

Review

Long-Term Validation and Governance Role in Contemporary Urban Tree Monitoring: A Review

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Abstract: Urban trees provide important ecosystem services, across ownership and governance structures, and tree inventories are an important tool enabling urban foresters and green space managers to monitor and perform the sustainable management of urban trees. For optimal management of urban trees, a better understanding is needed concerning how urban tree inventories can provide long-term monitoring overviews across administrative borders, and how inventory protocols should be adapted to address specific practitioner issues. In this review, 98 articles on urban tree inventories were examined, the primary focus being sampling design. A governance arrangement approach was applied to identify the policy-making arrangements behind the inventories. Stratification is commonly used in the sampling design, despite being problematic for long-term representativeness. Only 10% of the stratification sampling designs identified were considered as having long-term validity. The studies frequently relied on an individual sampling design aimed at a particular issue, as opposed to using an existing longitudinal sampling network. Although private trees can constitute over 50% of the urban tree population, 41% of the studies reviewed did not include private trees at all. Urban tree inventories focused primarily on tree data on a local scale. Users or private tree owners are commonly not included in these studies, and limited attention is paid to economic, cultural or social factors. A long-term validation of sampling methods in urban areas, and a multi-lateral approach to tree inventories, are needed to maintain long-term operational value for local managers in securing ecosystem service provisions for entire urban forests.

Keywords: urban forestry; urban trees; governance analysis; tree inventories

1. Introduction

Urban areas are undergoing transformation, with climate change and increased urbanization being two of many contemporary challenges [1]. Successful adaptation to climate change will hinge on the measures taken in urban areas, where the majority of the world's population resides [2]. Thus, cities are being forced to adopt long-term perspectives in the planning and management of their resources. Urban forest inventories should reflect this dynamic in order to anchor the role and relevance of urban trees. The multifunctional beneficial contributions of urban forests are well documented, and considerable effort is being devoted to making these benefits accessible to a wide range of urban residents [3–6].

Urban forests have been identified as key in delivering ecosystem services in urban environments, and as an indispensable resource in shaping resilient future cities [7]. However, residential developments can cause a 1% loss in urban tree canopy per year due to the construction of impermeable surfaces [8]. Despite this, urban forestry programs (management of urban trees and green spaces) are often limited to publicly-owned spaces, omitting privately-owned property [9,10].

The main responsibility for the management of urban forests lies at the local government level [11]. Thus, inventories of urban trees are often used by local governments as a tool to assess and manage their urban tree resources, despite multiple ownership forms and areas of administrative responsibility. The local government structure can be divided into three levels of activity: operational, tactical and policy [9]. Urban forest inventories are generally performed on the tactical level, using the data to inform policy and operations. Inventories are the basis for sustainable resource management, providing data for decision-making in urban forestry, while repeated measurements over time (monitoring) inform managers about trends and enhance their ability to identify potential threats [12]. Failing to recognize potential threats can lead to a significant decline in the provision of environmental benefits and, since trees are not easily replaced, a long delay before the supply of ecosystem services is returned to pre-disturbance levels. Many public managers struggle with a lack of available funds, knowledge or time to conduct or maintain an urban tree monitoring program [13,14], resulting in a worrying level of preparedness for an event of the loss of urban tree vegetation.

Existing urban tree inventories and monitoring schemes are based on spatial sampling assessment techniques that generally follow guidelines set by forest management and ecology specialists [3]. The sampling design applied in these methods offers much in terms of variability, but critical analysis is needed to identify approaches suitable for long-term monitoring in urban settings [15]. Sampling inventories can also make it possible to estimate the state of privately owned trees [16]. However, there are many potential pitfalls when setting up a new monitoring system. Over time, some methods can impede the unbiased representation of the population, and give an inaccurate description of the resource. This is due to the inherent variabilities and dynamics of the urban space, and the changing boundaries, land use and development driven by the high rates of urbanization and changes in land ownership [17]. The common approach of using spatial groupings within urban boundaries (stratification) can be problematic, since urban land is often re-classified, re-developed or re-purposed. Groupings based on spatial features can encompass a wider array of factors in forming urban forest ecosystem units in order to differentiate between sites with different conditions [18]. The stratification factor used for the grouping (land use, normalized difference vegetation index, socio-economic factor, etc.) can change over time, making comparisons of repeated measurements (e.g., permanent plot networks) problematic.

Spatial stratification continues to be commonly employed to obtain better estimates of urban forest sub-populations. For example, the i-Tree Eco program developed by the USDA Forest Service is one of the most frequently used urban forestry analysis and benefit assessment tools, used globally, with over 300,000 unique users [19]. The user's manual describes how the sampling design can be stratified when collecting field data [19].

Approximately 50% of what is often considered to be urban open space is privately owned [20,21], yet may still be accessible, physically or visually, and contribute much to the public in various ways, through providing amenity and ecosystem services. In truth, private households are a very important actor in urban tree management [22], as they sometimes own more than 50% of the urban tree cover [23]. Thus, it is relevant to consider a scale from private to public when defining or dealing with the management of urban trees [24]. There is great variation in the regulatory measures between countries (as well as between different local governments within a country) [25,26] regarding privately-owned trees, causing local practices to rely on stewardship networks to improve the survival of trees [27]. Small-scale variations in stewardship could be partially explained by the differences in attitudes that people exhibit towards trees, yet not many inventories include this type of surveying [28].

In order to provide holistic, overarching measures to manage all of the urban forest, inclusive governance structures need to be applied, since the private component of urban forests is dependent in large part on measures supported by local governments [2]. This involves appropriate frameworks to plan and manage key ecosystem services, regardless of whether these services are derived from public, semi-public or private land. To deal with the rising pace of urbanization and maximize environmental outcomes, active citizenship needs to be stimulated by enhancing relationships between communities.

However, from a public management perspective, residential area developments and trees owned by private individuals are inherently difficult/complex to monitor, and pose many dilemmas in relation to over-viewing, recording, monitoring and data gathering. Only 2.4% of Swedish municipalities that run a tree monitoring program include private trees [29], which means that the majority of the information which guides decision-making on a local scale is based solely on data gathered from public, park and street trees. Further research is required on how to successfully integrate privately-owned trees into city-wide urban planning and management, beyond the current scope of incentives and regulations [25,26]. We suggest that using inventories as instruments to introduce inclusive governance is the way towards a holistic understanding of urban tree dynamics.

Field inventories based on spatial sampling remain the most common approach to assessing the structure of urban forests. Accurate inventories are the basis of good natural resource management practice [30], and the use of urban tree inventories is a thoroughly researched topic. However, a critical evaluation, applying a long-term perspective to the sampling design, seems to be lacking, raising questions about the viability of contemporary methods. Against this background, we considered the research question of how to design a long-term monitoring system for comprehensive and inclusive urban forest management. In order to address this question, we studied:

- Common sampling design techniques used in urban tree inventories;
- the policy arrangement context in relation to urban tree inventories.

2. Materials and Methods

2.1. Urban Tree Sampling Terms and Definitions

Urban tree inventories are widely recognized as being key to creating an urban forest monitoring framework [31–33]. An inventory can be defined as “a written list of all the objects, furniture, etc. in a particular building” [34]. The colloquial use of the term in forestry research most commonly refers to inventories as assessments based on incomplete data, as opposed to a full record of the resource [16]. For example, national forest inventories worldwide do not draw up a complete list of all trees or forests within a particular area, but instead make estimates based on data collected from sampling plots. In this review, an inventory is defined as an assessment of a tree resource in a particular area, which is not necessarily based on a complete list of trees.

Single event inventories provide a snapshot of the current state of the trees in an urban forest, while repeated inventories (monitoring) provide an understanding of how tree populations change over time, and offer better information for policy and decision making with respect to urban forest management [16]. It is imperative that all subsequent inventory repetitions follow the same design and form, allowing the direct comparison of different snapshots and enabling the local government to draw correct assumptions.

Whenever an incomplete number of trees is selected to represent the urban forest in an area, the estimates contain inherent sampling errors [35], and aggregated data are reported in confidence intervals. However, the sampling error can be minimized by increasing the number of samples, or in other ways [36]. Different strategies have been developed to obtain more accurate estimates from sampled data in an effort to be representative of the urban forest as a whole. These include random, systematic, cluster and stratified sampling [37], all of which are dependent on the set inventory goals and objectives.

The use of stratification is widespread in sampling, the main benefit being the powerful analysis options it provides. The stratification method entails dividing the population into sub-populations (strata) using delineation criteria called stratification factors. With populations divided, sampling occurs at uneven densities between strata. Some common stratification factors applied in urban forestry include land use and local management units or other geographical units, such as ownership [18].

2.2. Structured Search and Bibliographic Overview

We performed a broad structured search of the literature in order to get a comprehensive overview of scientific articles published on sample urban forest inventories. The search included literature from 2001 onwards. In December 2019, the following search string was applied to Web of Science and Scopus: (cit* OR urban*) AND forest* AND tree* AND (monitor* OR invent*) AND (sampl* OR plot*). The search string components were location (cities and urban), population (trees and forests) and method (sampling, plots, monitoring, inventory), representing the frame of tree population and method used. Only publications written in English and only peer-reviewed articles published in international journals were included.

All the articles were reviewed and sorted via two screening processes (Figure 1). After consolidating results from both databases, 420 unique articles were identified. The first screening of these was based on abstract and title relevancy, the second screening was based on reviewing the body of the text for each individual entry. The end result was a final number of 98 articles. The criteria for excluding irrelevant articles were non-tree inventories, inventories in non-urban environments or articles not pertinent to the topic of urban forestry. The final 98 articles all included a tree inventory described in the methods section.

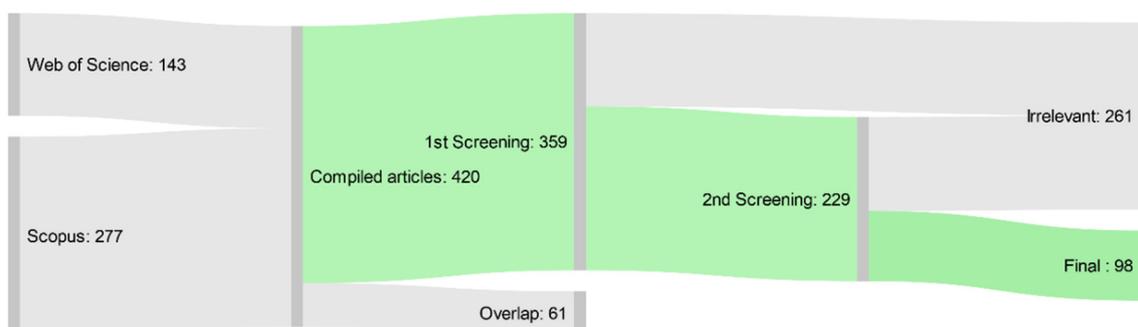


Figure 1. Sankey diagram demonstrating the literature review process and its iterations.

2.3. Validating Contemporary Sampling Methods for Long-Term Monitoring

The 98 articles were categorized based on: (i) stratification factor, (ii) possibility for long-term monitoring, and (iii) sampling method. The categorization also included information on the use of existing frameworks (e.g., the USDA Forest Service's Forest Inventories and Analysis, National Forest Inventory) or when the study used a new design.

The stratification factors were ranked on the basis of their susceptibility to change over time, based on the Urban Forest Ecosystem Classification framework [18]:

1. High stability. The basis for stratification has a low probability of changing over the coming 30 years, based on housing development age, infrastructure, and set distances from a specific point;
2. Medium stability. The basis for stratification has a low to medium probability of changing over the coming 30 years, based on human demographics (e.g., population) and urban vegetation structure;
3. Low stability. The basis for stratification has a high probability of changing over the coming 30 years, based on, e.g., socioeconomics and pollution rates.

2.4. Policy Arrangement Analysis

Governance factors were analyzed using the policy arrangement model (PAM), a conceptual framework developed in environmental policy studies to assist in understanding content and organization in a policy domain. According to Arts et al. [38], a policy arrangement is the state in which the interaction between four profoundly interconnected dimensions, namely actors, resources, rules of the game and discourses, solidifies into institutionalization. This is an unstable construct that will be forced to readjust as the interdependency of the dimensions changes. Here, the four dimensions

all provided insights into how an urban forest inventory may be organized within any political framework. The 98 articles were categorized according to the PAM model and its four dimensions, defined as:

Actors. Actors and coalitions. The initiative for an inventory was classified as the origin of the idea that led to the inventory being conducted. Actors were differentiated into public, private and academic. Inventories that had a pronounced official public role were classified as public initiatives, and cases when private individuals or organizations were the driving force were classified as private initiatives. Academic initiatives were defined as inventories formulated for the purpose of answering a scientific question;

Resources. The benefits derived from trees (or ecosystem services) that were mentioned in the individual studies were categorized into economic, cultural/historical, environmental and social categories.

Rules of the game. Formal rules and boundaries related to the inventories were interpreted as the organizational level at which the inventory operated. Three different scales of inventory were differentiated, namely, local, national and international, as defined by the boundaries of the area surveyed. Local scale was classified as scaling from site to multi-regional inventories;

Discourses. Views and narratives of the actors presented in the discussion and application of the data compiled in the inventory were used to distinguish discourses. Special focus was given to articles that involved views other than those of the actors themselves, and that speculated on the potential implications of the results. The actors involved in the inventory were then categorized as politicians, public servants, academics, private owners or end-users. In this context, the end-users are beneficiaries of ecosystem services provided by trees, e.g., a park visitor that is only indirectly involved in managing processes.

For each of the four policy arrangement dimensions, multiple aspects were included per category in cases where joint involvement was described in the methodology, such as shared initiative between academic and public actors in the experiment design.

3. Results

3.1. Bibliographic Overview

We found an uneven, but gradually increasing, number of published articles during the selected study period (2001–June 2019), with 2011 being the first year in which more than three articles within this subject were published (Figure 2). A relatively low number of articles was published in 2015, but this was followed by a substantial increase from 2016 onwards. The publications primarily originated from North America and Europe, accounting for 43% and 31%, respectively, of the total number of publications, compared with 2% from Australia and 1% from Africa (Figure 2).

We identified 30 studies (31% of the total) that used remote sensing data. This is in accordance with reports in the literature of an increasing trend of using remote sensing [39,40], or testing remote sensing accuracy against other types of inventories [41,42].

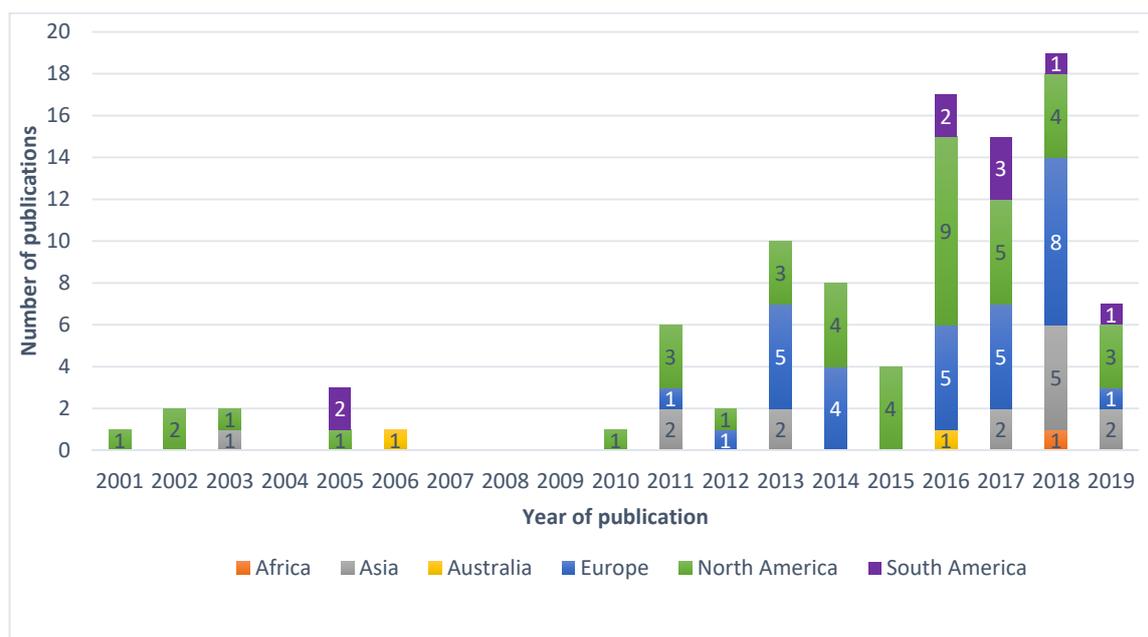


Figure 2. Number of publications per year in different regions, the full list of articles with bibliographic information is available as supplementary materials online.

3.2. Validating Contemporary Sampling Methods for Long-Term Monitoring

We identified 14 different stratification factors, all of which could be classified according to a framework for urban forest ecosystems [18]. In total, we distinguished five types of factors: climate, infrastructure, management, social and vegetation. In Table 1, these stratification factors are listed in relation to the respective stratification types. For each stratification factor, we assessed the stability for long-term studies (low, medium or high) and the chosen sampling method.

A total of 39 of the articles (40%) described the use of a type of stratification in their sampling design. In some cases, post-stratification was applied [43,44]. The stratification factors varied in relation to stability, and were primarily based on infrastructure, vegetation or social factors (Table 1).

Of the 39 studies that applied stratification, 20 were designed as long-term trials. None discussed the validation of stratification factors or the likelihood of change in these factors over different time scales. To better illustrate examples when validating stratification factors, Figure 3 outlines our interpretation of different decision-making scenarios that occur during sampling design, related to the necessity for validation.

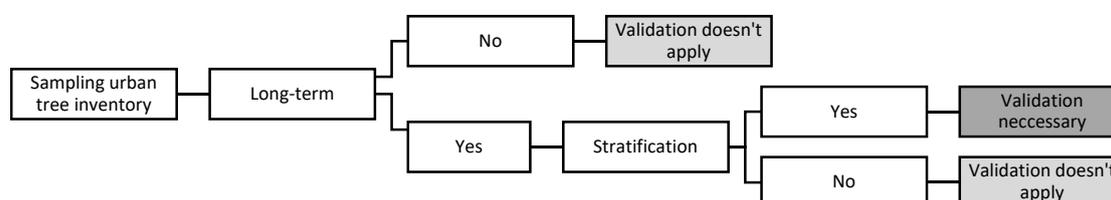


Figure 3. Diagram illustrating when validation of stratification factors is necessary for future representativeness.

Only one type of stratification (infrastructure) yielded stratification factors that were categorized as providing longitudinal stability and reliability to create a long-term network (Age of housing, Proximity to city center, Landscape type). Only one article reported a systematic stratified sampling method [45], while all others used a random stratified approach.

Table 1. Full list of articles that used stratification in their sampling design, grouped by type of stratification factor. Systematic stratified selection used set distances between sampling points, whereas random stratified selection uses a randomly selected point within the strata.

Type of Stratification	Stratification Factor	Stability	Sampling Method	References from the Literature Studied in This Article
Climate	Thermal differences	Medium	Stratified systematic	[45]
Infrastructure	Age of housing	High	Stratified random	[46]
	Landscape type	High	Stratified random	[46]
	Vicinity to city center	High	Stratified random	[47]
	Land use, land cover	Medium	Stratified random	[48–51]
	Traffic, traffic density	Low	Stratified random	[52,53]
	Pollution	Low	Stratified random	[54]
	Specific urban structure	Low	Stratified random	[52]
Management	Management units within a city (neighborhood, homogenous units within a city)	Medium	Stratified random	[21,43,55–59]
Social	Size of a community	Medium	Stratified random	[60]
	Index of human interference	Low	Stratified random	[61]
	Combination of socio-economic indicators	Low	Stratified random	[39,62]
Vegetation	Urban forest stand structure	Medium	Stratified random	[56,57,63]
	Vegetation properties	Medium	Stratified random	[64,65]
	Tree cover and other vegetation data	Medium	Stratified random	[40,44,65–69]
	Tree species composition	Medium	Stratified random	[70,71]

We found a varying degree of stability within the five types of stratification factors, the exceptions being the climate and management categories. We rated infrastructure as offering the best basis for monitoring. Management units are often utilized as delineators, indicating that inventories continue to have strong operational importance within urban forestry, yet given the relatively young history of urban forest management, these have been adapted as knowledge about urban trees has changed over time [72].

Social factors were graded as the least stable, due to rapidly changing global demographics [73], and they were featured in only four articles in our review. Generally speaking, stratification factors were found to be location-specific; even when different authors used a similar approach in stratifying their population, they used different methodologies to determine essentially the same factors. For example: tree species composition was determined using the broadleaves to conifers ratio index in one case [71], and individual species mixture in another [70]. This indicates large a difference in applications between regions, and makes determining a set of universal stratification factors challenging.

3.3. Governance Analysis

A total of 98 studies were initiated by academics, and 37 of these studies also included public perspectives (municipalities or government agencies) in the research topic, primarily by discussing the results from a public management perspective. A small proportion (5 out of 98) mentioned a private stakeholder inclusion/initiative in the conception of the study. The majority of the studies were conducted on the local government scale (92), some also applying the methodology to the national scale [41,44,74,75], but only one study [33] set its findings within an international perspective.

All studies highlighted the ecological aspects of trees in the urban environment. Economic impact was featured eight times and the social aspect four times, while only one article referred to the cultural values of urban trees. Only five studies involved joint initiation with private actors [58,59,76–78], which mirrors the fact that only eight studies [21,46,48,58,76,79–81] included private tree owners.

The results of the qualitative governance analysis are summarized in Table 2. According to the results, contemporary urban forest inventories are based on an academic (scientific) initiative and approach, with the focus being on local environmental perspectives. In studies that included multiple actors, we detected a higher potential for management application [49,61,82].

Table 2. Results of governance analysis according to the four dimensions of the policy arrangement model (PAM).

Actors	Resource	Rules of the Game	Discourses
Academic (98)	Economic (8)	Local (92)	Academic (98)
Public (37)	Environmental (98)	National (11)	Public servants (24)
Private (5)	Social (4)	International (2)	Private owners (8)
	Cultural (1)		Users (4)
			Politicians (0)
Multiple categories * (38)	Multiple categories * (12)	Multiple categories * (7)	Multiple categories * (27)

* Multiple categories row indicates how many of the articles in each separate aspect category (column) had joint perspectives.

4. Discussion

Inventories and monitoring are key components in the planning and management of any resource [3,16]. Urban forestry is largely based on tree inventories [14], and the importance of continuous long-term monitoring of urban tree stocks is gaining attention. Despite this, only 10% of the stratification factors identified in this review were rated as having high stability, i.e., allowing for long-term studies. Infrastructure is frequently used as a stratification factor. However, numerous articles use low stability factors, such as traffic density and pollution levels related to traffic. Likewise, social factors with low stability, such as socio-economic indicators, are used. Such factors fluctuate

over time, and therefore cannot be recommended from a long-term monitoring perspective. Vegetation factors, such as stand structure, tree cover and species composition, also fluctuate over time, but have medium stability from a long-term perspective. Too often, factors are selected based on current focus areas, with over-reliance on delineations that are less suitable for time-frames greater than a couple of years. Even though we cannot expect every trial to prioritize broad timescales, we believe that this contemporary trend is concerning, as it indicates that research on urban tree inventories is not sufficiently addressing the needs of the practice. In an urban forestry and green space management context, a transition from single inventories (a snapshot of the urban forest at a specific time) to long-term monitoring seem critical. This is especially relevant in instances where a new monitoring system is put into place by urban forestry managers in growing cities [67]. From a research perspective, these snapshots also limit the possibility for longitudinal studies, which is crucial for studies of long-term processes.

In line with Nielsen et al. [13] and Ordóñez et al. [83], we found that European and North American publications dominate the field of urban forestry in the study period, with a gradual increasing trend in the number of publications since 2010. This also reinforces the notion of the modest contributions to tree sampling and urban tree inventories in other regions [84], as well as the limited focus on the non-environmental benefits of urban trees. As reported previously, we can see that the geographical scope of scientific studies has expanded from being primarily North American during the early 2000s, and now spans all continents. The dominance of North American research up until 2018 reflects the overall expansion in the field of urban forestry, which developed in North America during the 1960s as an integrative, multidisciplinary approach to the planning and management of all forest and tree resources in and near urban areas [10]. This can be partially explained by the fact that it was not until the mid-1990s that the concept was adopted in Europe and elsewhere, following pioneering work by the US Forest Service on quantifying and modelling urban forest benefits in the Chicago Urban Forest Climate Project [10]. This late adoption is still evident in scales and scopes when comparing studies by region of origin; North American studies represent more than half of the studies that involved private stakeholders in discourses (5 out of 8), and they were most likely to involve the economic aspects of tree benefits (also 5 out of 8 studies). The scope of these studies was also more likely to include the social aspects of urban tree benefits (4 out of 4), which was most evident in recent studies.

Few articles represented more than just a single environmental aspect, which may be appropriate from a strictly scientific perspective, but it comes with the risk of restricting urban forest studies to environmental science, which accounted for 70% of the studies, instead of the multi-disciplinary field called for by many researchers and high level politicians [72,85,86]. Even if scientific studies often have the need to focus on a single perspective, we found a surprising lack of studies focusing on the aspects of social, cultural and economic value. Given the importance of these aspects, we would expect more studies focusing on the broader aspects of tree benefits. We can assume that the field of urban forestry is in a phase wherein new ways to interpret human–nature interactions are needed to better inform policymakers. With future studies being more conscious of the multidisciplinary nature of urban forestry research, trees can become better integrated in urban planning, as their contribution would be better translated across operational fields.

Since the study was restricted to articles written in English and published in peer-reviewed scientific journals, it is not surprising that all studies were driven by academics. However, tree inventory methods and findings at the local or national level may also be published as reports, guidelines and ‘grey’ literature, and thus a number of studies in which urban tree inventory methods are described and/or used as data sources may have been overlooked. By expanding the scope of further studies, it might be possible to get an even deeper understanding of the methods used when inventorying and monitoring the urban forest. We therefore encourage further studies to go beyond the scientific literature, and to also include other publications and languages.

The same applies for the geographically narrow focus in the literature reviewed. Only two studies adopted an international perspective, even though urban forestry is a highly international

field [33,83]. More international meta-studies could improve the understanding of international urban forest inventories and methods, which could lead to the greater harmonization of inventory methods between countries and cultures, enabling them to combine efforts and share data-based experiences dealing with global issues. We also see a need for access to detailed data on the entire urban forest, as the existing information and documentation of the effects of urbanization on the actual tree resource seems scattered and varied in its conclusions.

When looking at the background of performing the tree inventories, none of the studies focused on policy implication, while only four focused on users and eight on private owners. This lack of inclusiveness risks limiting urban forest monitoring to being an academic exercise, without connecting the results or the research field of urban forestry to either policymaking or practice. The potential for using tree data as the background for policymaking is inevitable, and it seems to have a great potential in the future [87], just as the omission of private owners needs to be addressed by future research, as data concerning the contribution of residential trees to the total amount of the urban forest is a prerequisite for the creation of a total overview of the urban forest. Without long-term and stable monitoring systems, local governments will face challenges in creating suitable frameworks to ensure sustainable management. So far, the academic literature within the field does not explore how the full potential of the urban forest as a resource can be fulfilled.

5. Conclusions

This review shows how contemporary urban tree monitoring data have limited concern for long-term stability and longitudinal perspectives. This approach leads to urban forest management based on a disproportional part of the urban tree population, and long-term strategies are exposed to a higher risk of failure.

Urban forestry research has a long tradition with the applied science approach to aiding management organizations in coping with future challenges. These different methods have their advantages and disadvantages, dependent on the basis and use. We found that the relation between the research basis and the actual use, expressed via (lack of) public perspectives, was significant.

The predominant use of sampling different strata at different densities can be the best approach to resolving immediate and short-term management issues. However, unless the stratification factors possess long-term stability, this approach will not provide representative longitudinal data. In order to achieve reliable long-term trials and monitoring systems, stratification should be implemented after careful consideration of stratification factor(s) and their likelihood of changing over the given time-frame. As each city is different, the choice of stratification factors should be fitted to its local context. We suggest using rigid, local infrastructure delineations related to city characteristics (age of buildings, proximity to city center) that, unlike socio-economic indicators, population density and vegetation composition, will endure the test of time, and not significantly impact the representability. In order to make individual inventories comparable, and to increase the likelihood of international perspectives being applied to local inventories, we propose using a thorough validation process to certify each suggested factor, instead of relying on preset factors.

Non-stratification is advisable. However, a grid-based sample seems least suitable, since it easily introduces a systematic sampling bias due to the frequent use of grids in urban design.

The majority of inventories did not acknowledge the potential involved in engaging a broader range of local (and private) actors in order to secure a broader image of the urban forest data, as well as ensuring shared ownership of the inventory and its results. The involvement of multiple actors could be extended to private–public collaborations between local government and private residents. As the latter own a large proportion of the trees in a city, this form of inventory design has a higher likelihood of involving privately owned trees, and can help raise awareness and stewardship of the entire urban forest population.

Remote sensing could solve issues of access to private property, but some of the variables that it is essential to monitor in urban forest environment (pathogens, species, tree condition) continue to be hard to assess when relying solely on remote imagery.

Human–environment interaction differs a lot over the urban landscape, and in order to manage for positive ecological outcomes in the long-term future, the way we assess the tree population needs to be frequently revisited, from a methodological as well as a paradigmatic standpoint. Researchers and practitioners need to internalize the interdisciplinary nature of urban forestry, and consider building in the capacity to collect such relevant data when designing monitoring systems.

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