Green cities and the risk for vector-borne disease transmission for humans and animals: a scoping review

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ABSTRACT

Background: Greening cities is a nature-based strategy to sustainable urban development that integrates natural elements like plants or water bodies, to mitigate climate change impacts and enhance human well-being. However, urban green infrastructures (UGIs) can influence the distribution of disease vectors, potentially affecting vector-borne diseases (VBDs). UGIs may provide new suitable environments for urban vectors, while also creating opportunities to mitigate VBD risks through

predation, competition, and dilution effects. This article examined the relationships between UGIs, vectors, and associated pathogens, impacting both human and animal health, highlighting knowledge gaps and identifying research priorities to support VBD risk mitigation measures and to guide smart urban planning and design.
Methods: A systematic literature search was conducted following PRISMA guidelines in three databases (Pubmed, Scopus, Web of Science). Selected articles involved (i) any aspect of a urban vector system, (ii) in UGIs, and (iii) statistically analyzing the effects of UGIs on VBD risk. Methods employed to characterize UGIs and VBDs were described and the identified impacts were summarized by vector group.
Results: Among the 99 articles reviewed, most addressed mosquito-pathogen systems (67) and tick-pathogen systems (29), with studies often confined to a single city or several cities within the same country and focused on one vector group. Urban vegetation generally appeared to heighten the risk of tick-borne diseases. In contrast, the influence of UGIs on the risk of mosquito-borne diseases varied depending on the vector system and on the environmental and climatic context. The diversity of indicators used to assess UGIs and VBD risks may affect the observed impact on VBD risk.
Conclusion: Given the increasing popularity of urban greening, it is crucial to investigate its potential implications for public health, and thereby urban planning decisions. However, the lack of standardized protocols complicates the accurate assessment of the effects of UGIs on the risk for VBD emergence and transmission and consequently, on potential mitigation measures.

Keywords: mosquitoes, ticks, sand flies, chigger mites, urban green infrastructure, city

Introduction

Urbanization is an ongoing global phenomenon that brings both opportunities and challenges. By 2050, approximately 70% of the world population will live in urban areas (UN Habitat, 2022). Urbanization offers opportunities to reduce poverty and inequality by increasing access to education and healthcare (United Nations, 2020). However, the rapid growth of cities, often poorly controlled, has led to social and economic inequalities, as well as health issues, primarily affecting the most vulnerable populations (Kuddus et al., 2020). City development drives environmental disruptions by modifying land use. As urban areas are responsible for most of the world's carbon emissions, increasing urbanization could further exacerbate pollution (UN Habitat, 2022). Urban landscapes are increasingly vulnerable to extreme events such as flooding or urban heat islands, negatively impacting human health (Heaviside et al., 2017). Climate change is expected to intensify both the frequency and severity of these events (Vautard et al., 2020). Additionally, urbanization induces habitat loss and fragmentation, leading to decreased biodiversity (E. L. Jones & Leather, 2012). Urban landscapes are a mosaic of highly heterogeneous environments (Breuste et al., 2008) that form complex interfaces connecting natural, rural, peri-urban, and urban ecosystems (Honnen & Monaghan, 2017). These interfaces increase interactions between humans, livestock, and wildlife, thereby increasing the risk of zoonotic pathogen emergence and transmission (Hassell et al., 2017; Pearce et al., 2018). High human density in urban areas and global connectivity through trade and travel further facilitate the introduction and spread of arthropod vectors and the pathogen agents they carry (Weaver & Reisen, 2010).

Greening cities is recognized as a key intervention to "make cities inclusive, safe, resilient, and sustainable," as outlined by the United Nations (UN) Sustainable Development Goals (United Nations, 2022). This concept involves integrating vegetation within urban environments through various initiatives, such as creating blue spaces (e.g, lakes, rivers, ponds) (Hyseni et al., 2021), preserving parks, planting trees, and establishing green corridors, which are defined as interconnected landscape elements that help to protect the environment (Aly & Amer, 2010). Urban green spaces mitigate environmental challenges and contribute to various ecosystem services. It reduces heat island effects (Gunawardena et al., 2017; Marando et al., 2022), alleviates flooding (Bai et al., 2018), and reduces air pollution by capturing carbon dioxide (Baró et al., 2014; Mexia et al., 2018). Moreover, urban green spaces restore and maintain city biodiversity (Archibald et al., 2017; Vergnes et al., 2012). Substantial evidence highlights the positive impact of urban greening on human well-being and health, including stress reduction, increased opportunities for physical activities that can lower the risk of non-communicable diseases like hypertension and obesity, and a decrease in respiratory diseases (Van Den Bosch & Ode Sang, 2017). These benefits align with recommendations from the recently established One Health High Level Expert Panel (OHHLEP), which promotes a holistic approach to health for people, animals, and the environment (WHO, 2021).

While Urban Green Infrastructures (UGIs; see Boxes 1 and 2) provide ecological and health benefits, they can also create new habitats within cities that favour the establishment and spread of arthropod vectors of human and animal pathogens. This raises the risk of Vector-Borne Disease (VBD, see Box 1) emergence and transmission in urban areas (Fournet et al., 2024). Hematophagous (blood-feeding) arthropods are key players in transmitting pathogens than can impact human and animal health. Many VBDs are on the rise worldwide, with their arthropod vectors spreading beyond native ranges due to climate change, globalization, and the intensification of international trade and travel (Cuthbert et al., 2023). Arthropod vectors such as mosquitoes and ticks are particularly able to adapt to new environments, often acting as invasive species due to their specific ecological, biological, and genetic traits (Renault et al., 2024). As such, UGIs may inadvertently increase habitat suitability for these disease vectors in urban areas, thereby increasing human-vector contact in these densely populated environments. On the other hand, UGIs may also support the establishment of predators and competitors of urban arthropod vectors, facilitating novel trophic networks that could reduce vector populations and mitigate VBD

risk (Prihandi & Nurvianto, 2022). Actually, increased biodiversity in UGIs can lead to shifts in vector population dynamics, host availability, and/or the presence of biological control agents, potentially resulting in dilution effects for pathogens (Keesing & Ostfeld, 2021).

This scoping review examined how UGIs and the process of urban greening influence VBD risks for humans and animals. The objectives were to: (i) assess the influence of different UGIs on the presence and abundance of vectors (e.g., mosquitoes, ticks, sand flies, and chigger mites) and VBD dynamics (e.g., dengue fever, West Nile fever, malaria, Lyme disease, leishmaniasis, and scrub typhus); (ii) identify UGIs characteristics such as connectivity, surface area, proximity to residential areas, and plants species that most affect vector populations and VBD dynamics; and (iii) compare the effects of UGIs on the same vector species across different locations, as well as within the same location when possible. Moreover, we identified critical knowledge gaps that require further research to inform VBD mitigation measures and guide the smart design of UGIs aiming to minimize VBDs risks while fostering greener cities. This work will help city planners and policymakers in understanding the VBD risks linked to urban greening, tailored to each city's epidemiological context, enabling them to implement landscape management strategies in a thoughtful and informed way.

Box 1. General definitions

Vector: an invertebrate, typically an arthropod, that transmits an infectious agent (Duvallet et al., 2018; Wilson et al., 2017) from one host (human or animal) to another (Blanc & Gutiérrez, 2015).

Vector Borne Disease (VBD): human or animal diseases caused by parasites, viruses, and bacteria that are transmitted by vectors (WHO, 2020).

Risk: According to the United Nations Office for Disaster Risk Reduction (UNDRR) (UNDRR, 2019), a risk is a "potential loss of life, injury or destroyed assets which could occur to a system, society or a community, determined probabilistically as a function of hazard, exposure, vulnerability, and capacity." The risk may be health, economic, ecological, social or political. It can be summarized as risk = hazard x exposure x vulnerability.

VBD risk: According to the UNDRR disaster risk definition (UNDRR, 2019), VBD risk can be defined as a hazard linked to an infected vector x exposure to this vector x vulnerability (of the vertebrate host population).

Urban green infrastructure (UGI): L. Jones et al. (2022) introduced the term "Urban Green Infrastructure" to categorize various green and blue spaces within urban environments. Their typology resulted in nine categories, including gardens, parks, amenity areas, other public spaces (e.g., cemeteries), linear features, constructed green infrastructures (e.g., green roofs or green walls), and three additional categories for urban water spaces. This review used the overarching term "urban green infrastructure" more broadly to also include vegetation in neglected urban spaces, such as wastelands and vacant lots (Yang et al., 2019), urban agriculture farms and urban forests (see Box 2).

Box 2. Classification of UGIs

We developed a classification system to describe urban green infrastructures (UGIs) as follows:

- **Urban green space typology:** This typology is based on the framework of L. Jones et al. (2022), which classifies urban green spaces according to their use, land cover, ownership, geometry, and management. For example, if an UGI is described as an 'urban park' or as

the connectivity between urban green spaces, it will be included in the class 'Urban green space typology'. This classification allows detailed descriptions including:

- **Use:** urban parks, cemeteries, zoos, urban farms, urban agriculture, etc.
- **Ownership:** residential areas, publicly-owned parks, etc.
- **Geometry:** green roofs, walls, etc.

Key characteristics of urban green spaces can be described by:

- **Shape and size:** This refers to the structural characteristics of urban green spaces, including overall shape, perimeter, and surface area.
- **Connectivity:** This term denotes the interconnectedness of green spaces or their connection to peri-urban environments.
- **Relevant features:** This refers to outstanding areas within urban green spaces, such as trails and edges.
- **Surrounding land cover:** This refers to the type of vegetation or soil present near urban green spaces.
- **Management:** This refers to maintenance approaches to the vegetation within the urban green space, such as grass-cutting or watering schedules.
- **Distance to urban green spaces:** Distance of sampling points to urban green areas.

- **Urban vegetation description:** This description focuses on the detailed characterization of urban vegetation including land cover, vegetation indexes, and specific vegetation traits such as height, tree density, diversity, etc. It provides a comprehensive description of the vegetation around the sampling points across different studies. For example, vegetation described using Normalized Difference Vegetative Index (NDVI) within a 200-meter buffer around a mosquito trap will be included in this category. Key components include:
  - **Type of vegetation:** This describes vegetation based on its land cover type, including grass, deciduous forest, etc.
  - **Litter composition:** This describes the composition of organic litter found within the vegetation, such as leaves and twigs.
  - **Vegetation index:** This index allows for an alternative vegetation description through remote sensing indices, tree cover percentage, or overall vegetation cover. The NDVI, is a remote sensing index used to determine the presence of vegetation. It ranges from -1 to 1, and the higher it is, the denser the vegetation (Martinez & Labib, 2023).
  - **Vegetation characteristics:** This encompasses many aspects of vegetation traits, including height, diversity, shade, size of tree holes, tree density, etc.
  - **Plant species:** This involves a thorough characterization of vegetation, with a focus on the presence and attributes of specific plant species studied within the area.
  - **Distance to urban vegetation:** Distance of sampling points to urban vegetation.

Methods

The 'Preferred Reporting Items for Systematic Reviews and Meta-Analyses' (PRISMA) guidelines (Page et al., 2021) were used to conduct a scoping review examining the links between UGIs, vectors, and VBD risk (Box 1). Key methodological steps are outlined in Figure 1 and detailed below. The PRISMA check-list is available in Additional file 1: Text S1.

Search strategy

A comprehensive search was conducted in October 2022 using three online databases: PubMed, Scopus, and Web of Science. The search strategy combined key concepts related to

"urban," "greening," "vector," and "vector-borne disease." All possible associated keywords for each key concept were included. A proximity operator was used when available to ensure that "greening" keywords referred specifically to urban areas (Additional file 2: Text S2). The query targeted titles, abstracts, and keywords, and searches were conducted using the CADIMA web tool (Kohl et al., 2018). All articles published up to October 6, 2022 (with no specified start date) were considered. Given that urban greening is a dynamic and relatively new management approach, relevant articles were expected to be limited. As a proxy for "greening cities", all articles assessing any component of VBD risk related to any aspect of UGIs were included.

Article selection

After the systematic database search, duplicates were automatically removed using CADIMA tool. The remaining articles underwent an initial systematic screening based on titles and abstracts, using the following inclusion criteria: articles (i) must be original research published in peer-reviewed journals in English; (ii) must address any aspect of the vector system in relation to human or animal health (e.g., vector species, pathogens, or hosts); and (iii) must focus on at least one UGI (e.g., urban park, green/blue corridor, vegetation index or similar). Subsequently, a full-text screening was conducted to further refine the selection. In this step, articles were included if they: (i) referred specifically to urban areas; (ii) examined any aspect of UGIs (e.g., urban parks, vegetation cover indices, or tree species); and (iii) statistically analyzed the effect of different UGIs (e.g., multiple parks, varying vegetation cover, or different tree species) on VBD risk including hazard, exposure, and/or vulnerability. Commentaries, editorial reviews, opinion papers, and articles from grey literature were excluded, as well as those focusing on VBDs in urban environments without reference to green spaces. Two of the authors (MM and CB) independently reviewed both screenings (titles and abstracts, and full-text articles) for inclusion and extracted articles data, with any disagreement resolved by consensus

Data extraction and description

From each article, the following metadata was extracted: location (continent, country, city), year of publication, year of sampling, vectors involved (i.e., groups of vectors (mosquitoes, ticks, sand flies, chigger mites), including genus, species, and life stage), as well as the disease and host of interest, when available. The methodology used for vector sampling was also documented, including the type of trap and frequency of collection, as well as the diagnostic tests employed to detect pathogens. The risk indicators from the studies were categorized into three groups: **"**vector data**"**, for indicators addressing vector presence, abundance, or density; **"**vector-borne pathogen data**"**, for indicators related to vector infection by pathogens or host disease prevalence/incidence; and **"**vector and vector-borne pathogen data**"**, for studies encompassing both vector and pathogen aspects. Metadata related to the description of UGIs were extracted as well, including the type of methodology used (e.g., general classification based on usage, remote sensing, or field description), the variables monitored (e.g., land-use classification or Normalized Difference Vegetation Index (NDVI)), and the buffer size used around sampling points, when available. The variables used to describe UGIs were classified into two categories: (1) urban green space typology and (2) urban vegetation description (Box 2).

Finally, the statistical framework used to analyze the effect of UGIs on VBD risk was also extracted from each article. All combinations of VBD risk and UGI variables (*VBD risk variable ~ UGI variable*) tested statistically were collected. For each interaction, the effect of UGI on VBD risk was classified into four categories: (i) harmful, when a variable describing the UGI increases VBD risk, (ii) beneficial, when a variable describing the UGI decreases VBD risk, (iii) variable when the effect of the UGI variable on VBD risk varies across sampling sites, independently of site characteristics, or (iv) no association when there was no significant relationship between the UGI variable and VBD risk. The data extracted from all of the articles can be found in Additional file 3: Dataset S1. All data and additional files are available online (Bartholomée & Mercat, 2025).

Results

Overview

The literature search yielded 1558 articles, of which 99 were included in the final selection after the different screening steps (Figure 1). Two-thirds of the articles focused on mosquitoes and mosquito-borne diseases or pathogens (67.7%, 67/99). One third addressed ticks and tick-borne diseases or pathogens (29.3%, 29/99). The remaining 3 articles examined chigger mites and sand flies. The main results of each article are detailed in Additional file 4: Table S1. Ninety percent of the articles featured studies conducted in a single city and country. However, studies in six articles investigated multiple cities within the same country (Levytska et al., 2021; Overzier et al., 2013; Pedrosa et al., 2020; Schorn, et al., 2011a; Schorn, et al., 2011b; Yadouléton et al., 2010) , and three reported on studies carried out in cities of different countries (Carbó-Ramírez et al., 2017; Georganos et al., 2020; Talbot et al., 2021). The geographic distribution of studies varied (Figure 2A). Most mosquito-related articles originated from North America (37.3%, 25/67) and South America (28.4%, 19/67), whereas more than 70% of tick-related articles originated from Europe (72.4%, 21/29). The articles were published between 1999 and 2022, with a notable increase in mosquito-related articles after 2007 and tick-related articles after 2010 (Figure 2B).

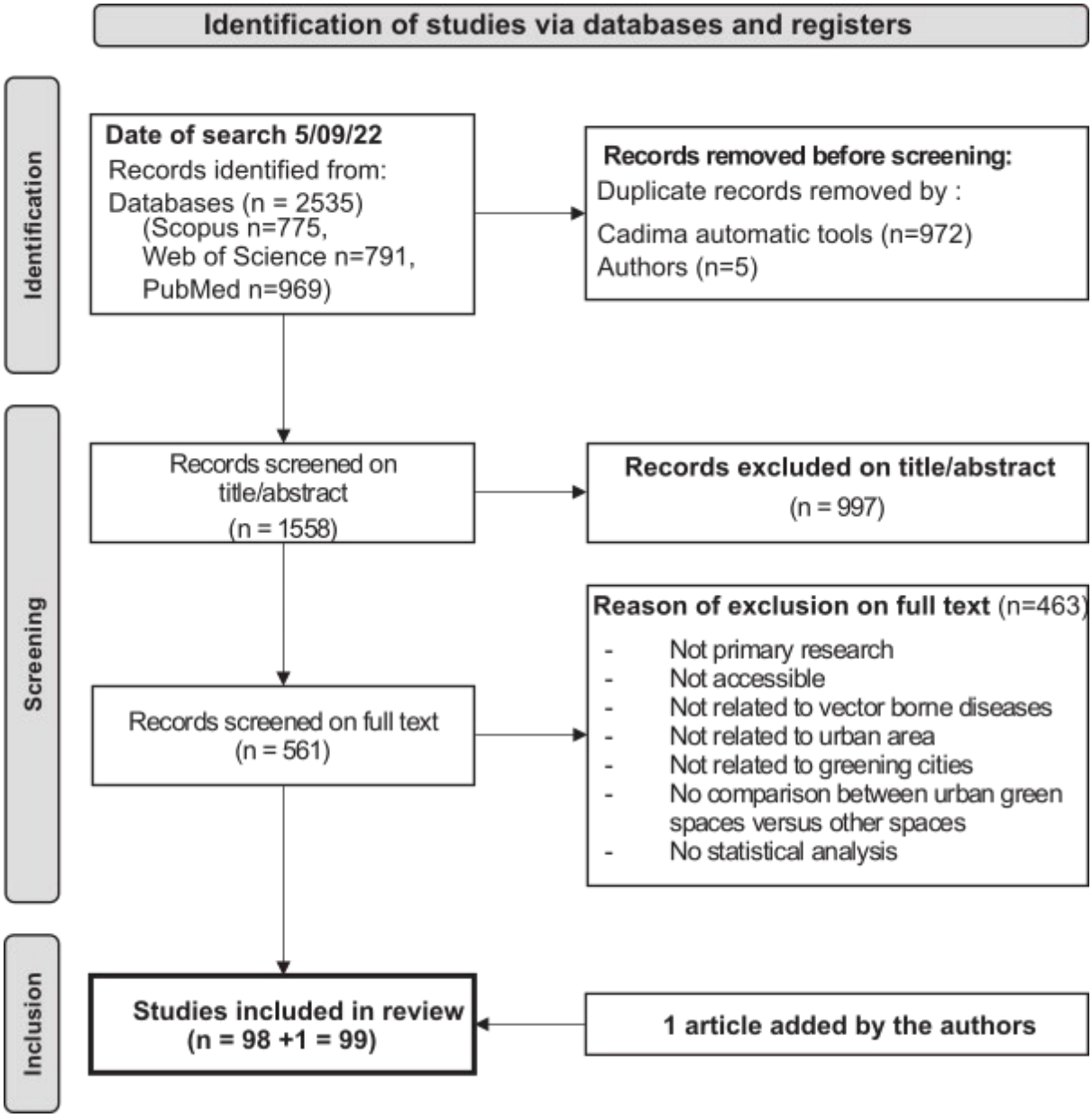

Figure 1 - PRISMA flow diagram for systematic review. It shows the number of article identified through cross-checking references .

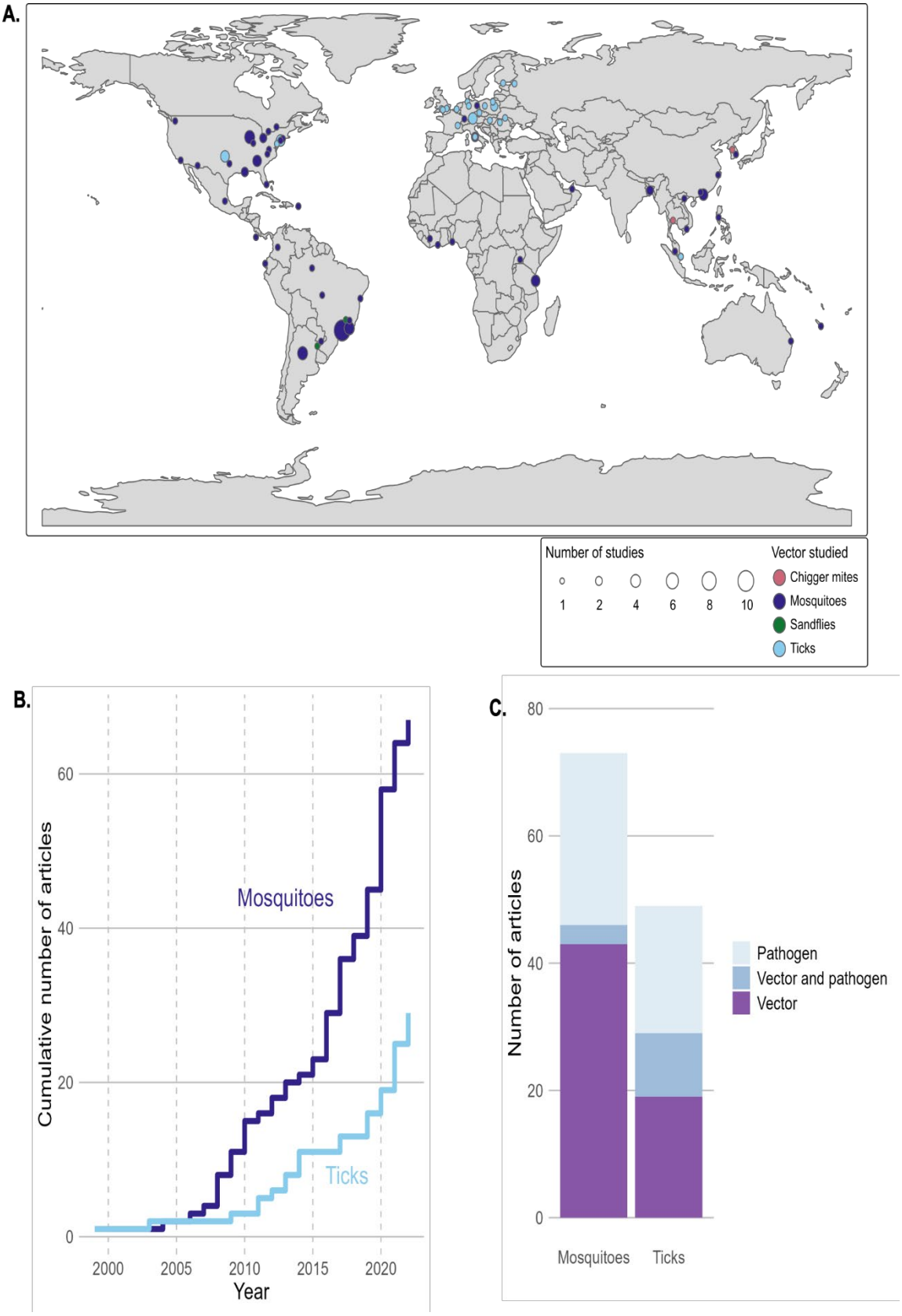

Figure 2 - Overview of the articles included. (A) Global distribution of articles (here a study refers to the investigation of a vector in a particular city, at a particular time, by a particular research team. For example, a single article may include two studies if the research was carried out in two different cities). An interactive map with the references of the studies (Bartholomée & Mercat, 2024) is available at

https://zenodo.org/records/15096123. (B) Cumulative number of included articles by type of vector by year of publication for mosquito-pathogen and tick-pathogen systems. (C) Number of included articles by type of data for mosquito-pathogen and tick-pathogen systems.

The selected articles were categorized based on their focus: those examining vectors alone were classified under the 'vector data' category, while those studying pathogens within hosts or vectors were classified under the 'vector-borne pathogen data' category (Table 1 and Figure 2C). Among the 67 articles on mosquito-pathogen systems, 43 concentrated on mosquito data and 25 on mosquito-borne pathogens data. Only three articles addressed both mosquito and mosquito-borne pathogens data: yellow fever virus and *Haemagogus leucocelaenus* and *Haemagogus janthinomys/capricornii* (Abreu et al., 2022), dengue virus and *Aedes aegypti* (Francisco et al., 2021), and malaria and *Anopheles gambiae* s.l. (Yadouléton et al., 2010). The most studied mosquito genera were *Aedes* (35 articles), followed by *Culex* (13 articles) and *Anopheles* (three articles). Associated mosquito-borne diseases included West Nile fever (10 articles), dengue fever (six articles), and malaria (four articles). Of the 29 articles on tick pathogen systems, 19 investigated the effects of UGIs on tick vectors, 20 examined the effects of UGIs on tick-borne pathogens, and 10 addressed both categories. Ticks from the *Ixodes* genus were studied the most (18 articles), with a focus on *Ixodes ricinus* (14 articles). The most extensively studied pathogen was the *Borrelia* spp. bacterium (11 articles) and small rodents were the most frequently studied host group (seven articles).

Table 1: Classification of articles in accordance with the vector-pathogen system and the UGIs under investigation

Group of vector-pathogen system and UGI description			Number
MOSQUITO-PATHOGEN SYSTEMS			67
Mosquito data			43
	Stage	Adult	25
		Immature	19
		Egg	8
	Species	*Aedes*	35
		Aedes aegypti	14
		Aedes albopictus	17
		Aedes hendersoni	1
		Aedes japonicas	1
		Aedes mediovittatus	1
		Aedes triseriatus	1
		Aedes vexans	1
		Culex	13
		Culex antillummagnorum	1
		Culex dolosus	1
		Culex pipiens	4
		Culex quinquefasciatus	6
		Culex restuans	3
		Culex salinarius	1
		Anopheles	3
		Anopheles gambiae s.l.	1
Mosquito-borne pathogen data			25
	Arbovirus		22
		Chikungunya virus – CHIKV	1
		Dengue virus – DENV	6
		Ross River virus – RRV	1
		Saint Louis Encephalitis virus - SLEV	1
		West Nile virus – WNV	10
		Yellow fever virus – YFV	1
	Avian haemosporidian parasites – *Avian haemosporidia*		1
	Malaria parasites – *Plasmodium* spp.		4
Mosquito and mosquito-borne pathogen data			3
	Dengue – *Aedes aegypti, Aedes albopictus*		1

	Malaria – *Anopheles gambiae* s.l.			1
	Yellow fever – *Haemagogus leucocelaenus, Haemagogus janthinomys/capricornii*			1
Pathogen diversity				2
	Avian haemosporidian parasites			1
	West Nile virus			1
TICK-PATHOGEN SYSTEMS				29
Tick data				19
	Stage	Adult		13
		Immature		18
	Species	*Amblyomma*		4
		Amblyomma americanum		1
		Dermacentor		2
		Dermacentor marginatus		1
		Haemaphysalis		5
		Haemaphysalis longicornis		1
		Ixodes		18
		Ixodes apronophorus		1
		Ixodes inopinatus		1
		Ixodes persulcatus		1
		Ixodes ricinus		13
		Ixodes scapularis		2
		Ixodes trianguliceps		1
		Rhipicephalus	*Rhipicephalus turanicus*	1
Tick-borne pathogen data				20
	Anaplasmosis – *Anaplasma phagocytophilum*			5
	Ehrlichiosis – *Ehrlichia* spp.			1
	Lyme-*Borrelia* spp.			11
	Piroplasmosis/Babesiosis – *Babesia* spp.			2
	Rickettsiosis - *Rickettsia* spp.			4
	Multiple tick-borne pathogens			4
Tick and Tick-borne pathogen data				10
	Anaplasmosis – *Ixodes ricinus*			2
	Lyme – *Ixodes ricinus*			7
	Lyme – *Ixodes scapularis*			1
	Rickettsiosis – *Ixodes ricinus*			1
OTHER VECTOR-PATHOGEN SYSTEMS				3
Sand flies				1
	Sand flies data	*Lutzomyia*	*Lutzomyia longipalpis*	1
Chigger mites				2
	Chigger mites-borne pathogen data	Human scrub typhus		1
TYPE OF UGI DESCRIPTION				
Urban green space typology				64
	Mosquito-pathogen systems			37
	Tick-pathogen systems			23
	Other vector-pathogen systems			3
Description of urban vegetation				58
	Mosquito-pathogen systems			44
	Tick-pathogen systems			11
	Other vector-pathogen systems			1

UGIs were described using the urban green space typology or the urban vegetation around the sampling points (Table 1, Box 2). Both approaches were commonly used for mosquito-pathogen systems (Figure 3), appearing in 44 and 37 articles out of 67, respectively. In contrast, for tick-borne pathogen systems articles (Figure 4), the urban green space typology was the dominant approach used in 21 out of 29 articles. Below, the impact of UGIs on mosquito-pathogen systems, then on tick-pathogen systems and finally on other vector-pathogen systems is examined.

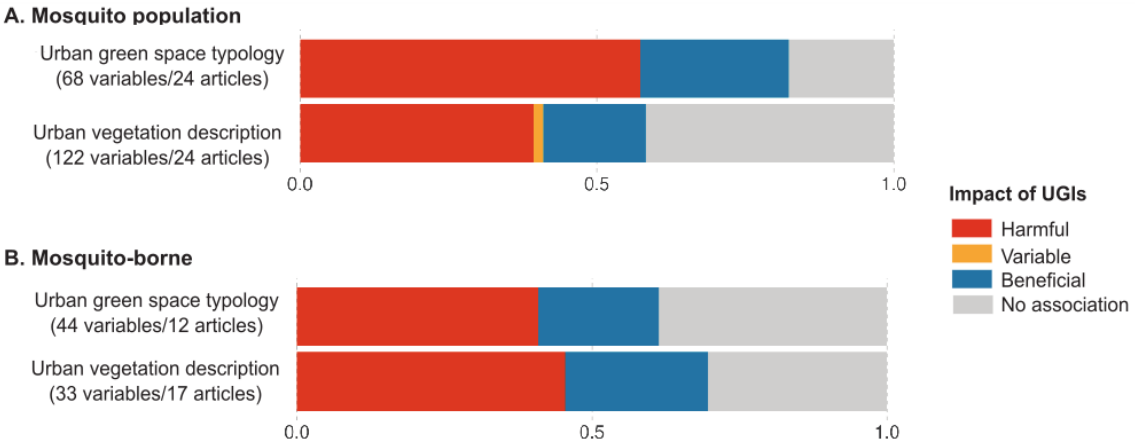

Figure 3 - Impact of UGIs on mosquito-pathogen systems. (A) Impact of UGIs on mosquito populations. (B) Impact of UGIs on mosquito-borne pathogen (prevalence of infection in host or vector). Numbers in brackets indicate the total number of variables tested and the total number of articles from which these variables were extracted. Colors represent the proportion of variables in all studies that increased risk (harmful effect, red), decreased risk (beneficial effect, blue), varied (variable effect, yellow), or showed no association (grey) with risk.

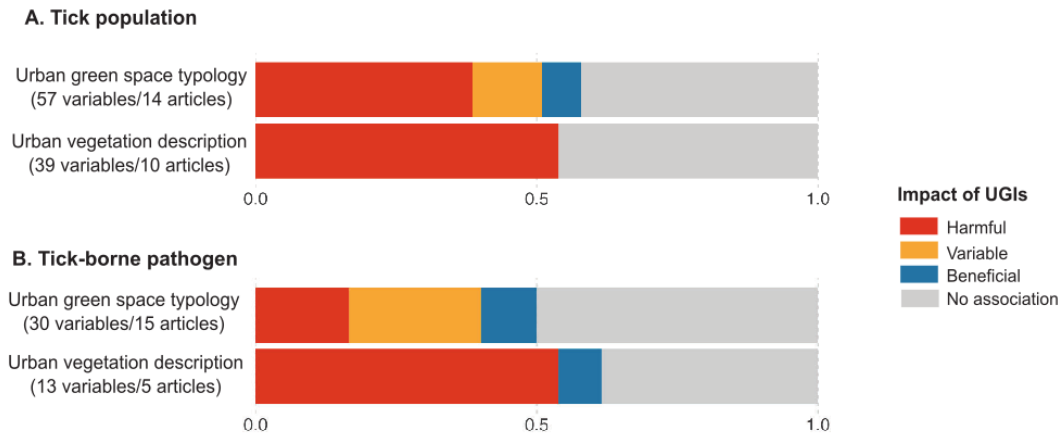

Figure 4 - Impact of UGIs on tick-pathogen systems. (A) Impact of UGIs on tick populations. (B) Impact of UGIs on tick-borne pathogen (prevalence of infection in host or vector). Numbers in brackets indicate the total number of variables tested and the total number of articles from which these variables were extracted. Colors represent the proportion of variables in all studies that increased risk (harmful effect, red), decreased risk (beneficial effect, blue), varied (variable effect, yellow), or showed no association (grey) with risk.

Mosquito-pathogen system

For each mosquito genus, we first addressed the effects of UGIs on mosquito populations, followed by their influence on mosquito-borne pathogens, and we concluded with overarching insights into the impact of UGIs on the specific mosquito-pathogen system relationship.

Effects on Aedes-pathogen system

Effects on *Aedes* populations

Of the 35 articles studying the genus *Aede*s, 17 focused on *Aedes albopictus* and 14 on *Aedes aegypt*i (Table 1). *Aedes vexans*, *Aedes mediovittatus*, *Aedes japonicus*, *Aedes triseriatus* and *Aedes hendersoni* each appeared in a single article. In this section, we mainly describe the results for the two major disease vectors, *Ae. aegypti* and *Ae. albopictus*.

UGIs appeared to be unfavorable habitats for *Ae. aegypti* (Figure 5A). The impact of UGIs on *Ae. aegypti* was mainly assessed using urban vegetation description indicators rather than urban green space typology indicators (Figure 5A), with most studies focusing on immature stages (78.6%, 11/14). Consistently, higher numbers of *Ae. aegypti* immature stages and adults have been recorded in densely urbanized areas compared to UGIs in several locations in Brazil. This trend has been observed using urban vegetation description indicators, such as in Rio de Janeiro (Honório et al., 2009) and in São Paulo (Arduino et al., 2020), and with urban green spaces typology indicators, such as in Mariana, Ouro Preto (Pedrosa et al., 2020) and São Paulo (Lorenz et al., 2020).

Using urban vegetation description indicators, locations with a high percentage of vegetation coverage, like urban forests or urban grass in Singapore (Sun et al., 2021) or arboreal vegetation in Argentina (Benitez et al., 2020) exhibited low mosquito abundance. Moreover, in New Orleans (United States of America, USA) (de Jesús Crespo & Rogers, 2021) cemeteries with a higher heat index supported higher mosquito populations than cemeteries with lower heat index. Reduced temperature in vegetated areas may explain why *Ae. aegypti* was less commonly found in areas with more vegetation cover (de Jesús Crespo & Rogers, 2021).

Using urban green space typology indicators, *Ae. aegypti* oviposition rates were observed to be higher (i) near houses compared to deeper forested areas in Rio de Janeiro (Lourenço-de-Oliveira et al., 2004), and (ii) in the peripheral part of the park with less vegetation near urban areas compared to the densely vegetated inner sections of the park (Heinisch et al., 2019). Also, other countries, including the USA (Puerto Rico) (Cox et al., 2007) and Vietnam (Huynh & Minakawa, 2022), have shown similar results. Breeding sites could be associated with residential areas, where artificial breeding containers like jars or planters were common (Huynh & Minakawa, 2022).

Despite the general negative association between *Ae. aegypti* and UGIs, the mosquito still thrived in areas with vegetation near breeding sites, even in densely populated environments. For instance, using the urban vegetation description, Estallo et al. (2018) observed in Córdoba (Argentina) that vegetation adjacent to breeding sites was positively associated with the likelihood of these sites supporting mosquito larvae. In the same city, Andreo et al. (2021) found that the distance to vegetated areas could have a variable impact on the presence of breeding sites depending on the month, from decreasing their presence in November to increasing it in March. A study by Landau & van Leeuwen (2012) found that *Ae. aegypti* adult abundance in Tucson (USA) increased with the percentage of medium to tall trees within 10 to 50 meters of trap locations. No association was observed with herbaceous or shrub vegetation (Landau & van Leeuwen, 2012). Using the urban green space typology, Sun et al. (2021) observed that adult *Ae. aegypti* were more abundant in areas in Singapore with buildings and managed vegetation than in zones with dense forest cover. In contrast to *Ae. aegypti,* UGIs generally supported *Ae. albopictus* populations, although the effects varied depending on the specific relationship between mosquito stage and UGI studied, using urban vegetation description and urban green space typology indicators (Figure 5B).

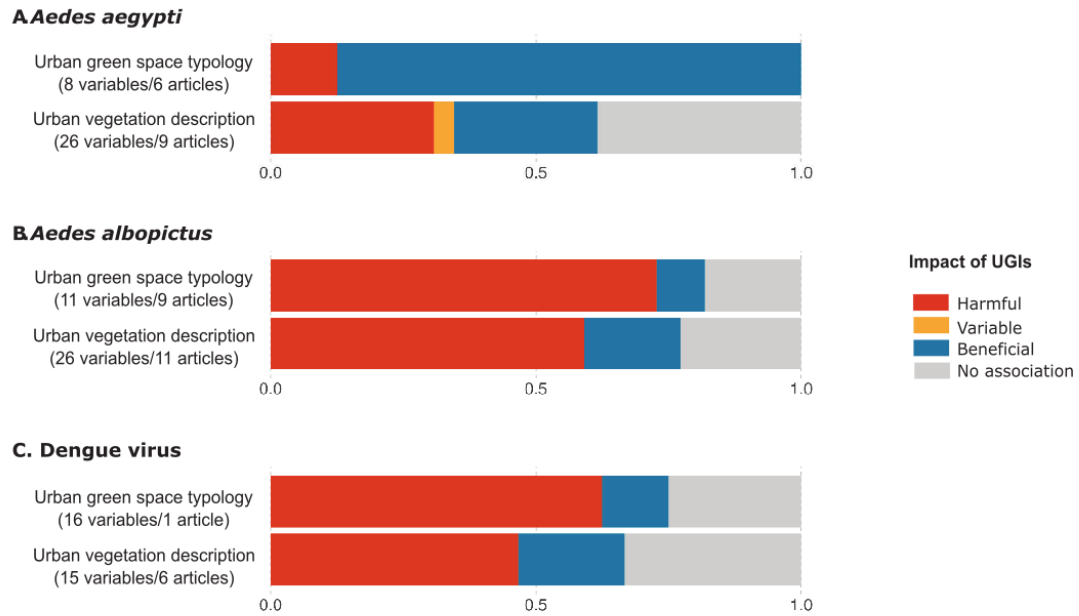

Figure 5 - Impact of UGIs on *Aedes*-pathogen systems. (A) Impact of UGIs on *Aedes aegypti* populations. (B) Impact of UGIs on *Aedes albopictus* populations. (C) Impact of UGIs on Dengue virus dynamics (prevalence of infection in host or vector). Numbers in brackets indicate the total number of variables tested and the total number of articles from which these variables were extracted. Colors represent the proportion of variables in all studies that increased risk (harmful effect, red), decreased risk (beneficial effect, blue), varied (variable effect, yellow), or showed no association (grey) with risk.

Aedes albopictus eggs and larvae were more abundant in urban green spaces near residential areas than in densely urbanized zones. This trend has been observed in Brazilian cities using urban green space typology indicators, such as in Mariana and Ouro Preto (Pedrosa et al., 2020) and São Paulo (Heinisch et al., 2019; Wilke et al., 2017), as well as using urban vegetation description indicators, such as in Rio de Janeiro (Honório et al., 2009; Lourenço-de-Oliveira et al., 2004) and São Paulo (Arduino et al., 2020). Urban green spaces can support more immature mosquito stages than more urbanized spaces. For instance, in Miami (USA), urban farms hosted more *Ae. albopictus* larvae compared to densely built areas (Wilke et al., 2020). Similarly, in Greensboro (USA) urban forests and urban parks yielded more *Ae. albopictus* eggs than campuses (Schwarz et al., 2020). Urban vegetation significantly supported the presence of breeding sites. Examples include the percentage of urban vegetation linked to egg abundance in Italy (Cianci et al., 2015) and the vegetation shade associated with breeding sites in Vietnam (Huynh & Minakawa, 2022). Francisco et al. (2021) also found a positive correlation between egg abundance and the percentage of urban vegetation in the Philippines. Conversely, a study in New Orleans (de Jesús Crespo & Rogers, 2021) reported no association between the presence of vegetation next to breeding sites and the presence of larvae. Positive correlations between tree cover and mosquito breeding may be explained by specific factors. Tree holes, for example, serve as breeding sites for *Aedes* spp. mosquitoes, such as those found in *Delonix regia* and *Magnifera indica* trees in Bangladesh (Chowdhury et al., 2014), or, for *Ae. albopictus* eggs in tree canopies in Greensboro (Schwarz et al., 2020). Trees can also create a favorable microclimate for mosquito development by mitigating urban heat island effects, reducing temperatures, and providing shelter (de Jesús Crespo & Rogers, 2021). Some breeding sites, like water-filled flower vases, were associated with gardening practices (Che Dom et al., 2016).

Regarding the abundance of *Ae. albopictus* adults, a similar trend emerged when using urban green space typology or urban vegetation description indicators. In Vietnam, urban parks hosted higher adult abundance than residential zones (Huynh & Minakawa, 2022). As observed in Brazil (Pedrosa et al., 2020), green spaces near residential zones also supported higher mosquito populations than in densely urbanized areas. In Malaysia's Klang Valley, urban farms had higher adult mosquito abundance than peri-urban farms (Lee et al., 2020). In Hong Kong (China), no differences in adult mosquito abundance were found between sites with green or bare roofs (Wong & Jim, 2018). Using the urban vegetation description, adult *Ae. albopictus* populations were generally more abundant in forested areas than in grassy areas, as observed in Singapore (Sun et al., 2021). Dense or poorly maintained vegetation can reduce the abundance of adults (Hendy et al., 2020; Sun et al., 2021). In Rome (Italy), Manica et al. (2016) found that adults prefered small urban green spaces, with a positive correlation between abundance and vegetation within 20 meters of the sampling trap and a negative correlation with vegetation at 300 meters. A potential explanation for the positive correlation between urban vegetation and *Ae. albopictus* adults is the role of certain plant species. Waxleaf Privet (*Ligustrum quihoui*) has been found to promote mosquito survival, while Glossy Abelia (*Abelia grandiflora*) enhanced female fecundity (Tian, 2019). However, in Manaus (Brazil), Hendy et al. (2020) reported no association between tree cover and adult abundance. The specific and context-dependent vegetation characteristics, such as the presence of certain plant species discussed here, played a critical role in mosquito abundance.

Articles addressing both *Ae. albopictus* and *Ae. aegypti* in UGIs where both species co-exist confirmed the contrasting effects of UGIs on these two mosquito species as presented in the section above (Arduino et al., 2020; de Jesús Crespo & Rogers, 2021; Heinisch et al., 2019; Honório et al., 2009; Huynh & Minakawa, 2022; Pedrosa et al., 2020; Sun et al., 2021). However, some articles found similar trends for both mosquito species distribution in UGIs. The abundance of immature stages of both species was positively correlated with the presence of vegetation adjacent to breeding sites, as observed in Brazil (Honório et al., 2009), Bangladesh (Paul et al., 2018), Malaysia (Che Dom et al., 2016), and the Philippines (Francisco et al., 2021). Moreover, a study from Rio de Janeiro observed a similar trend for both species, showing a decrease in the abundance of their immature stages with increasing distance to the peri-urban forest (Lourenço-de-Oliveira et al., 2004). In addition, a multi-country study from South America reported that the abundance of both species was positively correlated with decorative vegetation and the proximity of urban vegetation to residential areas (Talbot et al., 2021). In Bangladesh, *Aedes* spp. *(Ae. albopictus* and *Ae. aegypti*) breeding site positivity was associated with vegetation located near breeding sites (Paul et al., 2018).

Some studies have also explored the effects of UGIs on other *Aedes* species. For instance, *Aedes mediovittatus* larvae were more abundant in low-density residential areas, with over 20% vegetation cover, compared to forest patches and densely urbanized residential areas in Puerto Rico (Cox et al., 2007). In New Haven (USA), more *Aedes vexans* adults were found in moderately vegetated residential areas than in highly or un-vegetated areas (Brown et al., 2008). For *Aedes japonicus*, adult abundance showed no difference between green and bare roofs in Hong Kong (Wong & Jim, 2018). *Aedes triseriatu*s and *Aedes hendersoni* eggs were more abundant in urban forests than on urban campuses in Greensboro (Schwarz et al., 2020).

Effects on dengue virus dynamics

Dengue is an arboviral disease in which the virus (DENV) is transmitted primarily by *Aedes* mosquitoes, particularly *Ae. aegypti* and *Ae. albopictus*. Six articles examined the relationship between dengue incidence and UGIs (Table 1), revealing varying effects across locations and periods (Figure 5C). Only one of them used urban green space typology indicators and observed that the impact of urban green spaces on dengue incidence in humans varied by city in China, with effects ranging from no association to increased risk (Chen et al., 2020). Using urban vegetation indicators, the same authors found that dengue incidence was positively correlated with forest coverage in two Chinese cities (Chen et al., 2020). Three other studies reported a negative

correlation between UGIs and dengue incidence. First, Zellweger et al. (2017) reported that vegetation cover was either negatively correlated or not correlated with human cases, depending on the epidemic (2008-2009 versus 2012-2013) in Nouméa (New Caledonia). In São Paulo, Araujo et al. (2015) found higher human dengue incidence in areas with low to moderate vegetation cover compared to dense vegetation zones, a pattern also observed in Manila (the Philippines), where vegetation was negatively associated with dengue incidence (Francisco et al., 2021). The last two studies used remote sensing indices like NDVI, the weekly Enhanced Vegetation Index (EVI), and the Normalized Difference Water Index (NDWI) to assess the impact of vegetation on human dengue and reported inconsistent correlations, with no clear trend emerging (Ogashawara et al., 2019; Troyo et al., 2009).

Effects on Chikungunya virus dynamics

Chikungunya virus (CHIKV) is primarily transmitted by *Aedes* mosquitoes, particularly *Ae. aegypti* and *Ae. albopictus*. To date, only one study explored the link between UGIs and CHIKV dynamics and showed that, in Rio de Janeiro, where *Ae. aegypti* serves as the vector, a higher proportion of green parks was associated with reduced CHIKV incidence in humans (Freitas et al., 2021).

Concluding remarks on *Aedes*–pathogen systems

The impact of UGIs on *Aedes* mosquito populations differed between the two major arbovirus vector species: *Ae. aegypti* was more abundant in densely urbanized areas with less vegetation than in vegetated areas, while *Ae. albopictus* tended to be supported by UGIs, with variations depending on mosquito life stages and the type of UGI studied. Results showed no consistent trends regarding the effects of UGIs on dengue dynamics. This inconsistency may stem from DENV being transmitted by both *Ae. aegypti* and *Ae. albopictus*, which responded differently to UGIs. Identifying the primary vector in a given context is essential to assess dengue risk effectively. Notably, Francisco et al. (2021) in Manila was the only study that examined the influence of UGIs on both *Aedes* abundance and dengue incidence in humans. Their findings revealed a positive correlation between urban vegetation and mosquito eggs abundance but a negative correlation with dengue incidence in humans, underscoring the challenge of estimating VBD risk based solely on vector abundance.

Effects on Culex-pathogen systems

Effects on *Culex* populations

Of the 13 articles reporting on the effect of UGIs on *Culex* mosquitoes, six focused on *Culex quinquefasciatus* (Cox et al., 2007; de Jesús Crespo & Rogers, 2021; Landau & van Leeuwen, 2012; Sallam et al., 2017; Wilke et al., 2020; Wong & Jim, 2018), four on *Culex pipiens* (Brown et al., 2008; DeMets et al., 2020; Gardner et al., 2013; Trawinski & Mackay, 2010) and three on *Culex restuans* (Brown et al., 2008; DeMets et al., 2020; Gardner et al., 2013) (Table 1, Figure 6A and Figure 6B).

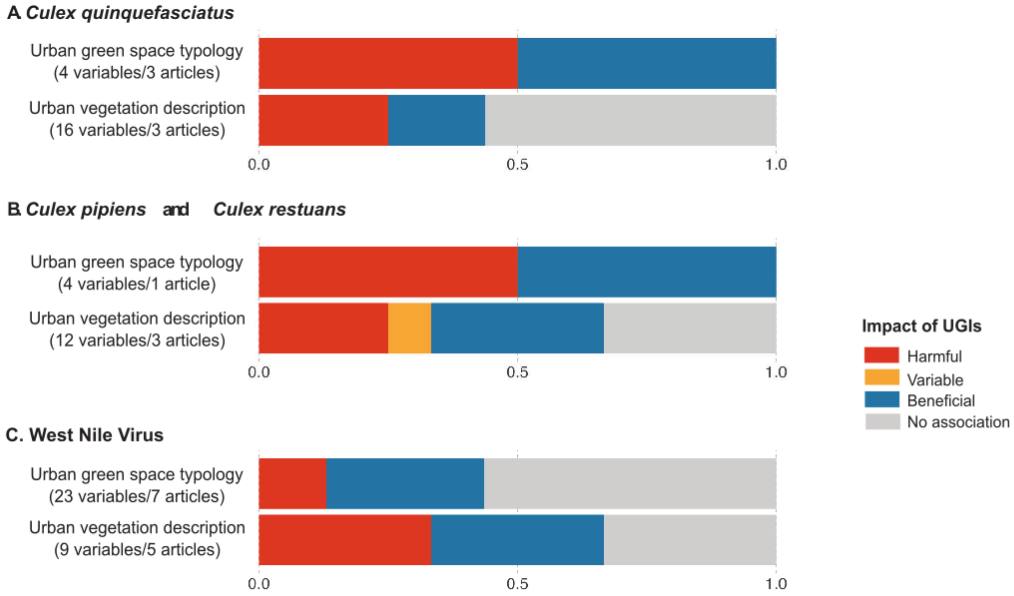

Figure 6 - Impact of UGIs on *Culex*-pathogen system. (A) Impact of UGIs on *Culex quinquefasciatus* populations. (B) Impact of UGIs on *Culex pipiens* and *Culex restuans* populations. (C) Impact of UGIs on West Nile virus dynamics (prevalence of infection in host or vector). Numbers in brackets indicate the total number of variables tested and the total number of articles from which these variables were extracted. Colors represent the proportion of variables in all studies that increased risk (harmful effect, red), decreased risk (beneficial effect, blue), varied (variable effect, yellow), or showed no association (grey) with risk.

Regarding *Cx. quinquefasciatus*, the diversity of urban green vegetation description indicators studied made it difficult to identify a clear trend, regardless of the type of indicator used to describe UGIs (Figure 6A). When considering urban green space typology, Cox et al. (2007) found that *Cx. quinquefasciatus* larvae were more abundant in low-density residential areas with over 20% vegetation cover, compared to forest patches and densely urbanized residential areas in Puerto Rico. Urban agriculture positively influenced the abundance of *Cx. quinquefasciatus* in Miami, where Wilke et al. (2020) reported higher numbers of adults and immature stages in two urban farms than in other urban areas, particularly in farms surrounded by densely urbanized zones. A specific study on green roofs in Hong Kong found that there were less *Cx. quinquefasciatus* males near green roofs than near bare roofs (Wong & Jim, 2018). Using urban vegetation description, *Cx. quinquefasciatus* was mainly positively associated with the percentage of medium and high tree height between 10 and 50 m around the sampling traps, compared to the percentage of herbaceous and shrub vegetation in Tuscon (USA) (Landau & van Leeuwen, 2012). In New Orleans, Sallam et al. (2017) observed higher vector-host contact in urban non-forest wetlands compared to forest wetlands which was positively associated with tree density. In another study in New Orleans,de Jesús Crespo & Rogers (2021) found that *Cx. quinquefasciatus* larvae were more often located in cemeteries with open canopies than in cemeteries with closed canopies.

The impact of UGIs on *Cx. pipiens* and *Cx. restuans* did not reveal any clear trend as well Figure 6B). Urban vegetation, measured indirectly by NDWI, was positively correlated with the abundance of *Cx. pipiens* and *Cx. restuans* in Toronto (Canada) (DeMets et al., 2020), but showed the opposite effect or no correlation in Amherst (USA) (Trawinski & Mackay, 2010).) DeMets et al. (2020) noted that NDVI was not associated with the abundance of *Cx. pipiens* and *Cx. restuans*. In Chicago (USA), non-flowering shrubs and specific tree species, such as oak and pear, favored the abundance of immature stages of *Cx. pipiens* and *Cx. restuans*, while flowering shrubs and

ash trees had the opposite effect (Gardner et al., 2013). Additionally, deciduous tree density showed no impact on abundance. When considering urban green spaces within residential areas, *Cx. pipiens* and *Cx. restuans* preferred moderately vegetated residential areas over residential areas with sparse or dense vegetation, as observed in New Haven (USA) (Brown et al., 2008).

Some studies have also explored the effects of UGIs on other *Culex* species. *Culex salinarius* females were more abundant in highly vegetated residential areas than in sparsely or moderately vegetated areas in New Haven (Brown et al., 2008). In Rio de Janeiro, *Cx. dolosus* was more commonly found deeper in urban forests than near residential areas (Lourenço-de-Oliveira et al., 2004). Similarly, *Cx. antillummagnorum* in Puerto Rico was more abundant in urban forests and low-density residential areas, with over 20% vegetation cover, than in densely urbanized residential areas (Cox et al., 2007). Additionally, in Hanoi (Vietnam), the abundance of female *Cx. vishnui* and *Cx. tritaeniorhynchus* was higher in urban rice fields than in urban forest areas (Ha et al., 2021). A study in Cleveland (USA) examined *Culex* mosquitoes without identifying them to species level (Yang et al., 2019). In this study, adult mosquito abundance was positively correlated with grass and shrub cover, while tree canopy coverage had no significant effect. The same study found that vegetation diversity, biomass, and the presence of vacant lots did not influence *Culex* abundance.

Effects on West Nile virus dynamics

West Nile virus (WNV) is primarily transmitted by *Culex* spp. mosquitoes and circulates within bird populations, particularly among corvids (crows, blue jays, etc.) (Chancey et al., 2015; Levine et al., 2016, 2017; Liu et al., 2011). Humans and horses serve as dead-end hosts. Ten articles examined the effects of UGIs on WNV dynamics, all of which were conducted in North America (Table 1). The impact of UGIs on WNV dynamics was mainly explored using urban green space typology indicators compared to urban vegetation indicators (Figure 6C).

Eight of the ten studies focused on the effect of UGIs on WNV infection in *Culex* spp (Levine et al., 2016, 2017; Liu et al., 2008; Liu & Weng, 2012; Lockaby et al., 2016; Myer & Johnston, 2019; Poh et al., 2020; Talbot et al., 2019). One study, conducted in Indianapolis reported a positive association between mosquito infection and UGI in the form of urban agriculture using green space typology indicators (Liu et al., 2011). Urban agriculture was suggested to offer stable temperatures and moisture conditions more suitable for mosquito breeding (Liu et al., 2008). Four studies highlighted that UGIs may have no effect on mosquito infection rates (Figure 6C), including three using urban green space typology indicators. In Ottawa (Canada), Talbot et al. (2019) found no relationship between the proportion of urban park areas and WNV infection rates. In Atlanta (USA), Levine et al. (2016, 2017) found that mosquito infection rates were generally similar across urban green spaces (urban wooded parks or urban parks with water, urban forests, and urban zoos), though infected mosquitoes were more prevalent in wooded parks than in zoos. The fourth study, conducted in Los Angeles (USA), used urban vegetation indicators and observed no association between mosquito infection rates and the urban vegetation (described using NDVI), possibly due to the cross-correlation of NDVI with higher elevation, which is less conducive to mosquito habitats (Liu & Weng, 2012). In contrast, three studies found a negative correlation between UGIs and mosquito infection, all using urban vegetation indicators (Figure 6C). Lockaby et al. (2016) found a negative correlation between the probability of mosquito infection and both the percentage of pine forests—likely due to drier conditions—and the area of forest patches, possibly explained by a dilution effect. According to the authors, large forest patches were associated with high avian species diversity, which reduced the probability of contact between infected *Culex* mosquitoes and competent host species. Another study in Atlanta by Myer & Johnston (2019) highlighted a negative correlation between NDVI and mosquito infection, a trend also observed in Dallas (USA) by Poh et al. (2020).

Five studies investigated the association between WNV incidence/seroprevalence in hosts and UGIs, focusing on birds and humans (Figure 6C). One study in Northern Virginia (USA) found a positive correlation between urban vegetation indicators and WVN incidence in corvids, with a peak of infection in medium and high canopy density areas compared to impervious surfaces with

601 lower canopy density (Liu et al., 2011). In contrast, four studies identified a negative or no
602 association between UGIs and WNV incidence (Figure 6C), three using urban green space
603 typology indicators and one using urban vegetation indicators. In Atlanta, WNV seroprevalence
604 was higher in passerine birds in residential areas than in more vegetated areas and lower in urban
605 forests compared to parks with wooded and paved areas (Levine et al., 2016, 2017). In Cleveland,
606 WNV incidence in humans was lower in urban green spaces compared to residential areas
607 (LaBeaud et al., 2008). Finally in Ottawa, no association was found between the proportion of
608 green parks and human WN case incidence (Talbot et al., 2019).
609 Two studies addressed WNV genetic diversity in *Culex* spp. and bird hosts. In mosquitoes, the
610 genetic diversity of WNV decreased or remained unchanged within urban green spaces (Amore et
611 al., 2010; Bertolotti et al., 2008), while in birds, WNV genetic diversity was higher in urban green
612 spaces compared to residential areas (Bertolotti et al., 2008). According to the authors, this higher
613 diversity in urban green spaces may be explained by the greater diversity of bird species
614 associated with a higher availability of natural habitats in urban green spaces compared to
615 residential areas.
616
617 Effects on other *Culex*-borne pathogens
618 A study in Argentina found that prevalence in humans of Saint Louis encephalitis virus,
619 transmitted by *Cx. quinquefasciatus*, was lower in low-density residential areas than in densely
620 populated regions (Vergara Cid et al., 2013). Similarly, in Brisbane (Australia), incidence of Ross
621 River virus in humans, a virus transmitted by *Aedes vigilax* and *Culex annulirostris*, was positively
622 associated with the percentage of riparian and bushland areas (Muhar et al., 2000).
623
624 Concluding remarks on *Culex*-pathogen systems
625 The diversity and specificity of UGI indicators made it challenging to discern clear trends
626 regarding their impact on *Culex* mosquitoes. For WNV dynamics, findings indicated that UGIs often
627 negatively affected mosquito infection rates, though their effects can vary significantly depending
628 on urban and environmental contexts. Additionally, UGIs tended to reduce or have no significant
629 effect on WNV incidence in birds as well as in human hosts compared to impervious residential
630 areas. The dynamics of WNV transmission remains complex and influenced by various factors,
631 including plasticity in the feeding behavior of mosquitoes, host availability, and diversity in the
632 ability of bird host species to amplify and further transmit the virus to the vector mosquitoes (Levine
633 et al., 2016, 2017).

634 *Effects on Anopheles-pathogen systems*
635

636 Effects on *Anopheles* populations
637 Only three of the selected articles focused on *Anopheles* spp. mosquitoes, all indicating a
638 positive correlation between urban agriculture and the presence or abundance of *Anopheles*
639 mosquitoes and mainly using urban green space typology indicators (Dongus et al., 2009; Matthys
640 et al., 2010; Yadouléton et al., 2010). Dongus et al. (2009) reported a higher presence of
641 *Anopheles* larvae in urban crop cultivation areas, such as sugarcane and leafy vegetable farms,
642 and in urban agricultural zones compared to non-agricultural areas in Dar es Salaam (Tanzania).
643 The presence of wells or irrigation systems was also positively correlated with the probability of
644 presence of *Anopheles* larvae (Dongus et al., 2009). Similarly, Matthys et al. (2010) found
645 *Anopheles* larvae most frequently in agricultural trenches over other irrigation types in urban
646 farming in Abidjan (Côte d'Ivoire). In Benin, Yadouléton et al. (2010) reported higher human biting
647 rates near vegetable farms compared to households located farther away from these agricultural
648 zones across several cities.
649
650 Effects on *Plasmodium* dynamics

Malaria is a parasitic disease caused by *Plasmodium* spp., which is transmitted between human hosts by *Anopheles* spp. mosquitoes. Four of the 99 selected studies explored the dynamics of malaria related to UGIs (Georganos et al., 2020; Kabaria et al., 2016; Matthys et al., 2006; Yadouléton et al., 2010), including two that examined the relationship with urban green space typology indicators and two with urban vegetation indicators. In Benin, Yadouléton et al. (2010) found that *Anopheles* spp. infection rate was higher in households close to vegetable farms than in households farther away. Similarly, malaria prevalence in the human population of Côte d'Ivoire was higher in urban agriculture areas (Georganos et al., 2020), particularly within mixed crop systems compared to traditional smallholder rice plots (Matthys et al., 2006). The prevalence of malaria was also positively linked to riparian vegetation in Tanzania and Uganda (Georganos et al., 2020) and to the percentage of urban vegetation based on NDVI in Tanzania (Kabaria et al., 2016).

Concluding remarks on *Anopheles*-pathogen systems

These results showed a positive association between UGIs, specifically urban agriculture, for both *Anopheles* spp. abundance as well as malaria prevalence in humans, and in the vector mosquitoes.

Effects on Haemagogus and on yellow fever dynamics

In Rio de Janeiro, Abreu et al. (2022) studied the relationships between UGIs and the yellow fever vector system, which involves the vectors *Haemagogus leucocelaenus* and *Haemagogus capricornii*, as well as human and non-human primates as hosts. The study found no difference in vector abundance between urban forests, urban pastures, and densely urbanized areas, but the abundance of vectors was positively associated with the NDVI. Furthermore, the prevalence of yellow fever in humans and non-human primates was higher in urban forest fragments than in heavily urbanized areas. Both *Hg. leucocelaenus* and *Hg. capricornii* showed higher infection rates for yellow fever virus (YFV) in urban forest settings compared to other urban areas.

Effects on other mosquito-pathogen systems

Only four studies evaluated the influence of UGIs on the abundance of all mosquitoes collected. In São Paulo, Medeiros-Sousa et al. (2017) found a positive association between mosquito abundance and urban parks. Another study in Sinop (Brazil) reported higher abundance of adult mosquitoes in urban forested parks and in urban forest fragments than in urbanized areas (Vieira et al., 2020). In Hong Kong, the abundance of all adult species was lower on green roofs compared to bare roofs (Wong & Jim, 2016) and low-elevation gardens (Wong & Jim, 2017). One multi-site study indicated that, in both Mexico and Germany, there was no association between seroprevalence of avian haemosporidia in birds and urban forests (Carbó-Ramírez et al., 2017).

Concluding remarks on the impact of UGIs on mosquito-pathogen systems

Globally, the influence of UGIs on mosquito populations and mosquito-borne disease transmission remain inconclusive and context specific: UGIs have been associated with increased, decreased, or negligible effects on vector risk, showing no consistent trend across cities and vector systems. Further research is urgently needed to clarify the effects of UGIs on mosquito vector populations dynamics and associated mosquito-borne disease risk in cities (Figure 3, Additional file 5: Table S2, Additional file 6: Table S3).

Effects of UGIs on tick-pathogen systems

Effects on Ixodes-pathogen system

Effects on *Ixodes* populations

Across 19 articles on UGIs and tick populations, thirteen articles centered on *Ixodes ricinus* in Europe and two on *Ixodes scapularis* in North America (Gregory et al., 2022; VanAcker et al., 2019). Six of the thirteen articles observed a positive correlation between UGIs and *I. ricinus* population density, with one using urban green space typology indicators and five using urban vegetation indicators (Figure 7A). Higher tick densities may be linked to greater connectivity between urban and peri-urban environments, allowing movement of the host, as observed in Antwerp (Belgium) (Heylen et al., 2019). Using urban vegetation indicators, *I. ricinus* was more abundant at woodland edges and within forests than in grasslands, as demonstrated in Salisbury (United Kingdom, UK) (Hansford et al., 2017), London (UK) (Hansford et al., 2021), and Rome (Di Luca et al., 2013), as well as in urban parks in Bath (UK) (Hansford et al., 2022). Additionally, *I. ricinus* was more prevalent in deciduous or mixed forests than in coniferous forests, as noted in Poznań (Poland) (Michalik et al., 2003). This habitat preference can be explained by the presence and the abundance of small mammals (e.g., hedgehogs, *Apodemus* spp.) (Borşan et al., 2020; Michalik et al., 2003) and larger mammals such as white-tailed deer (Hansford et al., 2017) which serve as hosts for ticks.

In contrast, eight articles reported no consistent trend between UGIs and tick population density (Figure 7A), with seven articles using urban green space typology indicators and one using urban vegetation indicators. Studies conducted in Lyon (France) (Mathews-Martin et al., 2020), Helsinki (Finland) (Junttila et al., 1999), Cluj-Napoca (Romania) (Borşan et al., 2020), and Warsaw (Poland) (Welc-Falęciak et al., 2014) revealed differences in *I. ricinus* abundance between urban green spaces, like urban parks, though these studies did not explain the observed variations. Other articles conducted in St Petersburg (Russia) (Tretyakov, 2009) and in Olstzyn (Poland) (Kubiak et al., 2019) found no significant differences in vector abundance across urban parks and urban forests. In Budapest (Hungary), Hornok et al. (2014) observed that tick abundance could vary by the month of sampling, sometimes being higher in cemeteries than in urban forests or parks or showing no differences. Finally, a study in Bath revealed no differences in tick vector abundance between woodland and grassland or between mixed and deciduous forests (Hansford et al., 2022).

In the two articles on *I. scapularis* in the city of New York (USA), urban green space connectivity and host accessibility were important in determining tick populations density. Enhanced connectivity, measured by park-to-park links (VanAcker et al., 2019), was correlated with increased tick numbers. Permeable garden edges did not seem to raise the probability of tick detection (Gregory et al., 2022). High canopy cover around parks (VanAcker et al., 2019) or gardens (Gregory et al., 2022) was associated with increased tick counts, while lower tick numbers were found in grasslands or bare soil.

Other *Ixodes* species, such as *I. persulcatus, I. trianguliceps,* and *I. apronophorus*, have been observed in urban parks, such as in St. Petersburg (Tretyakov, 2009). In Hanover (Germany), Hauck et al. (2020) reported that *I. ricinus* and *I. inopinatus* densities were higher in urban mixed forests than in urban parks, with no difference between deciduous and mixed forests and between mixed forests and urban parks.

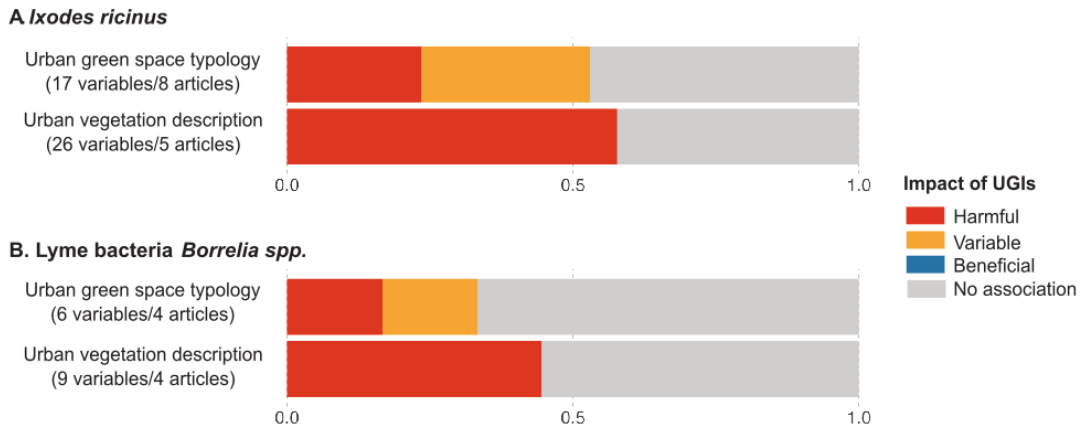

Figure 7 - Impact of UGIs on *Ixodes*-pathogen systems. (A) Impact of UGIs on *Ixodes ricinus* populations. (B) Impact of UGIs on Lyme bacteria *Borrelia* spp. (prevalence of infection in host or vector). Numbers in brackets indicate the total number of variables tested and the total number of articles from which these variables were extracted. Colors represent the proportion of variables in all studies that increased risk (harmful effect, red), decreased risk (beneficial effect, blue), varied (variable effect, yellow), or showed no association (grey) with risk.

Effects on *Borrelia* spp. dynamics

Eleven articles focused on *Borrelia spp.* (Table 1), the bacterial pathogens causing Lyme disease, primarily transmitted by *Ixodes* ticks. The presence of infected ticks is closely linked to the movement and presence of competent hosts, such as the striped field mouse (*Apodemus agrarius*), a major reservoir for *Borrelia burgdorferi* (Gryczyńska et al., 2021). The effects of UGIs on tick infection rates were primarily studied using urban vegetation indicators compared to urban green space typology indicators (Figure 7B).

Five articles reported a positive correlation between UGIs and *Borrelia* dynamics, with two relying on urban green space typology and three on urban vegetation indicators (Figure 7B). In Budapest (Hungary), the *Ixodes* infection rates were higher in urban forests than in cemeteries (Hornok et al., 2014). In New York city, VanAcker et al. (2019) demonstrated that higher connectivity among urban green spaces—measured by a park's contribution to network connectivity—increased tick infection rates. Patterns of the effects of urban vegetation indicators on *Borrelia* infection closely aligned with the impact on *Ixodes* tick abundance. Infection rates were higher in urban woodlands compared to grasslands in London (Hansford et al., 2021) and at woodland edges compared to grasslands in Bath (Hansford et al., 2022). In New Castle county (USA), *Rosa multiflora* presence in urban forests was associated to higher infection rates in ticks (Adalsteinsson et al., 2018), as did woody debris compared to leaf litter.

Seven articles, including four using urban green space typology and three employing urban vegetation indicators, found no link between UGIs and *Borrelia* dynamics (Figure 7B). Urban parks were not significantly associated with *Borrelia* spp. infection rates in ticks in some European cities including Prague (Czech Republic), Helsinki, Budapest and Olsztyn (Hornok et al., 2014; Junttila et al., 1999; Kubiak et al., 2019; Kybicová et al., 2017). There was no significant difference in ticks' infection rates between grasslands and woodlands in Salisbury (Hansford et al., 2017) and in Bath (Hansford et al., 2022), or between coniferous and deciduous forests in Poznań (Michalik et al., 2003).

Effects on other tick-borne pathogens dynamics

Four studies focused on the *Rickettsia/I. ricinus* vector-pathogen system in various cities in Germany cities (May & Strube, 2014; Overzier et al., 2013; Schorn, et al. 2011a) and Poland cities (Welc-Falęciak et al., 2014). They found no differences in ticks' infection rates within urban green spaces, without offering specific explanations for these results. Five studies investigated the relationship between UGIs and the *Anaplasma phagocytophilum/I. ricinus* system. Infection rates for *An. phagocytophilum* varied within and between German cities' green spaces (May & Strube, 2014; Schorn et al., 2011b). However, studies from Hungary and Poland (Hornok et al., 2014; Welc-Falęciak et al., 2014) found no significant differences between different urban green spaces. Infection rates were higher in ticks in urban parks than in peri-urban parks in Prague (Kybicová et al., 2017) and higher in urban parks than in cemeteries in Budapest (Hornok et al., 2014). One study explored the *Babesia/I. ricinus* system and reported no association between ticks' infection rates and urban green spaces in Germany (Schorn, et al. 2011a).

Two studies conducted in Ukraine (Levytska et al., 2021) and in Belgium (Heylen et al., 2019) examined multiple pathogens (*Rickettsia spp.*, *Babesia spp.*, *Bartonella spp.*, and *Anaplasma phagocytophilum*) collectively. The findings indicated that and infection rates with these tick-borne pathogens were not affected by urban green spaces or their connectivity.

Concluding remarks on *Ixodes*-pathogen systems

The abundance of *Ixodes* ticks was influenced by host movement, likely shaped by connectivity between urban green spaces and by local vegetation characteristics, with ticks exhibiting a preference for deciduous or mixed forests. Variations in *Ixodes* tick abundance across different urban green spaces were location-specific and depended on the time of year. *Borrelia* infection rates in ticks were strongly linked to the presence and movement of competent hosts, particularly in woodlands or connected urban green spaces, reflecting the influence of UGIs on *Ixodes* populations. However, the effect of urban green spaces on ticks' infection rate varied by location and specific characteristics, which may explain why some UGIs have minimal impact. For other tick-borne pathogens, infection rates in ticks did not exhibit any consistent pattern in relation to UGIs.

Effects on Amblyomma-pathogen system

Only one study focused on *Amblyomma americanum*. This tick was positively associated with urban green spaces, particularly with permeable garden edges and increased canopy cover around yards in New York city (Gregory et al., 2022). The presence of log and brush piles in the yard also favored the probability of tick presence, which is not influenced by the presence of low canopy and grass around the yard.

Two studies reported results on other *Amblyomma*–pathogen systems. In Oklahoma (USA), infection rates of *A. americanum* with *Rickettsia spp.* or *Ehrlichia spp.* were comparable between residential and non-residential areas (Small & Brennan, 2021). Additionally, Noden et al. (2022) found that the percentage of developed land surrounding sampling points did not affect infection rates of *A. americanum* with *Borrelia spp.*, *Rickettsia spp.*, or *Ehrlichia spp*. Altogether, these results highlighted that *Amblyomma* tick populations were positively associated with the presence of urban green spaces, without evidence of differences in pathogen infection rates.

Effects on other tick species populations

Only one study focused on *Haemaphysalis longicornis* in New York city, showing that its presence was positively associated with logs and brush piles in yards, while it was unaffected by the permeable edge or the surrounding land cover of sampled yards (Gregory et al., 2022). In Italy, *Dermacentor marginatus* and *Rhipicephalus turanicus* were more prevalent in open landscapes, including pastures and wheat fields, than in deciduous woodlands (Di Luca et al., 2013).

Four studies explored the relationship between UGIs and various tick species from different genera. In Romania, *I. ricinus* and *Haemaphysalis punctata* were found to be unaffected by vegetation cover (Borşan et al., 2020). In Singapore, Kwak et al. (2021) observed higher infestation rates of small mammals by ticks such as *Amblyomma helvolum*, *Dermacentor auratus*,

Haemaphysalis semermis, and *Ixodes granulatus* in old secondary forests compared to young secondary forests, with no influence from scrubland. In Oklahoma, Roselli et al. (2022) found that bird infestations by ticks, including *A. americanum*, *Amblyomma maculatum*, and *Haemaphysalis leporispalustris*, were not affected by the surrounding land cover of park sampling sites. In New York City, Hassett et al. (2022) reported that the densities of *I. scapularis*, *Amblyomma americanum*, and *Haemaphysalis longicornis* were negatively influenced by park management practices and were higher along trails than in park edges. Human-tick contact was also more frequent on trails than in natural open spaces. These results revealed no consistent trends across tick species, although park management practices were thought to reduce overall tick abundance.

Concluding remarks on tick-pathogen systems

We found no record of negative effects of UGIs on tick populations. UGIs allowed the presence of ticks in cities and had either no or a positive effect on tick populations and the transmission of tick-borne diseases (Figure 4, Additional file 7: Table S4, Additional file 8: Table S5). Tick abundance and the prevalence of infected ticks were primarily determined by the movement of competent hosts between urban green spaces and peri-urban environments, as well as by local vegetation characteristics.

Effects of UGIs on others vector-pathogen systems

Only one study assessed the impact of UGIs on sand fly populations. In Correntes (Argentina), abundance of *Lutzomyia longipalpis* was higher in areas with low NDVI and in presence of farm animals compared to areas with high NDVI (Berrozpe et al., 2017).

Two studies in Asia investigated chigger mite vectors (Trombiculidae), known carriers of *Orientia tsutsugamushi*, the bacterium responsible for scrub typhus. Park et al. (2015) reported that human scrub typhus prevalence was higher in urban parks than in residential areas in South Korea. Additionally, in Thailand, rodent (*Rattus rattus*) infestation rates were higher in peri-urban and large parks than in small parks in urban centers and were negatively associated with distance from open fields (Wulandhari et al., 2021). This suggested that environmental characteristics of urban parks may influence vector abundance and that proximity to open fields may increase vector populations (Wulandhari et al., 2021).

It is noteworthy that, due to the lack of study, no conclusive trend can be drawn concerning the relationships between UGIs and other vector-pathogen systems, including some of major public health concerns.

Discussion

Since the early 2000's, a growing body of research has emphasized the need to investigate the relationship between UGIs and the risk of VBD introduction and expansion. While urban green spaces may result in increased VBD emergence and transmission for city-dwellers, they also hold potential for VBD risk mitigation through careful UGI planning and management (Fournet et al., 2024). This review highlighted the diverse impacts of UGIs and urban vegetation features on arthropod vectors of human and animals diseases and associated VBD dynamics in cities. These impacts varied significantly depending on vector system and the local socio-ecological and epidemiological context.

The selection of databases and keywords may have resulted in the exclusion of certain articles. For instance, one study lacking the specified keywords was identified through cross-referencing. However, the geographic and thematic heterogeneity of available studies underscores the need for more comprehensive and systematic sampling and monitoring of interactions between UGIs, disease vectors and VBDs affecting humans, but also animals. This should be achieved through an integrative One Health approach, as promoted by the UN in June 2021, which aims to sustainably balance and optimise the health of people, animals and ecosystems (OHHLEP, 2022). Such an approach should consider local sociological, political, and ecological contexts and use

harmonized protocols and robust theoretical frameworks for data acquisition and analysis. This will help build scientific evidence and promote stakeholders' engagement to mitigate VBD risk in green cities. Below, we discuss key challenges and propose research avenues to advance this effort.

Data acquisition

Developing standard protocols for longitudinal monitoring of disease vector populations, pathogen dynamics, and urban vegetation features is essential. These protocols would enable local in-depth assessment of the risk of exposure to VBDs in green cities, and support comparative studies across different UGIs, study sites, and eco-socio-epidemiological contexts.

First, the studies included in this review encompassed considerable variability in sampling schemes and arthropod trapping methods, even among studies focusing on the same vector species. These inconsistencies can limit the representativeness of findings due to the limited number of spatial or temporal replicates (Amore et al., 2010; Carbó-Ramírez et al., 2017; de Jesús Crespo & Rogers, 2021; Dongus et al., 2009; Francisco et al., 2021; Georganos et al., 2020; Ha et al., 2021; Huynh & Minakawa, 2022; Matthys et al., 2006; Sallam et al., 2017; Wilke et al., 2017). The diversity of indicators used to assess VBD risk further complicates comparisons between studies on diseases and pathogens. For example, some studies relied on indicators based on vector abundance. Yet these metrics are known to vary significantly depending on the physiological stage of the vector sampled (eggs, larvae, adults) and are often uncorrelated with one another or with disease transmission risk (Corriveau et al., 2003). For example, a recent study in Leiden (the Netherlands) demonstrated that distribution of *Cx. pipiens* life stages differed across urban green and grey spaces where ovipositioning rates (number of egg rafts) and larval life stages were far more abundant in residential areas compared to adults being more abundant in parks (Krol et al., 2024). Other studies relied on indicators such as disease incidence and prevalence in humans, or vector infection rates, each representing distinct temporal outcomes of pathogen transmission, therefore challenging their comparison. Human health data are often aggregated spatially (Freitas et al., 2021) or tied to residential locations of patients (Muhar et al., 2000; Troyo et al., 2009), which may not correspond to sites where the patient acquired infection through the bite of a vector (Lilienfeld, 1983). This mismatch can distort within-city fine-scale risk assessments. Moreover, the approach can be limited due to a low number of reported cases (Talbot et al., 2019) or underestimation of cases (Zellweger et al., 2017). Detection and monitoring of pathogens in animal hosts remain scarce despite their importance for comprehensive VBD risk assessment (ECDC, 2023). Advancements in technology offer promising solutions for improving spatial and temporal resolution in monitoring. For instance, 'smart' mosquito traps based on machine learning approaches can identify and register mosquito counts and species (ECDC, 2023). Non-invasive eDNA surveys (L'Ambert et al., 2023) and metabarcoding (Bohmann et al., 2022.) can enable precise pathogen and vector detection, as well as vertebrate host diversity monitoring. Merging DNA-metabarcoding with ecological network analysis should provide novel insights into vector-pathogen-host interactions (see more below) and is a promising approach to understand and build resilient terrestrial ecosystems (Evans et al., 2016). Tailoring these methods to assess VBD risks in UGIs, will pave the way for integrated and harmonized (meta)data collection and analysis.

Second, there is a need for precise, consistent characterization of urban green spaces, and associated vegetation. The diversity of definitions and descriptions used to characterize urban landscapes, particularly UGIs, made it difficult to generalize findings across studies (Cianci et al., 2015; Talbot et al., 2019). To address this, controlled vocabularies and ontologies are needed to standardize both field and remote data acquisition. The typology proposed by L. Jones et al. (2022) provided a clear and comprehensive framework for classifying UGIs. Further development of this typology could significantly enhance the comparability of UGI studies. Aligning the spatial scale of measurements with the specific impacts being monitored presents an additional challenge (Landau & van Leeuwen, 2012; Manica et al., 2016). Longitudinal studies (Mackenstedt et al., 2015; Tarsitano, 2006), for instance, are complicated by the continuous evolution of urban landscape design and use over time. Importantly, many studies have shown that landscape factors

influencing VBD risks are context-dependent (Brown et al., 2008; Chen et al., 2020; Cianci et al., 2015; Gardner et al., 2013; Landau & van Leeuwen, 2012; Sun et al., 2021; Yang et al., 2019). This emphasizes that relying on a single index cannot determine the relationship between vegetation and VBD risk. For example, using NDVI alone cannot differentiate between deciduous and coniferous vegetation, which may have opposite effects depending on the vector system studied (Lockaby et al., 2016). Moreover, the effects of similar UGIs may vary depending on factors such as the year of observation (Zellweger et al., 2017), or the specific city being investigated (Chen et al., 2020). As a result, some landscape indices and summary statistics used in these studies may not adequately capture the complexity of data needed for a thorough investigation. Notably, biotic interactions significantly influence vector arthropod fitness and the dynamics of pathogen transmission within ecosystems. For example, vector trophic behavior can shift with the seasons (Hedeen et al., 2016; Levine et al., 2017), and host-switching or niche-switching throughout the seasons can lead to complex epidemiological outcomes (Lefèvre et al., 2013; Lejal et al., 2021). Indeed, vegetation may impact mosquito population dynamics in multiple ways. It may directly serve as resting site or sugar source for adults (Peach et al., 2019). Indirectly, vegetation can alter abiotic and biotic factors by modifying microclimates and by providing habitats for various animal species, including pathogen hosts, mosquito competitors, and predators (Benitez et al., 2020; Cianci et al., 2015; Myer & Johnston, 2019). As detailed below, integrating the full range of interactions mediated by arthropod disease vectors into an ecological network (food web) approach can help identify relevant biotic and abiotic factors to help design composite indicators for VBD risk assessment in UGIs.

Finally, the multifaceted nature of VBD transmission dynamics requires consideration of additional drivers beyond biological and physical parameters associated with vector and pathogen prevalence. In particular, incorporating socio-economic parameters into VBD risk assessments has been proposed to bridge ecological and epidemiological findings. While this information is crucial to assess human exposure to arthropod bites and, to a certain extent to the pathogens they may transmit, quantifying host-vector contact both within and outside UGIs remains challenging. Targeted Knowledge-Attitude-Practices (KAP) surveys and citizen science-based approaches should be encouraged. Mobile applications such as Mosquito Alert (Južnič-Zonta et al., 2022), Muggenradar (Kampen et al., 2015), iMoustique mobile application (Gautreau, 2024) or Citique (Hassler et al., 2024) are promising tools to improve completeness and reliability of data acquisition. Earlier work has shown that such data are extremely valuable for modelling, vector management, and communication with the general public (Abourashed et al., 2021; Južnič-Zonta et al., 2022; Kampen et al., 2015). In this context, standardized (minimal) metadata sets should be developed for studies and case reports to ensure unbiased data assessment and interpretation, while also facilitating data sharing in accordance with FAIR (Findability, Accessibility, Interoperability and Reuse) principles (Wilkinson et al., 2016).

Theorical frameworks and models

As this work demonstrated, most studies on the impacts of UGIs on vectors and VBD dynamics relied on univariate analyses of associations between (sometimes ill-defined) urban green metrics and vector and/or pathogen presence or abundance. These analyses frequently failed to account for key confounding factors, such as human density (Bertolotti et al., 2008; Sallam et al., 2017; Vergara Cid et al., 2013), income levels (Chen et al., 2020; LaBeaud et al., 2008; Matthys et al., 2010; Zellweger et al., 2017), or urbanization features like building age (Sun et al., 2021). To address these limitations, various theoretical, statistical, and/or process-driven frameworks and models are being developed to explore the relationships between landscape features (mainly abiotic parameters) and population dynamics of arthropod vectors or VBD epidemiology. These models range from global-scale analyses (Eberhard et al., 2020) to regional-scale studies (Ducheyne et al., 2018). At a more local scale, deterministic weather-driven population dynamic models based on generic frameworks (Cailly et al., 2012) are particularly valuable. These models can map the environmental carrying capacity and identify hotspots for arthropod vector abundance, such as *Ae. albopictus,* in tropical and temperate environments (Marti et al., 2022;

Tran et al., 2020). When tailored to urban green spaces, these process-based models can be generalized further by incorporating additional variables, such as local weather parameters of importance, landscape features and vector data.

Furthermore, hematophagous arthropod vectors are part of complex ecological interaction networks. These organisms contribute to ecosystem functioning and stability in multiple ways, with food webs top-down and bottom-up effects (Bellekom et al., 2021; Macfadyen et al., 2009; Ostfeld et al., 2018). Arthropod vectors may serve as prey for insectivore species at higher trophic levels, act as competitors with other species sharing similar habitats and resources, and have a major top-down influence as vectors of pathogens to a wide range of hosts. In this context, developing multilayer ecological networks (Pocock et al., 2012) appears promising to shed light on complex and/or unexpected ecological interactions with direct relevance to vector populations and disease dynamics (Bellekom et al., 2021; Ostfeld et al., 2018; Renault et al., 2024).

Once trained and validated with robust field data, predictive modeling and machine-learning tools can help to forecast the impact of urban green planning on VBD risks (Wilke et al., 2023). When combined with future urban (re)naturation scenarios and considering relevant Shared Socio-economic Pathways (SSPs), these models can simulate entomological and epidemiological outcomes resulting from changes in urban vegetation across various time horizons. Such simulations are crucial for identifying high-risk spatial and temporal scenarios, enhancing preparedness for VBD outbreak.

Stakeholder engagement and implications for urban planning

Stakeholder engagement is vital for the development of effective public policies. City planners should adopt integrated, participatory approaches (Gulachenski et al., 2016; Landau & van Leeuwen, 2012; Millins et al., 2017; Sprong et al., 2018; Syal, 2021) and embrace a One Health strategy that considers social, ecological, economic, and technical dimensions (Ellwanger et al., 2022; Koren & Butler, 2006). Such an integrated approach requires robust communication and education campaigns targeting many stakeholders, including citizens, health professionals, urban planners, technicians, entomologists, biologists, architects, botanists, urban ecologists, and sociologists (Ellwanger et al., 2022). These efforts are important for fostering collaboration and ensuring comprehensive VBD risk assessments (Wilke et al., 2023). Gaps in knowledge as well as public health and research priorities may be different across the world, prompting the need for tailored strategies. For example, in New York (USA), the primary concerns are Lyme disease (Gregory et al., 2022; Hassett et al., 2022; VanAcker et al., 2019) and West Nile fever (Myer & Johnston, 2019) whereas in Madrid (Spain), recent leishmaniasis outbreaks highlighted the need for a better understanding of sandfly ecology in UGIs (Arce et al., 2013). In both cases, urban park managers are in the frontline to inform VBD risk assessments and contribute to mitigation plans through wildlife management. In Africa and in South America, basic research is being conducted on mosquito-pathogen systems, but there is a critical lack of studies on ticks and tick-borne diseases systems in urban ecosystems despite emerging concerns such as the spread of *Amblyomma cajennense* and transmission of *Rickettsia rickettsii* in urban green spaces in Rio de Janeiro (Szabó et al., 2013).

International knowledge exchange is essential, particularly between countries with long-term experience of vector presence and countries that have been recently affected. For example, *Ae. albopictus* is well-established in Italy but is now colonizing Belgium (Deblauwe et al., 2022). Similarly, countries actively advancing urban greening efforts may share insights with those that are just beginning. Most studies on urban greening have been conducted in Europe or America, with relatively few in Africa and Asia. However, a recent study in Gabon investigated the influence of urban green spaces on VBDs, focusing specifically on urban forest ecosystems (Obame-Nkoghe et al., 2023). This highlights the growing interest on these issues in different regions and the need for international cooperation.

In 2019, the Food and Agricultural Organization (FAO) published a report advocating for the global expansion of urban agriculture to address future food shortages (Taguchi & Santini, 2019). The report promoted the development of urban farms and agriculture, often associated with

ecopastoralism (urban grazing) involving livestocks. Such developments may contribute to the introduction of competent hosts such as cattle for pathogens like the Crimean-Congo Hemorrhagic Fever Virus (CCHFV), transmitted by the invasive tick *Hyalomma marginatum* (Vial et al., 2016). While urban agriculture improves food access and supports ecological urban green space management, it also presents city planners with the challenge of controlling vector populations in these rapidly changing environments.

Although the impact of UGIs on plant health was out of the scope of this review, the risk of introducing agricultural pests, such as the tree moth (Ciceoi et al., 2017), into cities and contaminating peri-urban forests and/or surrounding crops cannot be ignored and should be carefully assessed when introducing greenery into urban area. This is particularly important when introducing exotic plant specimens that can serve as hosts and reservoirs for devastating pathogens or their vectors (Atkins et al., 2021).

Lastly, city planners should consider the impact of global warming in their risk assessments. We did not identify articles that explicitly consider global warming as a contributing factor to VBD risks associated with urban green spaces. However, climate warming can significantly influence the spatial and temporal distribution of vectors. For instance, the tick *Hyalomma marginatum* is expanding its range into southern France (Bah et al., 2022). Similarly, for *Ae. albopictus*, future projections—though to be interpreted cautiously—identified potential hotspots in the southern United Kingdom, Germany, and Benelux, while southern Spain and Portugal are predicted to become less suitable due to drought and hot summers (Caminade et al., 2012).

Conclusion

In the context of climate change that our world is facing today and given the dynamics of increasing urbanization, renaturing cities appears essential. However, this can lead to the emergence of vector-borne diseases affecting humans, animals, and plants. This risk must be considered in urban policies to enable prevention. The increase in the diversity of vectors, pathogens, and hosts could contribute to a dilution effect that would reduce the risk, but this must be assessed to provide solid foundation for comprehensive risk assessment and informed urban planning. In response to these concerns, only a close partnership between scientists, policymakers, urban planners, and citizens can enable the sustainable development of cities, thereby improving human health and well-being.

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Conflict of interest disclosure

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Authors' contributions

FS was the principal investigator of the VECTOH Project and coordinated the manuscript draft with FF. MM and CB conducted the literature review, analyzed the articles and drafted the original version of the manuscript. NM conceptualized the data extraction and description, including the interactive map with references. All co-authors contributed to revision of the manuscript, and approved the final version of the manuscript for publication. All authors read and approved the final manuscript

Data, scripts, code, and supplementary information availability

Supplementary information and data are available online: https://doi.org/10.5281/zenodo.15165981, (Bartholomée & Mercat, 2025).

The interactive map of studies is available online: https://zenodo.org/records/15096123, (Bartholomée & Mercat, 2024).

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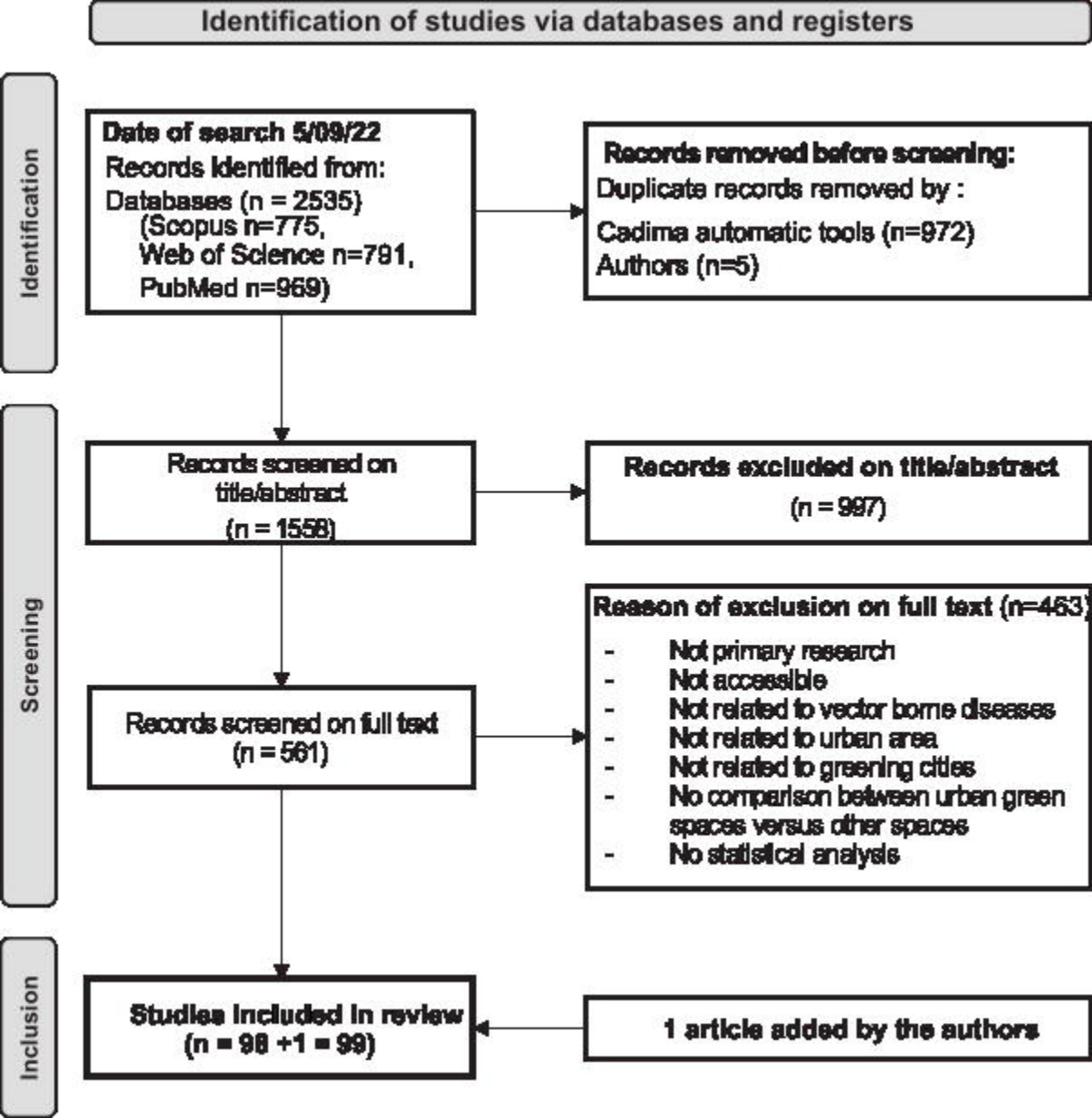
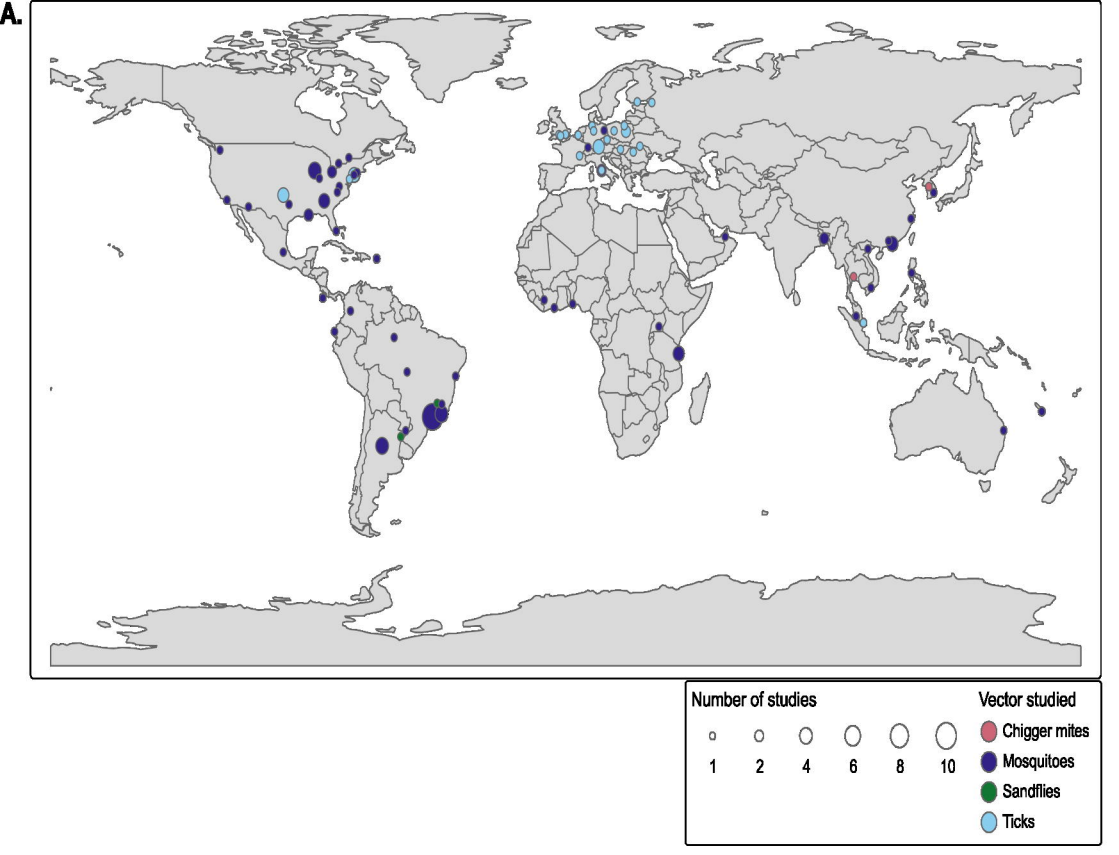
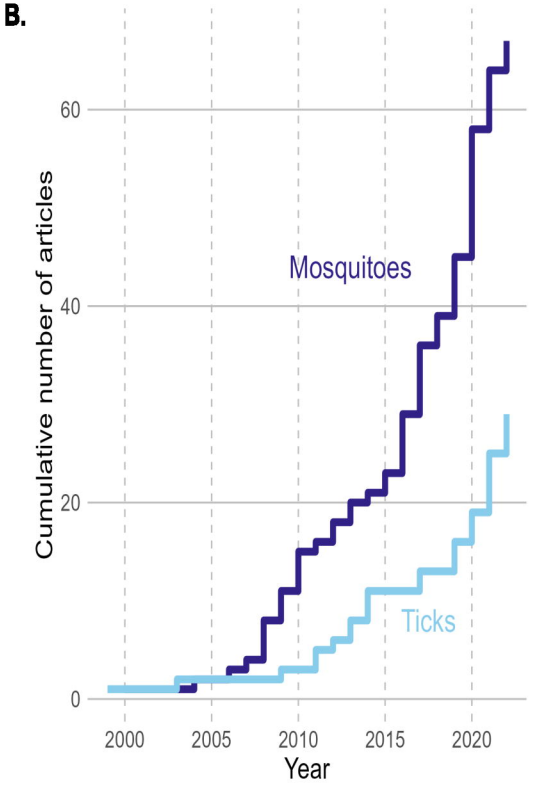
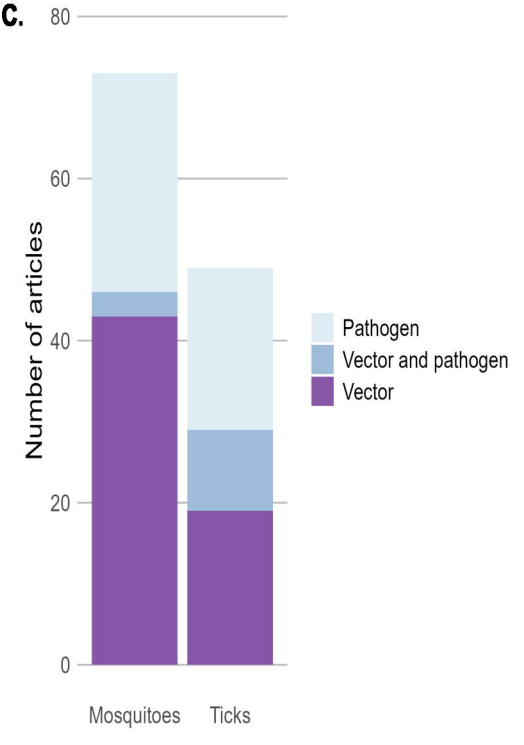
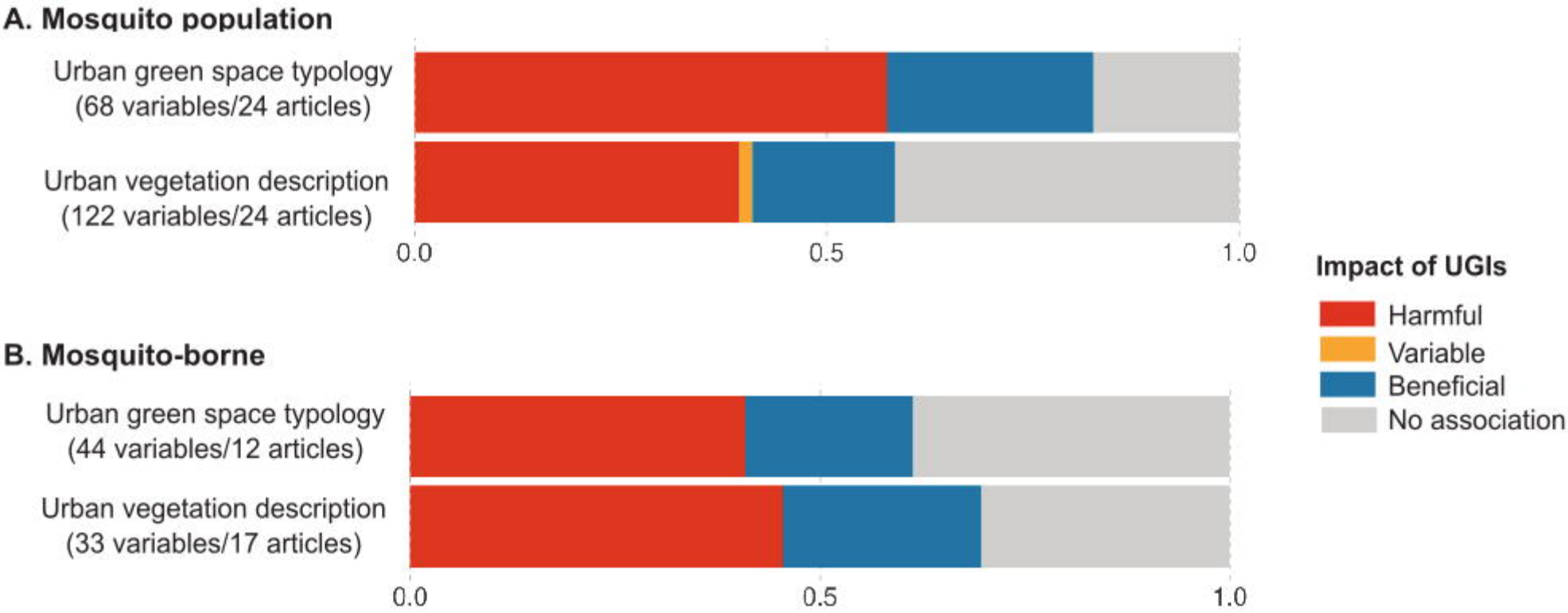
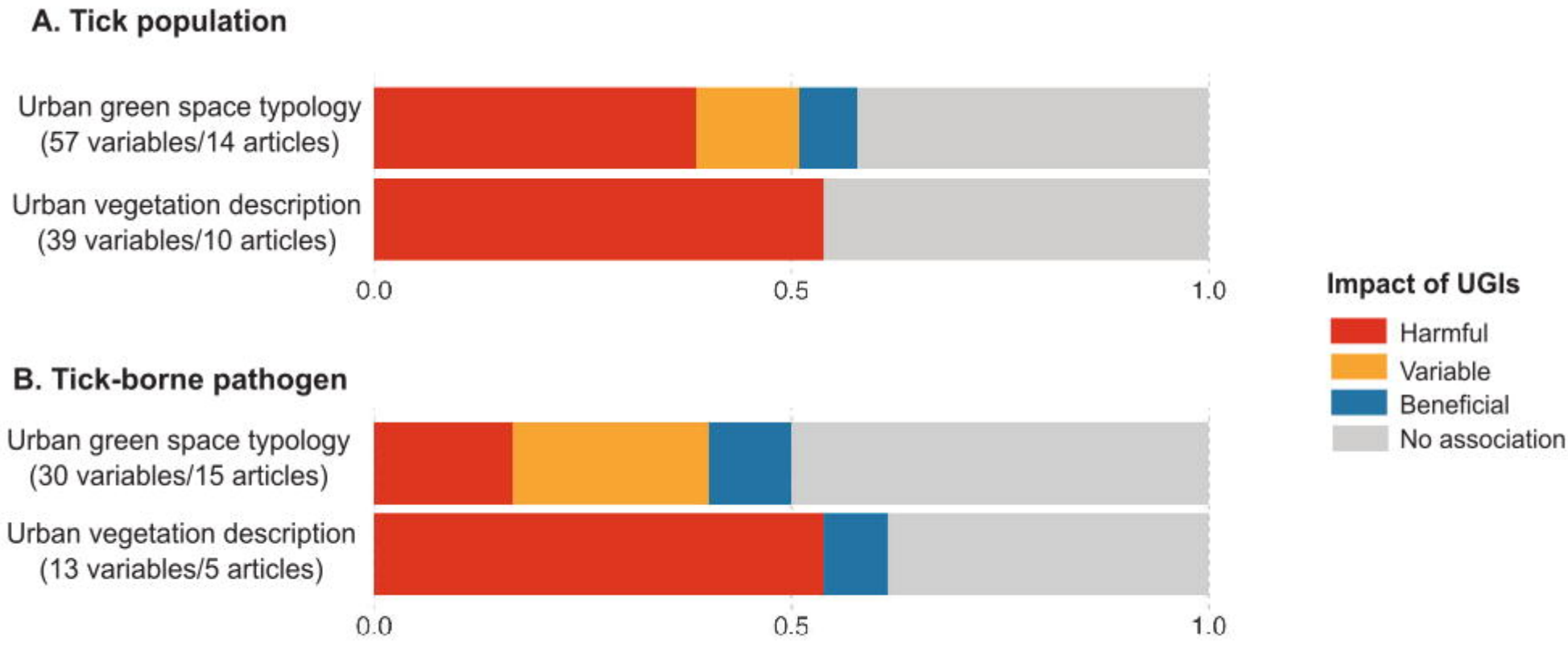

Identification of studies via databases and registers
Identification
Date of search 5/09/22
Records identified from:
Databases (n = 2535)
(Scopus n=775,
Web of Science n=791,
PubMed n=969)
Records removed before screening:
Duplicate records removed by :
Cadima automatic tools (n=972)
Authors (n=5)
Screening
Records screened on title/abstract
(n = 1558)
Records excluded on title/abstract
(n = 997)
Records screened on full text
(n = 561)
Reason of exclusion on full text (n=463)
- Not primary research
- Not accessible
- Not related to vector borne diseases
- Not related to urban area
- Not related to greening cities
- No comparison between urban green spaces versus other spaces
- No statistical analysis
Inclusion
Studies included in review
(n = 98 +1 = 99)
1 article added by the authors

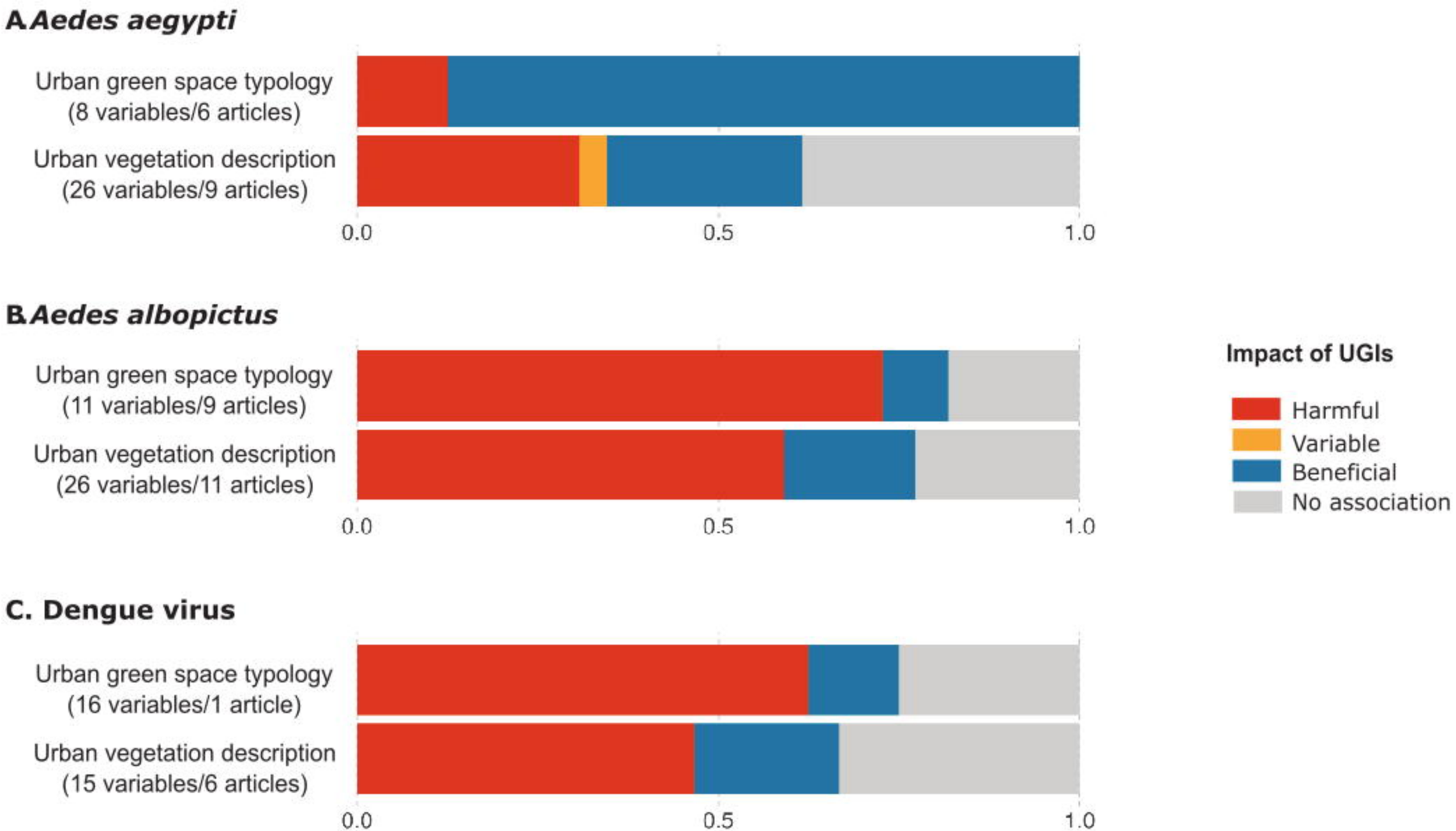

A.
Number of studies
1
2
4
6
8
10
Vector studied
Chigger mites
Mosquitoes
Sandflies
Ticks

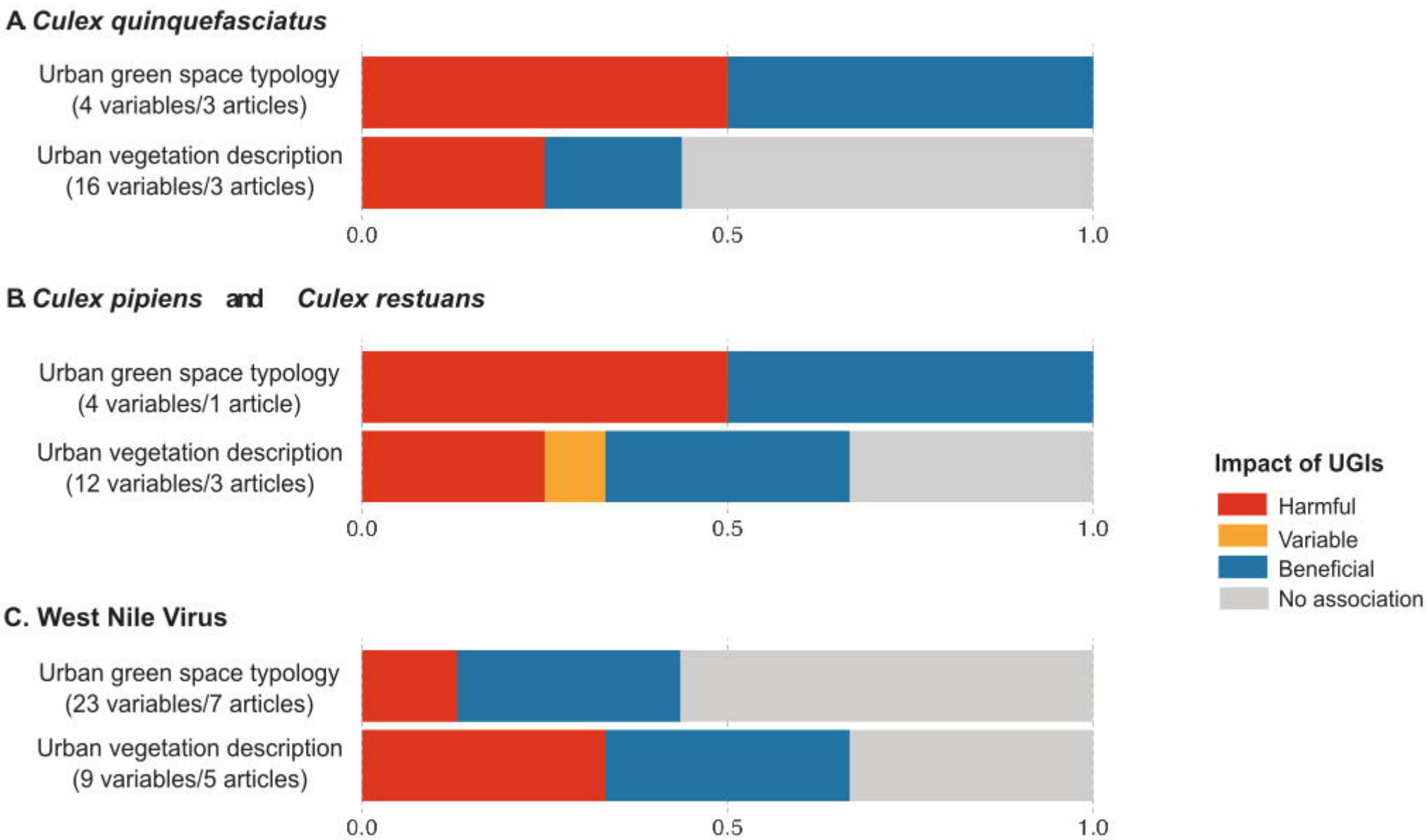

B.
Cumulative number of articles
0
20
40
60
Mosquitoes
Ticks
2000
2005
2010
2015
2020
Year

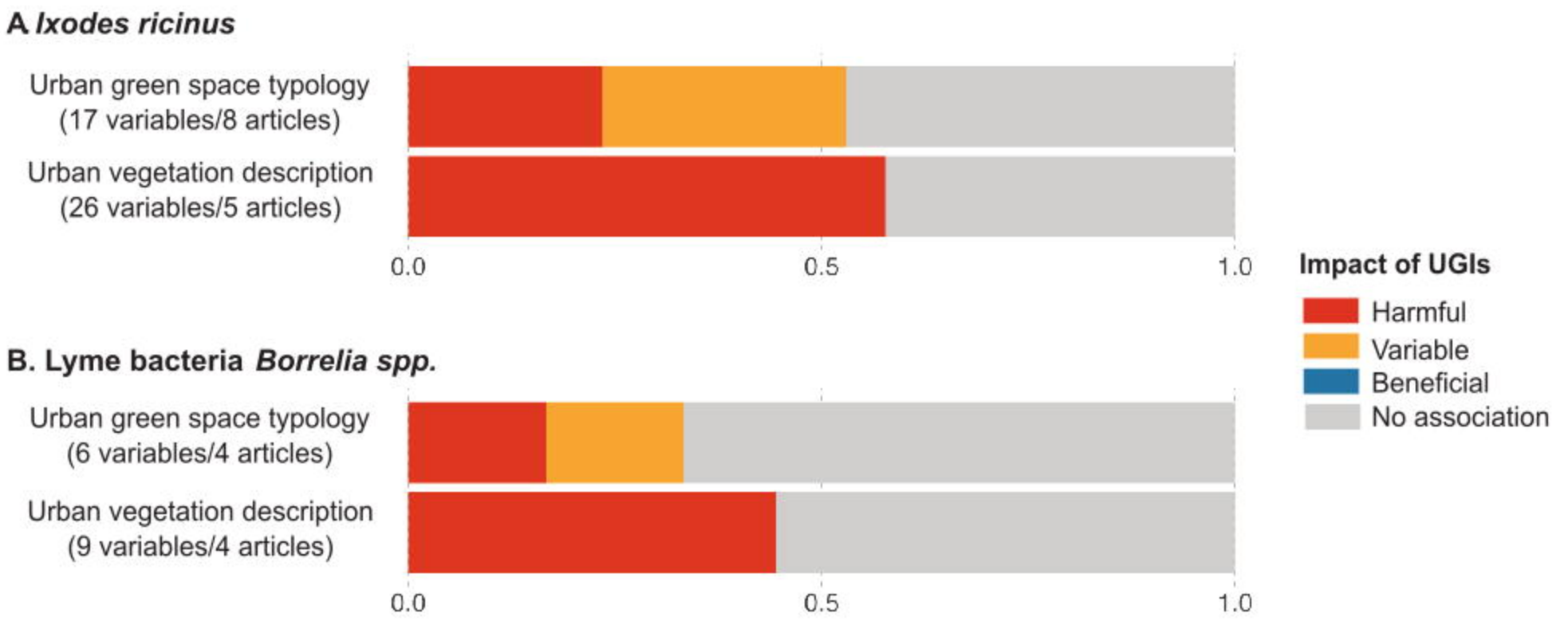

C.
Number of articles
0
20
40
60
80
Pathogen
Vector and pathogen
Vector
Mosquitoes
Ticks


A. Mosquito population
Urban green space typology
(68 variables/24 articles)
Urban vegetation description
(122 variables/24 articles)
0.0
0.5
1.0
B. Mosquito-borne
Urban green space typology
(44 variables/12 articles)
Urban vegetation description
(33 variables/17 articles)
0.0
0.5
1.0
Impact of UGIs
Harmful
Variable
Beneficial
No association


A. Tick population
Urban green space typology
(57 variables/14 articles)
Urban vegetation description
(39 variables/10 articles)
0.0
0.5
1.0
B. Tick-borne pathogen
Urban green space typology
(30 variables/15 articles)
Urban vegetation description
(13 variables/5 articles)
0.0
0.5
1.0
Impact of UGIs
Harmful
Variable
Beneficial
No association


A. Aedes aegypti
Urban green space typology
(8 variables/6 articles)
Urban vegetation description
(26 variables/9 articles)
0.0
0.5
1.0
B. Aedes albopictus
Urban green space typology
(11 variables/9 articles)
Urban vegetation description
(26 variables/11 articles)
0.0
0.5
1.0
C. Dengue virus
Urban green space typology
(16 variables/1 article)
Urban vegetation description
(15 variables/6 articles)
0.0
0.5
1.0
Impact of UGIs
Harmful
Variable
Beneficial
No association


A. Culex quinquefasciatus
Urban green space typology
(4 variables/3 articles)
Urban vegetation description
(16 variables/3 articles)
0.0
0.5
1.0
B. Culex pipiens and Culex restuans
Urban green space typology
(4 variables/1 article)
Urban vegetation description
(12 variables/3 articles)
0.0
0.5
1.0
C. West Nile Virus
Urban green space typology
(23 variables/7 articles)
Urban vegetation description
(9 variables/5 articles)
0.0
0.5
1.0
Impact of UGIs
Harmful
Variable
Beneficial
No association


A. Ixodes ricinus
Urban green space typology
(17 variables/8 articles)
Urban vegetation description
(26 variables/5 articles)
0.0
0.5
1.0
B. Lyme bacteria Borrelia spp.
Urban green space typology
(6 variables/4 articles)
Urban vegetation description
(9 variables/4 articles)
0.0
0.5
1.0
Impact of UGIs
Harmful
Variable
Beneficial
No association