cape Region of South Africa suggest that range expansions were facilitated by human-mediated jump-dispersal and pre-adaptation to transformed landscapes. *African Entomology, 27*(1), 135–145. https://doi.org/10.4001/003.027.0135

Rogerson, C. M., & Rogerson, J. M. (2020). Municipal caravan parks in South Africa: Geography, management and planning. *Bulletin of Geography. Socio-Economic Series, 49*(49), 109–124. https://doi.org/10.2478/bog-2020-0027

Roy, S., Byrne, J., & Pickering, C. (2012). A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones. *Urban Forestry and Urban Greening, 11*(4), 351–363. https://doi.org/10.1016/j.ufug.2012.06.006

Sánchez-Tójar, A., Lagisz, M., Moran, N. P., Nakagawa, S., Noble, D. W. A., & Reinhold, K. (2020). The jury is still out regarding the generality of adaptive 'transgenerational' effects. *Ecology Letters, 23*(11), 1715–1718. https://doi.org/10.1111/ele.13479

Scholes, M. C., Crouch, A., Erasmus, B. F. N., Schwaibold, U., Vogel, C. H., & Thormeyer, T. (2013). Initiatives to enhance African Environmental Science. *Environmental Development, 5*(1), 164–168. https://doi.org/10.1016/j.envdev.2012.11.007

Seto, K. C., Güneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences of the United States of America, 109*(40), 16083–16088. https://doi.org/10.1073/pnas.1211658109

Shackleton, C. M., Cilliers, S. S., du Toit, M. J., & Davoren, E. (2021). The need for an urban ecology of the global South. In C.M. Shackleton, S.S. Cilliers, E. Davoren, & M. J. du Toit (Eds.), *Urban ecology in the global South* (pp. 1–26). Springer Nature.

Shackleton, C. M., Hurley, P. T., Dahlberg, A. C., Emery, M. R., & Nagendra, H. (2017). Urban foraging: A ubiquitous human practice overlooked by urban planners, policy, and research. *Sustainability, 9*(10). https://doi.org/10.3390/su9101884

Shapiro, S. S., & Wilk, M. B. (1965). *An analysis of variance test for normality (complete samples)* (Vol. 52, Issue 3). https://www.jstor.org/stable/2333709.

Shwartz, A., Turbé, A., Julliard, R., Simon, L., & Prévot, A. C. (2014). Outstanding challenges for urban conservation research and action. *Global Environmental Change, 28*(1), 39–49. https://doi.org/10.1016/j.gloenvcha.2014.06.002

Smales, L. R., Halajian, A., Mokgawa, M. P., & Luus-Powell, W. J. (2017). A new species of Centrorhynchus Lühe, 1911 (Acanthocephala: Centrorhynchidae) from the lizard buzzard *Kaupifalco monogrammicus* (Temminck) (Aves: Accipitridae) in South Africa. *Systematic Parasitology, 94*(3), 423–430. https://doi.org/10.1007/s11230-017-9710-z

Stranga, Y., & Katsanevakis, S. (2021). Eight years of bioinvasions records: Patterns and trends in alien and cryptogenic species records. *Management of Biological Invasions, 12*(2), 221–239. https://doi.org/10.3391/mbi.2021.12.2.01

Tan, P. Y., & bin Abdul Hamid, A.R. (2014). Urban ecological research in Singapore and its relevance to the advancement of urban ecology and sustainability. *Landscape and Urban Planning, 125*, 271–289. https://doi.org/10.1016/j.landurbplan.2014.01.019

Thompson, L. R., Sanders, J. G., McDonald, D., Amir, A., Ladau, J., Locey, K. J., Prill, R. J., Tripathi, A., Gibbons, S. M., Ackermann, G., Navas-Molina, J. A., Janssen, S., Kopylova, E., Vázquez-Baeza, Y., González, A., Morton, J. T., Mirarab, S., Xu, Z. Z., Jiang, L., ….. Knight, R. & The earth microbiome Project consortium (2017). A communal catalogue reveals Earth's multiscale microbial diversity. *Nature, 551* (7681), 457–463. https://doi.org/10.1038/nature24621.

Tóth, Z., Szlavecz, K., Epp Schmidt, D. J., Hornung, E., Setälä, H., Yesilonis, I. D., Kotze, D. J., Dombos, M., Pouyat, R., Mishra, S., Cilliers, S., Yarwood, S., & Csuzdi, C. (2020). Earthworm assemblages in urban habitats across biogeographical regions. *Applied Soil Ecology, 151*. https://doi.org/10.1016/j.apsoil.2020.103530

Trimble, M. J., & van Aarde, R. J. (2014). Supporting conservation with biodiversity research in sub-Saharan Africa' s human-modified landscapes. *Biodiversity Conservation, 23*, 2345–2369. https://doi.org/10.1007/s10531-014-0716-4

Lee, A. T. K., & Nel, H. (2020). BirdLasser: The influence of a mobile app on a citizen science project. *African Zoology, 55*(2), 155–160. https://doi.org/10.1080/15627020.2020.1717376

UNESCO. (2020). *UNESCO Institute for statistics. Accessed 30 October 2022*.

United Nations. (2016). *Urbanization and development: Emerging futures. World Cities Report 2016*. Nairobi: United Nations.

United Nations. (2021). The Sustainable Development Goals Report: Make cities and human settlements inclusive, safe, resilient and sustainable.

United Nations Department of Economic and Social Affairs (Population Division). (2018). *World Urbanization Prospects: The 2018 Revision, Online Edition*.

United Nations Department of Economic and Social Affairs (Population Division). (2019). *World Population Prospects 2019, Online Edition. Rev. 1*.

United Nations. Economic Commission for Africa (2018). Towards Achieving the African Union's recommendation of expenditure of 1% of GDP on research and development. Addis Ababa. © UN. ECA. https://hdl.handle.net/10855/24306.

van der Walt, L., Cilliers, S. S., du Toit, M. J., & Kellner, K. (2015). Conservation of fragmented grasslands as part of the urban green infrastructure: How important are species diversity, functional diversity and landscape functionality? *Urban Ecosystems, 18*(1), 87–113. https://doi.org/10.1007/s11252-014-0393-9

van Zyl, A. J. (1994). The influence of the environment on breeding success of a suburban population of Crested Barbets *Trachyphonus vaillantii*. *Ostrich, 65*(3–4), 291–296.

Vinkler, P. (2008). Correlation between the structure of scientific research, scientometric indicators and GDP in EU and non-EU countries. *Scientometrics, 74*(2), 237–254. https://doi.org/10.1007/s11192-008-0215-z

Wangai, P. W., Burkhard, B., & Müller, F. (2016). A review of studies on ecosystem services in Africa. *International Journal of Sustainable Built Environment, 5*(2), 225–245. https://doi.org/10.1016/j.ijsbe.2016.08.005

Widdows, C. D., & Downs, C. T. (2016). Urban roost temperatures of large-spotted-genets: The effect of anthropogenic structures. *Journal of Thermal Biology, 57*, 66–71. https://doi.org/10.1016/j.jtherbio.2016.02.004

World Bank. (2021). *Urban population growth. Accessed 30 October 2022*.

World Cities Report. (2016). *Urbanization and development: Emerging futures*.

Wu, J., Xiang, W.-N., & Zhao, J. (2014). Urban ecology in China: Historical developments and future directions. *Landscape and Urban Planning, 125*, 222–233. https://doi.org/10.1016/j.landurbplan.2014.02.010

Yvoz, S., Cordeau, S., Zuccolo, C., & Petit, S. (2020). Crop type and within-field location as sources of intraspecific variations in the phenology and the production of floral and fruit resources by weeds. *Agriculture, Ecosystems and Environment, 302*. https://doi.org/10.1016/j.agee.2020.107082

Zhang, X. Q. (2016). The trends, promises and challenges of urbanisation in the world. *Habitat International, 54*, 241–252. https://doi.org/10.1016/j.habitatint.2015.11.018

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