Bulletin of the *Transilvania* University of Braşov
Series II: Forestry • Wood Industry • Agricultural Food Engineering • Vol. 13(62) No. 2 – 2020
https://doi.org/10.31926/but.fwiafe.2020.13.62.2.4

RECOGNIZING THE ROLE OF FORESTS IN URBAN CLIMATE MITIGATION AND ADAPTATION: STATE OF THE ART, LESSONS LEARNED, AND THE WAY FORWARD

Vitaliy SOLOVIY[1,*] Ion DUBOVICH[1]
Taraș KULESHNYK[1]

Abstract: *Research on nature-based solutions, green infrastructure, and ecosystem services to support climate action in cities has proliferated over the past decade. However, relatively little attention has been paid to the unique features of urban forests under climate change. This paper addresses this gap by providing an integrative critical review of 44 articles published during the 2000-2020 period. The review allowed to identify three key themes that require further research: (1) the need to strengthen the framing of urban forests under climate change in the light of other discourses; (2) the need to better understand the complexity of urban forest benefits and exposures, and (3) the need to facilitate further knowledge integration to support more informed and inclusive decision making. The paper concludes by highlighting prospects for collaboration across science, policy and practice contexts.*

Keywords: *urban forests, climate change, cities, mitigation, adaptation.*

1. Introduction

Nature-based climate solutions in cities, such as parks and green roofs, have gained momentum in the past few years, in theory, policy, and practice [12]. They deliver multiple co-benefits and provide a robust and adaptive path compared to the technology-focused 'grey' infrastructure.

There has been a wealth of research highlighting climate mitigation and adaptation potential of forests at global, regional and national scales [3]. However, unlike other types of climate solutions,

[1] Department for Ecological Economics, Institute for Ecological Economics and Management, Ukrainian National Forestry University, General Chuprynka St 103, Lviv 79057, Ukraine.
Correspondence: Vitaliy Soloviy; email: vitsoloviy@yahoo.com.

forests at the city scale have received little attention, compared to the rapidly growing body of research on green urban infrastructure, ecosystem services, and nature-based solutions.

Therefore, this paper aims to address this gap, highlighting the state of the art and lessons learned in urban forestry in the context of climate change. It has three objectives. First, it provides a review of interdisciplinary research on urban forestry in the context of climate change, which we conceptualise through the climate-city-forest nexus, aiming to grasp the diversity of interactions and relationships between those three realms.

Secondly, we identify key recurring narrative themes and their influence on academic, policy and practical engagement with the climate-city-forest nexus. And third, based on the identified themes, we conclude with suggestions for further research that can help to recognize the role of forests in urban climate governance.

2. Materials and Methods

This article utilizes a critical and integrative review methodology [38]. The research process included the following stages:

1. The research scope has been defined to include peer-reviewed papers on the role of forests in urban climate change mitigation and adaptation published between 2000 and 2020 in peer-reviewed journals, as well as official reports and guidelines issued by authoritative organisations. The following keywords have been selected: “climate”, “urban”, “city”, “forest”, “tree”;
2. Initial search in Google Scholar for groups of keywords was conducted using the “all in title” criterion with four relevant keywords combinations leading to 164 results in total (Table 1)
3. Working with the created database, publications were further excluded based on duplications (25 results) and low impact with zero citations (41 resources), leaving 98 resources;
4. Based on the further abstract review, the next group of resources was excluded based on multiple similar contributions by the same author, absence of significant insights or limited relevance (66 results), leaving 32 resources;
5. Using forward-snowballing based on the selected articles, 12 new resources were added considering their relevance to the scope and aim of the research. This led to the final selection of 44 resources;
6. All articles were screened for full-text to generate a quantitative database for analysis.

Table 1

Initial search: keyword groups and results

Keywords groups			Results
climate	urban	forest	73
climate	urban	tree	64
climate	city	forest	19
climate	city	tree	4
Sum			164

3. Results

This paper provides an integrative critical review and analysis of 44 documents on the climate-city-forest nexus, while other supplementary references have been used where necessary to provide extra insights.

Figure 1 provides an overview of the types of analysed literature, the majority of which comprised single case studies (36.4%) and academic reviews (25%). The database also included frameworks, reports, multi-case studies, guidelines, and two strategies.

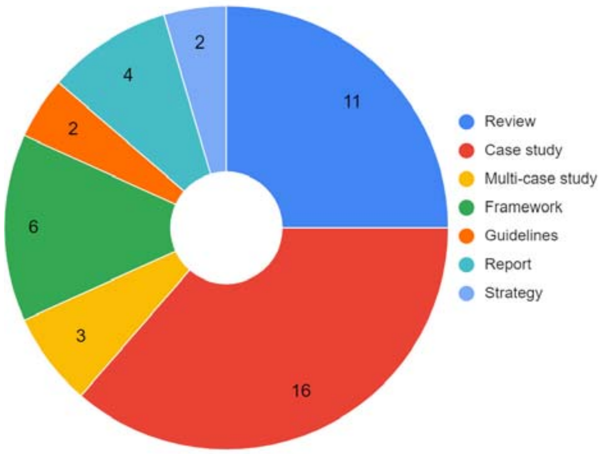

Fig.1. *Reviewed literature typology*

As Figure 2 suggests, despite some early research and guidelines, the climate-city-forest nexus has started to gain prominence since 2015, which can be linked to the adoption of UN Sustainable Development Goals and the recognition of cities' contribution to addressing climate change within the Paris Agreement.

The coverage of social, environmental, and economic dimensions across reviewed publications is presented in Figure 3.

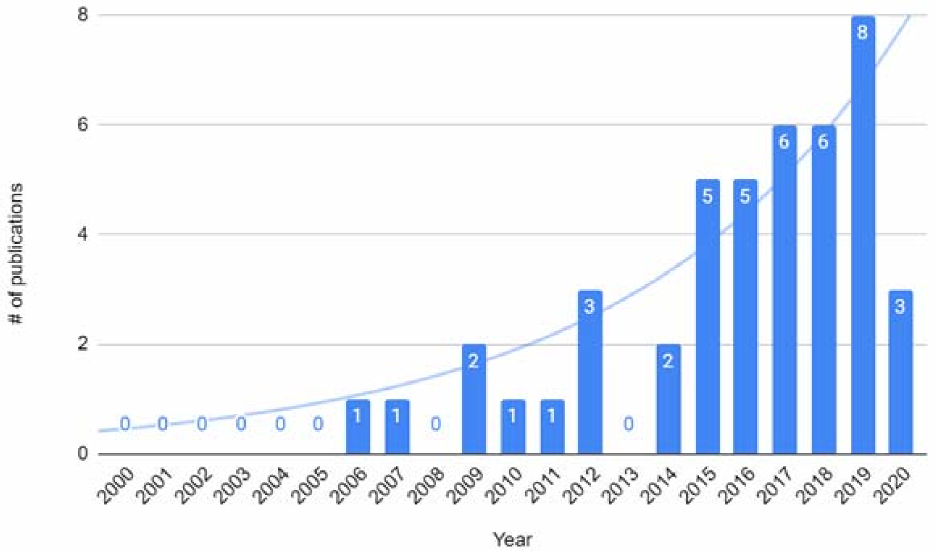

Fig. 2. *The number of publications included in the review per year*

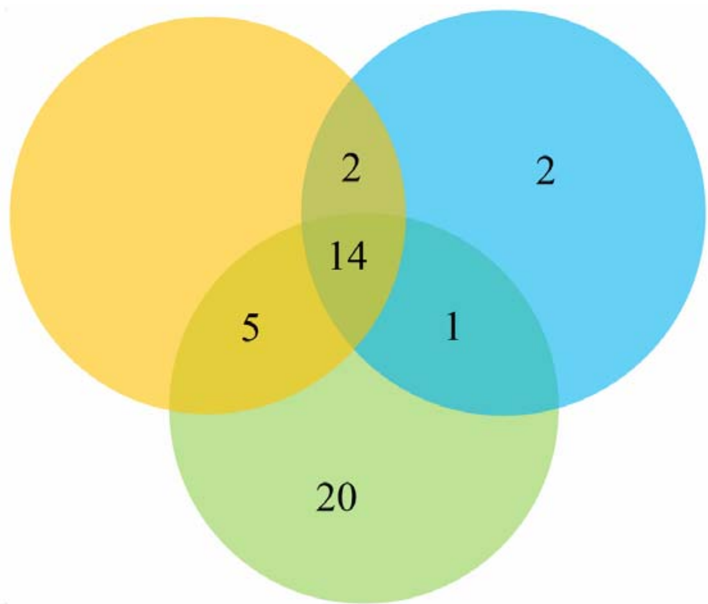

Fig. 3. *The dimensions covered by the papers*
(Green – Environmental, Blue – Economic, Orange – Social)

The diagram suggests that most of the studies focus on the environmental aspects of urban forest governance under climate change, while there is also a tendency towards integrative approaches. No studies focused solely on social aspects and two studies explored economic facets. Five studies were performed at the intersection of environmental and social dimensions, two at the intersection of economic and social dimensions, and one at the intersection of economic and environmental dimensions.

4. Discussion

4.1. The Position of Forests within Urban Climate Discourses

An urban forest may be defined as "all publicly and privately-owned trees within an urban area — including individual trees along streets and in backyards, as well as stands of the remnant forest" [28]. There are also other types of areas in cities covered by trees and woody vegetation such as parks, gardens and, rooftops. It has been estimated that covering 4% of land globally, cities could be home to 121 billion trees [11].

The current status of urban forests has been relatively well described in recent literature [3], [7]. Urban forests are unique in their multifunctionality and are one of the closest approximations of 'wild nature' in direct urban context. On the other hand, peri-urban and non-urban forests face pressure under urban expansion, with land development often leading to deforestation or integration of forest patches into the new urban habitat. Symbiotic integration of forest and city or keeping wide areas of forest to the wild remain rare.

The trajectories of those possibilities depend on metaphors and frameworks that guide urban governance and decision-making with an emerging overlap of research on nature-based solutions, green urban infrastructure, ecosystem services, sustainable forestry, and urban climate governance [12]. An increasingly common practice is to integrate urban forestry into seemingly "broader" discourses. While this allows for a broader scope of options, it may also hinder the effective use of available knowledge in already well-established and elaborate research tradition, while not allowing to fully capture the unique role and benefits of urban forests [2].

4.2. The Multifaceted Status of Urban Forests under Climate Change

Urban forests are some of the most promising urban climate solutions, with benefits such as carbon capture and storage, reduction of heat island effect, and improved stormwater management among others [14], [41]. Even in solely monetary realms, urban forests provide around 225% return on investment [11]. Urban forests disservices, and trade-offs have also been recognized, including often significant management costs, allergens, and risks of injury by power tools used for tree maintenance [11]. Most of the prospective disservices can be prevented or resolved. For example, it is possible to choose non-allergenic tree species, under a possible rise in allergies due to climate change [31].

Multiple efforts have been directed at quantifying and valuing urban forests [36], highlighting both economic [23], [39] and socio-cultural values [2], [14]. There are also multiple contributions that are not directly linked to climate change but that may become important if it aggravates, such as food and fuel security, watershed protection, prevention of land and soil degradation.

Multiple climatic factors influence urban forest composition [15], [32], and there has been growing evidence that climate change may increase the vulnerability of urban trees and forests [4], [18], [20], [44] particularly in warmer cities, creating the need for climate-ready trees and climate-resilient urban forest management [6], [19], [21].

Common climate-aggravated exposures include heat stress, moisture variation, drought, wind, insects, and diseases, among others [29]. Studies have also highlighted the variability in exposures caused by different degrees of urbanization [41], climate-triggered differences in germination, leafing, and flowering phenologies [13], [22], as well as the speed of growth and the lifespan of trees in urban and non-urban areas [24], [34].

It is important to recognize that urban forest exposures do not fully overlap with nearby 'wild nature' exposures, yet it also means unique possibilities to increase resilience through monitoring and timely interventions while decreasing risks to biodiversity [43].

4.3. Knowledge Integration for Better Decision-Making

Urban forest governance under climate change has been mostly conceptualised within broader developments in urban sustainability and climate governance. However, there have also been efforts for creating specific frameworks regarding the climate-city-forest nexus [4], [33], [45], tailored decision-support software [25], [40], scenario modelling and simulations [27], [35]. Thus, it is possible to see the emergence of a more systematic understanding of urban forests and their peculiarities under climate change.

Policy-oriented research and practical examples are starting to emerge, such as the report by the Clean Air and Urban Landscapes Hub on Risks to Australia's urban forest from climate change and urban heat [17], the climate-change sensitive Urban Forest Strategy by Melbourne [8], Urban Forest Strategy in Vancouver [26], and other city-focused assessment reports and guides [1], [5], [9], [16], [37], [42]. They remain distinct examples, as most urban forest governance frameworks do not yet integrate climate mitigation and adaptation, despite significance of the climate-city-forest nexus.

Practitioners often lack knowledge and tools to make climate-sensitive decisions, while responsibilities are often distributed across multiple jurisdictions, which limits coordination and funding [10]. Also, managers may have different perspectives on where the intervention points lie and how to most effectively distribute resources among multiple priorities [30], [41].

5. Conclusion

The recurring themes outlined above have been significant for shaping the climate-city-forest nexus, providing background for further developments in the field.

First and foremost, there is a need for a more integrative framing of urban forests under climate change, beyond differently oriented discourses of nature-based solutions, green infrastructure, and ecosystem services. In the upcoming years, urban forestry will need to defend its place among green roofs, green walls, and urban parks.

Secondly, progress in systematic assessment of urban forest vulnerability and effective decision-making is needed. This requires inter- and transdisciplinary research on multiple value perspectives regarding urban forests. This also requires going beyond many disparate case studies based on different methodologies and devising frameworks that could be flexibly adapted across different contexts to facilitate effective knowledge exchange and progress tracking.

Future sustainable governance of urban forests under climate change also requires greater recognition of cross-scale and cross-level dynamics, while integrating multiple domains: land use, development, energy, transport, health and climate action planning.

Integrative and holistic thinking can be witnessed in research, yet its reflection in practice and policy remains limited. There is an evident need in more collaborative governance of urban forests as green commons. This could support a quantum leap in allowing nature to come back into the city and nourishing social-ecological resilience under climate change.

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