forests

Article

Urban Forest Indicators for Planning and Designing Future Forests

Sara Barron [1,*], Stephen R.J. Sheppard [1] and Patrick M. Condon [2]

[1] Forest Resources Management, Faculty of Forestry, University of British Columbia, Vancouver, BC V6T 1Z4, Canada; stephen.sheppard@ubc.ca
[2] School of Architecture and Landscape Architecture, Faculty of Applied Science, University of British Columbia, Vancouver, BC V6T 1Z4, Canada; pcondon@sala.ubc.ca
* Correspondence: sara.fryer.barron@gmail.com; Tel.: +1-604-763-7728

Academic Editors: Francisco Escobedo, Stephen John Livesley and Justin Morgenroth
Received: 8 May 2016; Accepted: 9 September 2016; Published: 16 September 2016

Abstract: This paper describes a research project exploring future urban forests. This study uses a Delphi approach to develop a set of key indicators for healthy, resilient urban forests. Two groups of experts participated in the Delphi survey: International academics and local practitioners. The results of the Delphi indicate that "urban tree diversity" and "physical access to nature" are indicators of high importance. "Tree risk" and "energy conservation" were rated as indicators of relatively low importance. Results revealed some differences between academics and practitioners in terms of their rating of the indicators. The research shows that some indicators rated as high importance are not necessarily the ones measured or promoted by many municipal urban forestry programs. In particular, social indicators of human health and well-being were rated highly by participants, but not routinely measured by urban forestry programs.

Keywords: indicators; urban forest; Delphi; urban design; green infrastructure; climate change; ecosystem services

1. Introduction

Our world is rapidly urbanizing, while, at the same time, facing uncertain futures. If we want our cities to continue to be livable, dynamic places for the world's citizens, we must plan ahead for climate change. One important aspect of a city's functioning is in its urban forest. Urban forests provide a wide range of benefits, from ecosystem services [1–3], climate change adaptation [4,5] and climate change mitigation [6–8], to improvement in human health and well-being [9–11] Unfortunately, in many places in the world, urban forests are rapidly being lost to create residential spaces for the global migration to cities [12,13]. Urban forests are also threatened by changing climate, including spreading pests and diseases, changes to precipitation, and increased storm events.

In order to address these challenges, many cities are implementing tree-planting programs to increase the urban forest [14,15]. While these programs have excellent intentions, many lack an overall vision about the values to be achieved by the tree planting, and the urban forest design best fit to achieve these values. A dichotomy also exists between what cities strive for, and what they monitor as key indicators. For example, there is increasing awareness of the role of urban forests in enriching human health and well-being [9–11], but none of the indicator sets or management parameters surveyed included a measure of how trees can be planted to enhance their effects on human health.

The main aim of this study is to develop a decision support framework, centered on a set of key indicators, which can be used to build and test various scenarios of future urban forests. A decision support framework for urban forest design is proposed to help cities achieve their future forest vision.

A decision support framework translates "big picture" thinking at the vision level into values, goals, indicators, and targets, which will lead to specific strategies and actions to enable implementation [16]. A framework creates a transparent linkage between practical strategies and actions on the ground and the goals and objectives inspiring them.

The purpose of the Delphi research was to select a small, but broad set of key urban forest indicators to drive the design and measurement of future forest scenarios. Criteria and indicators are a commonly used tool in the profession of forestry [17–19] and urban design [20]. There have been a few studies looking at indicator sets for urban forestry [21–26]. None of the existing indicator sets captured the full range of urban forest benefits required for this study. This study is focused on urban forests in the context of climate change, and looks at issues of human health and well-being. Indicators addressing these issues were not in most indicator sets reviewed. Additionally, it is hoped that many communities implementing urban tree planting programs could use the indicators selected. This indicator set could provide communities with limited resources a simple but fairly comprehensive framework for planning future urban forests.

Indicators are a common tool used to measure progress towards an objective. For example, the use of criteria and indicator sets is well established in sustainable forest management plans [17–19] and literature exists on what constitutes a good indicator [17]. According to their literature review, Harshaw et al. [17] list the characteristics of a good indicator as:

- Relevant
- Credible
- Measurable
- Cost-effective
- Connected to [urban] forestry

These characteristics were used to evaluate the initial list of indicators for this project.

While indicators are primarily used to measure performance, Kellett [20] proposes "indicators are also very useful, arguably more useful, in community planning and design to direct alternatives and choices toward targets when opportunity is far greater to modify direction or approach" [20]. He differentiates between "enabling" indicators that can direct design from "performance" indicators that simply measure the results of design [20]. For example, tree canopy cover is an "enabling" indicator because it can be used to direct design decisions. A community could use a canopy cover target of thirty percent to guide design, while also using the indicator to measure the resulting forest to see if this cover was achieved. A performance indicator, on the other hand, can only be used once the design is in place. An example of a performance indicator could be "tree health". This indicator is important, but difficult to guide design decisions. For the purposes of this study, "enabling" indicators will be used that can both direct design choices for a series of alternative futures, as well as measure the results of these futures once they are modeled. Dobbs et al. argue that the urban forest structure determines its ability to provide ecosystem services [21]. Enabling indicators are those that determine the structure of the urban forest. No literature reviewed to date has proposed using indicators as a design input for visioning future forests.

There have been a few recent attempts to create indicator sets for urban forest resources [22–24]. Current indicator sets proposed for urban forestry have shortcomings. First, there is a lack of uptake for the indicators sets. Kenney et al. [22] noted that Clark et al.'s indicator set [23], while comprehensive, has had little uptake by municipalities in the decade since being proposed. If municipalities aren't using the indicators, this could show they aren't measuring the issues urban foresters are most interested in. While most cities have a set of management parameters, a study by Östberg et al. [24] found few parameters that were used by multiple cities. This lack of standardization between cities makes comparison of performance between cities difficult. For example, some cities may collect tree diversity data, while others may collect data about habitat areas. Many collect some data about tree cover, but even this measure is not easily compared between cities, as the definition of what constitutes a "city" is not standardized. Some cities include the suburban periphery, while others may focus on the downtown core. It is hoped that a shorter list of easily measurable indicators could provide a first step towards building common basis for cities to begin measuring and comparing urban forest assets.

2. Materials and Methods

This research used an email Delphi approach to solicit feedback from experts in the field of urban forestry. Participants were asked to rate indicators that could be used to design and measure urban forests, and then comment on a decision support framework for future urban forests. The goal for this study was to evaluate a set of key urban forest indicators.

2.1. Delphi Approach

The Delphi approach is a well-established research method that asks experts to lend their opinion to a structured problem in order to develop informed solutions [27,28]. The method provides structured feedback to participants after each round in order to facilitate an anonymous dialogue about the subject matter. It has been used once before to solicit expert feedback on parameters for urban forest inventories [24].

The Delphi method has known weaknesses [27]. These include: Its reliance on a careful selection of expert participants, the lengthy time required for a multiple round survey, participant attrition, ease of ability to be manipulated by the facilitator, an inability to handle discord easily, and limited interaction between participants. This study used a number of methods to help address these weaknesses. Academic participants were carefully screened based on relevant publication history. Local practitioners were selected based on their management positions within local governments. The study attempted to reduce time between rounds, but slow response rates were a problem. Participants were lost between the first and second rounds. This study used a combination of quantitative and qualitative feedback to help clearly communicate feedback received in order to increase transparency and reduce the possibility of facilitator manipulation.

Using the Delphi method, participants worked iteratively to select a small set of key indicators using both a likert scale for rating indicators and qualitative feedback. Qualitative feedback was encouraged, as suggested by Landeta [27] to get a better understanding of participant choices. The feedback was summarized and returned to experts in the second round of the Delphi. It was also used to modify the rationales for each indicator.

2.2. Email Delphi Method

This study used electronic mail to contact participants and distribute the survey. Before email, researchers undertaking a Delphi study used posted mail surveys to contact participants and collect feedback [28]. Email provides a faster method of communication than regular mail, but recent developments in social media and other online platforms could provide an even more user-friendly approach. Participant attrition was an issue in this study, and an exploration of other methods of delivering a Delphi survey is recommended.

2.3. Indicator Selection

Indicators were developed from relevant literature that represented a wide range of economic, environmental and social issues [21–26]. The indicators included both quantitative and qualitative issues (see Appendix Table A1). Indicators were reduced to those indicators that could function both as design drivers ("enabling indicators") and as measurement tools for the resulting design (Table 1). The urban forestry literature also underrepresents social values of urban forest measures [29]. The indicator sets reviewed contained few social indicators.

New indicators were created to capture social values of human health and well-being. Urban forests' contribution to human health and well-being has been the subject of much recent research [9–11], but the indicator sets reviewed did not sufficiently capture this dimension.

Dobbs et al. [21] did address human health and well-being, acknowledging "that quantifying the relationship between the urban forest and human well-being in terms of psychological and social values is critical in assessing ESG [Ecosystem Services and Goods]" [21] (p. 199). Their research focused on regulation indicators, such as air quality services of urban forests, in more detail than other dimensions of human health and well-being. This research builds on their indicator list to include two additional indicators that attempt to capture recreation and psychological benefits of urban forests.

Two indicators were introduced to test whether the experts agreed that these were important aspects of urban forestry. In order to fit within the study's requirement for indicators that could be used to direct design decisions, the indicators introduced had to be spatially explicit. The first new indicator: "physical access to nature", captures the equitable distribution of urban forest assets within a community. This indicator relates to the literature examining the human health benefits of additional physical activity linked to increased greenspace within a community [30–33]. Through these studies, access to nature has been tied to increased recreation, particularly walking, which is beneficial to both physical and mental health of residents.

The next indicator: "visual access to nature", attempts to capture the psychological health benefits of natural views from residences and workplaces. Views of nature have long been recognized as having positive benefits for human health and well-being [10,34]. Increasing visual access to nature for community residents could work towards lowering stress levels and improving mental wellness.

Indicators relating to the management of urban forests were well represented in existing indicators sets, but are not within the scope of this research project. This project recognizes that they are a critical contribution to the future of urban forests, but not within the scope of this research.

The reduced list was then sent to selected academic experts and local practitioners for the first round of the Delphi questioning. Participants were provided with identical questionnaires listing twelve indicators. Each indicator had a brief description, a rationale statement, and a likert rating scale. The likert scale asked participants to rate each indicator in terms of low importance (1) to high importance (5). Participants were also given space and encouraged to propose additional indicators they felt were missing from the list.

2.4. Expert Selection

The opinions of international and local expertise were sought. Linstone suggests a suitable minimum panel size of seven [28], which fit with the scope of this study. The targets were eight participants from each group.

2.4.1. Local Practitioners

The region of Metro Vancouver, in British Columbia, Canada, was chosen as the location for testing local practitioner preferences. Metro Vancouver faces all of the challenges outlined in the introduction of this paper, and it hosts a wide range of local governments, each with a unique approach to managing their urban forest [14]. The 13 local municipalities within the Metro Vancouver region with populations over 50,000 people were contacted. Emails were sent to either the identified urban forestry manager, parks manager, or to the general urban forest email if one was listed on the website. From the first email, names of appropriate local experts were suggested, and finally 18 local practitioners working in municipalities were asked to participate in the study. Ten of these expressed willingness to participate, and seven returned their first round survey. Only four local practitioners returned the second round survey. Two rounds of reminders were sent to encourage greater survey response.

2.4.2. Academics

Nineteen academics were identified and contacted for willingness to participate in the study. Academics were identified based on publication of relevant urban forestry research, including social science research. They were also selected based on geographical distribution. Academics from all continents were contacted, with the exception of Antarctica. Two academics suggested alternate names to stand in for them because of time constraints. Twelve academics expressed interest in participating in the study, and nine returned the first round survey. These nine represented eight countries from five continents. Six returned the second round survey. Again, two rounds of reminders were sent to encourage greater survey response.

3. Results

Few participants provided comments on the decision support framework, as the key focus of the exercise was to rate a list of indicators. Those that did comment questioned the terminology. Definitions of words such as: Goals, objectives, and values, have different implications within different fields of study. The discipline of Forestry often uses "criteria and indicators" to develop and measure scenarios. Social science research often discusses "values". Following the feedback, the decision support framework was modified slightly.

See Table A2 for decision support framework.

3.1. Delphi Round One

Table 1 shows the mean likert scale results of the first round with all participants combined. "Urban tree diversity" and "physical access to nature" were rated as the most important indicators. "Tree risk" and "energy conservation" were rated as the indicators with lowest importance. The order of the indicators within the survey was not changed, but seemed to have little effect on the ranking. The highest rated indicators were first and ninth within the survey, while the lowest ranked were fourth and sixth.

Table 1. Mean rankings and frequency of rating, all participants (n = 15).

Indicator	Rating	1	2	3	4	5
Urban Tree Diversity	4.9				2	13
Physical Access to Nature	4.9				2	13
Canopy Cover	4.3			1	8	6
Stormwater Control	4.2		1	3	3	8
Visual Access to Nature	4.1	1		1	7	6
Habitat Provision	4.1		1	1	9	4
Air Quality Improvement	4.0		2	1	7	5
Available Growing Space	3.8	3		1	4	7
Greenhouse Gas Sequestration and Storage	3.6	1	1	5	4	4
Energy Conservation	3.4	1	2	5	4	3
Property Value Benefits	3.3	1	1	9	1	3
Tree Risk	3.1	2	2	6	2	3

Generally, the mean ranking of indicators follows the consensus of the group. As seen in Table 1, indicators with high consensus (fewer different responses) are highest on the list. One notable exception to this rule was the "visual access to nature" indicator. One participant rated this 1: Low importance, one rated it 3, and the remaining participants rated it 4 or 5.

3.2. Comments

Participant comments are presented in the following section. They are presented by indicator in the order that all participants ranked the indicators. For each indicator, the rationale statement sent to participants is provided, as well as the revised statement following the Delphi, to give a better understanding of each indicator.

3.2.1. Urban Tree Diversity

Rationale statement provided in Round One: A diverse urban forest increases the ability of the forest to withstand change. Trees should be of diverse ages, species, genera, and families in order to ensure the forest can adapt to future climate change scenarios.

Revised rationale statement following Delphi: A diverse urban forest increases the ability of the forest to withstand change, which is of key importance to the long-term stability of the forest. Diversity is also influential on psycho-social outcomes of urban forests. Trees should be of diverse sizes, ages, species, genera, and families in order to ensure the forest can adapt to future climate change scenarios. Public opinion about desirable tree sizes/types/forms can help inform the creation of a diverse urban forest. This opinion will vary between communities.

In the participant comments, "urban tree diversity" was connected to climate change adaptation, ecosystem service provision, long term planning, decision making, psycho-social outcomes, cultural values, forest stability, and forest resilience. Participants commented that this was a useful indicator linked to many different aspects of urban forest planning. Good diversity is important to long term stability, resiliency, and is an important base for a range of ecosystem services. One participant noted that it "should be balanced with species selection for cohesive and consistent streetscapes" (Participant One). Another noted that companion plants should be included in the diversity discussion.

3.2.2. Physical Access to Nature

Rationale statement provided in Round One: Access to nature has been tied to increased recreation, particularly walking, which is beneficial to both physical and mental health of residents. It could also promote more sustainable commuting, as residents are more likely to walk, jog, or cycle to work along aesthetically pleasing routes. Ensuring equal access to nature for all residents within a community promotes greater equality.

Revised rationale statement following Delphi: Access to nature has been tied to increased recreation, particularly walking, which is beneficial to both physical and mental health of residents. "Play in nature" is very important for people to gain connection to nature and urban forests. It could also promote more sustainable commuting, as residents are more likely to walk, jog, or cycle to work along aesthetically pleasing routes. Ensuring equal access to nature for all residents within a community promotes greater equality. Urban forests should also provide a diversity of potential uses.

Participants commented that "physical access to nature" was an important indicator linking urban forests to human health. They noted that this indicator could start to address issues such as equitable distribution of green spaces and improved population health. Safety, structure, size, and accessibility of greenspace were noted as important considerations when using physical access as a measure of urban forest success. It was also noted that the type of community (dense urban vs. sprawling suburban) could change the way this indicator was measured.

3.2.3. Canopy Cover

Rationale statement provided in Round One: Canopy cover is a very common metric used to evaluate a city's urban forest. It is relatively easy to measure and communicate with the general public.

Revised rationale statement following Delphi: "Canopy cover" is a very common metric used to evaluate a city's urban forest. It is relatively easy to measure and communicate with the general public and a good starting point for quantifying a community's urban forest. "Canopy volume" estimates total leaf area of a tree's canopy, which provides more information about a tree's overall ecosystem service provision. Communities with sufficient means are encouraged to measure "canopy volume", as well as "canopy cover".

"Canopy cover" is an important indicator that is becoming commonly used. It was highly rated by both academics and practitioners. The ease of using and communicating this indicator was noted by participants as reasons to continue using "canopy cover" as an urban forest indicator.

Another was the ability to communicate long-term trends using "canopy cover". One participant noted the use of "canopy cover" in communicating the "borderless nature of the urban forest to the public and decision-makers" (Participant One). Some participants noted that with emerging three-dimensional technologies, such as LiDAR, canopy cover could eventually be measured in the third dimension as canopy volume, which would capture a more robust measurement of the urban forest in a community. One participant noted that "while canopy cover is an important measure, it does not tell as complete a story as canopy volume does in terms of the overall ecosystem services that trees provide" (Participant Two).

3.2.4. Stormwater Control

Rationale statement provided in Round One: Trees filter and infiltrate storm water, cleaning and moderating the amount of water running into engineered systems. If designed and planned with this function in mind, urban forests can provide both cost savings and enhanced environmental benefits for urban areas.

The rationale statement was not revised, as participants generally agreed with the statement provided.

"Stormwater control" was rated as an important indicator for measuring urban forests. Participants commented that this indicator was "widely recognized as one of the most important services provided by the urban forest" (Participant Three). Another mentioned that it was "an extremely powerful tool for raising support for green infrastructure" (Participant One). There was disagreement about the ease of measuring this indicator, though many participants noted that tools, such as iTree measure the stormwater control benefits of urban forests.

3.2.5. Visual Access to Nature

Rationale statement provided in Round One: There is growing evidence that access to nature, even when viewed through a window, is beneficial to well being. Increasing visual access to nature for community residents could work towards lowering stress levels and improving mental wellness.

The rationale statement was not revised, as participants generally agreed with the statement provided.

Participants commented that "visual access to nature" was an important indicator for connecting populations to nature. It was ranked highly by most participants, but one participant gave it a low importance rating on the scale. There was concern that the actual content of the view, and what constitutes "natural" would be difficult to define. There was consensus that natural should include trees, not just anything that is green, because trees "give us a vital third dimension (height) to our experience and interaction with them" (Participant Four). This indicator had the most comments and suggestions about possible measurement techniques.

3.2.6. Habitat Provision

Rationale statement provided in Round One: Urban forests can help protect biodiversity and provide habitat for urban flora and fauna. Different types of urban forest provide different amounts and quality of habitat. For example, a naturalized park would likely support more urban nature than a concrete planter holding a non-native species.

Revised rationale statement following Delphi: Urban forests can help protect biodiversity and provide habitat for urban flora and fauna. Quantity and quality of habitat varies in urban forests. For example, a large park with diverse trees and understory plantings would likely support more urban nature than a concrete planter holding a non-native species.

While some participants noted this was an important indicator, most were concerned about the difficulty of defining "habitat" and measuring success. One participant noted that, "it is a mistake to concentrate just on native species, particularly in the light of the pests and diseases issue and the changes that have already contributed to the urban heat island—changes that are only going to get worse. We need a resilient urban forest, comprising many species, as they have many roles to fulfill as well as 'nature'" (Participant Five). Other participants also linked this indicator to the "urban forest diversity" indicator.

3.2.7. Air Quality Improvement

Rationale statement provided in Round One: Research shows that the presence of trees is generally beneficial for the air quality and human health in an area. Trees absorb a variety of air pollutants in varying amounts, depending on a number of characteristics such as species, age, location, tree health, etc.

The rationale statement was not revised because this indicator was dropped from the list after the first round.

There was less consensus on the merits of measuring air quality improvement benefits of urban forests. Some participants noted that, "the air pollution reduction benefits of urban trees are under debate" (Participant Three). It was agreed that poor urban air quality is an important health concern, but that measuring the urban forests' contribution to this was difficult and would likely be relatively small. A few participants noted that pollen and VOC production would have to be taken into account when measuring a forest's net air quality improvement. It was also noted that this concept was not well understood or appreciated by the general public.

3.2.8. Available Growing Space

Rationale statement provided in Round One: The amount of available growing space indicates the potential of a community to increase and maintain their urban forest. Without space and suitable soil, the urban forest will be difficult to expand and manage.

Revised rationale statement following Delphi: The amount of available growing space indicates the ability of a community to increase and maintain their urban forest. Without sufficient soil volume and quality, the urban forest will be difficult to expand and manage. Focusing efforts on providing adequate space for trees, and planting the correct tree in the available space, will result in substantially reduced costs associated with maintenance (pruning) and infrastructure damage caused by trunk buttress flare and root expansion. The challenge is for communities to prioritize and plan for adequate growing space and soil volumes well in advance.

"Available growing space" was connected to tree health, tree canopy size, planning, and permeability. Participants commented that "space" should be measured in three dimensions, because adequate soil volume was of key importance to forest health. Along with property value benefits, this indicator generated the most comments, with every participant writing an opinion on the challenges in using this indicator. Many noted that it was an important indicator or priority during development of a new project or area, and that is was often overlooked. Participants also noted the need to consider public versus private landownership when looking at "available growing space".

3.2.9. Greenhouse Gas Sequestration and Storage

Rationale statement provided in Round One: Greenhouse gas sequestration and storage measures the amount of carbon dioxide absorbed and stored by trees and within the soil of urban forests. Carbon dioxide is the most abundant greenhouse gas derived from fossil fuels. The amount of carbon absorbed and stored reflects the contribution of urban forests to mitigating climate change. This indicator proposes bundling the two values to convey the full impact of trees on carbon mitigation.

The rationale statement was not revised, as participants generally agreed with the statement provided.

While climate change was acknowledged as an important concern, there was less consensus about the amount of carbon sequestered and stored by urban forests, and the value urban citizens place on this issue. Some participants suggested that other greenhouse gases, such as ozone and methane, be included. Others commented that inclusion of other components, such as urban soils, was important.

One participant suggested that "the only reason to make carbon calculations might be to choose species and spacings wisely, and to convey to the public that trees are exceptional agents of climate-change mitigation" (Participant Four). Another participant noted that the indicator "can be a part of a good case for advocacy for funding urban forest initiatives" (Participant Six).

3.2.10. Energy Conservation

Rationale statement provided in Round One: Energy conservation measures the contribution of the urban forest to reducing a community's energy use. This could be a reduction in building energy use through shading during hot summers.

The rationale statement was not revised because this indicator was dropped from the list after the first round.

Participants appreciated the energy conservation benefits of urban forests, but there was debate about how the scale of measuring this indicator might fit with the other urban forest indicators. Interventions and detailed measurements would make more sense on a site-specific scale, not at the scale of the entire urban forest. As one participant noted, "while I rate it low, it's possible that the public would really appreciate this as an indicator. It's one of the few indicators where the individual can feel they're making a measurable difference" (Participant Seven). A few different participants noted this personal benefit. It was also noted that the type of energy savings would differ globally, and that design opportunities would be regionally based.

3.2.11. Property Value Benefits

Rationale statement provided in Round One: Trees can contribute to an individual's economic well-being if they increase property value. Economic indicators such as this can be easy to communicate with residents.

The rationale statement was not revised because this indicator was dropped from the list after the first round.

Property value was included as an indicator for two reasons. The first is that it provided a clear economic indicator missing from the list. The second reason is to acknowledge the history of research surrounding urban forests and property value [1]. While difficult to rationalize as an enabling indicator, it could provide some guidance to designers about tree planting locations to promote more equitable distribution of urban forest resources.

"Property value benefits" was another indicator where scale was an issue noted by participants. At a finer scale, issues, such as tree maintenance, hazard trees, and other undesirable characteristics, would be important considerations. Many pointed to ethical concerns about an indicator that favors property owners, and single-family residences specifically. As one participant pointed out "higher prices mean that certain parts of the population are 'frozen out' and have less access to the urban forest" (Participant Three). Another pointed out that those living in high-rise towers would see little property value benefits in adjacent urban forests.

3.2.12. Tree Risk

Rationale statement provided in Round One: Often residents' concerns about urban forests stem from fears of potential damage to people, structures or utilities due to tree or limb fall during storms or from disease. Urban forests with lower risk due to healthy trees planted in appropriate locations might be more compatible with community members. Tree age by species should be considered when factoring risk for trees.

The rationale statement was not revised because this indicator was dropped from the list after the first round.

"Tree risk" was ranked as the least important indicator in the first round. While participants noted that tree risk can be a large part of the urban forestry discourse, and was important from a management perspective, they pointed out that perception of risk and actual risk were often at odds.

One participant pointed out that it was time consuming to measure, and "would be more trouble and cost than it would be worth" (Participant Eight). One participant argued that it is equally important to communicate the negative side of urban forestry, so the "tree risk" indicator helps achieve this.

3.3. Academic vs. Practitioner

The following section describes the differences between the academic and practitioner groups in round one of the Delphi.

The academic participants rated "urban tree diversity" and "access to nature" as top indicators (see Table 2). It is interesting to see social indicators connecting urban forests to their residents ranked as top indicators. These indicators were not specifically mentioned in previous urban forestry indicator sets. Practitioners placed less importance on "visual access to nature", but did rank "physical access to nature" as the highest priority, with every practitioner giving it a rating of five.

Table 2. Academic and practitioner ratings.

Indicator	Academic Rating	Practitioner Rating
Urban Tree Diversity	4.9	4.9
Physical Access to Nature	4.8	5.0
Visual Access to Nature	4.4	3.9
Canopy Cover	4.3	4.4
Stormwater Control	4.1	4.3
Habitat Provision	3.9	4.3
Available Growing Space	3.6	4.0
Energy Conservation	3.5	3.3
Air Quality Improvement	3.5	4.6
Tree Risk	3.1	3.1
Greenhouse Gas Sequestration and Storage	3.1	4.1
Property Value Benefits	2.8	3.9

Practitioners ranked "air quality improvement" as more important than academics. The academics that gave this indicator a low ranking cited recent research that found urban forests had a relatively minor impact on air quality improvement. This could demonstrate a lag time of results from published academic studies being shared amongst professionals working in the field. The survey had similar results for "greenhouse gas sequestration and storage", which was ranked seventh in overall importance by practitioners and eleventh by academics.

The major difference in comments between the groups was the regional focus of the practitioners. They connected each indicator with regional urban forestry issues. For example, many practitioners mentioned evergreen conifers as important storm water management trees in a region where most storm water falls during times when deciduous trees have lost their leaves.

3.4. Comments/Suggestions for Additional Indicators

Most suggestions for additional indicators included management and public perception/awareness indicators. This is a noted, though deliberate, shortcoming of this particular project, which is focused on indicators that can be used to drive design decisions for urban forests.

Suggested indicators included:

- Safety and Security
- Spirituality
- Sense of Place
- Products Derived from the Urban Forest
- Urban Forest Management
- Public Support for the Urban Forest

- Land Tenure
- Presence of Invasive Species
- Presence of Beneficial Pollinators
- Presence of Urban Wildlife

The first three indicators are specifically social issues that attempt to capture a dimension of urban forestry often missing in the literature. Although none of these were rated above the top indicators selected in the first round, they did receive mostly positive qualitative responses from participants during the second round. Each had a wide range of responses indicating a lack of consensus for these indicators. Each of these issues seemed more regionally appropriate, and could be used as a subset of indicators for specific locations.

3.5. Delphi Round Two

3.5.1. Academic

Academic participants were sent a new survey with the top seven indicators chosen by academics in round one and a list of indicators proposed by academic participants during round one. Revisions were made to the description and rationale statement for each indicator. Participants were asked to comment on these and to comment on metrics suggested for each indicator during round one.

The only change in indicator ranking from academic participants was the switching of canopy cover and visual access to nature (see Table 3). The rest of the indicators were ranked in the same order, so the survey reached consensus on their relative importance.

Table 3. Academic consensus after Round Two.

Indicator	Round Two Score	Round One Rank
Urban Tree Diversity	5.0	1
Physical Access to Nature	4.8	2
Canopy Cover	4.3	4
Visual Access to Nature	4.0	3
Stormwater Control	3.8	5
Habitat Provision	3.8	6
Available Growing Space	3.2	7

3.5.2. Practitioner

Practitioner participants were sent a new survey with the top seven indicators chosen in round one and a list of indicators proposed by practitioner participants during round one. Revisions were made to the description and rationale statement for each indicator. Participants were asked to comment on these and to comment on metrics suggested for each indicator during round one. There was a very low return rate on the practitioner responses; results are presented (see Table 4), but do not represent a group consensus.

Table 4. Practitioner results after Round Two.

Indicator	Round Two Score	Round One Rank
Physical Access to Nature	5.0	1
Urban Tree Diversity	5.0	2
Stormwater Control	5.0	5
Air Quality Improvement	4.5	3
Habitat Provision	4.0	6
Greenhouse Gas Sequestration & Storage	4.0	7
Available Growing Space	4.0	8
Canopy Cover	3.5	4

4. Discussion

Urban forests are valued for a range of reasons that are not often captured in a community's design, planning, and management of their forest. This research uses indicators within a decision support framework to create a more comprehensive approach to guide design and planning for future urban forests. As cities are increasingly acknowledging the important role of green infrastructure and natural systems in improving livability and viability, these indicators could be ubiquitous in planning approaches for greening global cities.

The study shows that some indicators ranked as high importance are not necessarily the ones measured or promoted by many urban forestry programs. As Kenney et al. [22] point out, simply using absolute canopy cover targets to guide urban forest management goals "does not provide a comprehensive assessment of urban forest stewardship in a community and does not account for an area's potential to support a forest canopy" [22] (p. 108). At the same time, an overly complex set of indicators is overwhelming for most communities to measure and communicate with the public. This study has created a basic set of indicators that captures a range of important urban forest values. It is hoped that this indicator set could provide a foundation for guiding planning decisions for global future urban forests.

The results indicate that social indicators, such as human health and well-being, are important considerations when planning urban forests. Recent research demonstrates that these values are not always included in urban forest valuation [29]. When included, social indicators were rated highly by participants, and made up a large portion of suggested additional indicators. More research into additional social indicators, both enabling and performance indicators, could yield measurement tools that better reflect values held about urban forests.

One participant pointed out that the indicators were "operating at different levels" and suggested following McPherson et al.'s conceptual approach of structure, function, and value [35], to categorize the indicators. Table 5 divides the indicators into structural and functional indicators.

Table 5. Structural versus functional indicators.

Structural Indicators	Functional Indicators
Urban Tree Diversity	Stormwater Management
Physical Access to Nature	Habitat Provision
Canopy Cover	Air Quality Improvement
Visual Access to Nature	Greenhouse Gas Sequestration and Storage
Available Growing Space	

The structural indicators can be conceptually divided into diversity, distribution, and density indicators. "Urban tree diversity" was the most highly rated indicator, which reflects the argument that urban forests of diverse species and ages "provide a wider range of benefits over the long term" [22] (p. 108). Distribution indicators, such as physical and visual access to nature, begin to describe where urban forest components should be located to provide benefits for all urban citizens. Finally, density indicators such as "canopy cover" and "available growing space" direct the amount of space dedicated to the urban forest resource. The structural indicators are easily categorized as "enabling" indicators; they direct urban forest design and planning in a spatially explicit way.

The functional indicators are not as easily spatialized, or conceived as "enabling" indicators. Fortunately, much recent research in urban forestry provides design directions to optimize these indicators [2–8,10]. We can use this research to make design choices that optimize storm water management (leaf area index, thresholds for impervious surface area), habitat provision (ideal patch sizes, connectivity corridors), air quality improvement (low VOC species, tree location near pollution sources), and greenhouse gas storage and sequestration (tree location to cool buildings, tree location to enhance physical activity). When combined (see Table 6), the structural and functional indicators, when used with targets set by a community, create a comprehensive set of instructions to guide planning and design of urban forests.

Table 6. Final indicators.

Selected Indicators
Urban Tree Diversity
Physical Access to Nature
Canopy Cover
Stormwater Control
Habitat Provision
Air Quality Improvement
Visual Access to Nature
Available Growing Space
Greenhouse Gas Sequestration and Storage

Future Research

Academic experts from a wide range of social, political, and ecological contexts came to consensus on a set of indicators that can be used to guide the design of future urban forests. Their results were quite similar to a group of practitioner experts from one region, indicating that these values are shared, not just within the academic community, but also with a wide range of professionals working in the field of urban forestry.

This study is the first part of a three phase research project that intends to test the physical arrangement of forest and urban form components in order to understand where there are synergies and where there are conflicts between these components in planning for future sustainable and resilient communities. The next phase of this project will test the ability of these indicators to guide design and planning decisions through the creation of a set of future forest scenarios for a community in the Metro Vancouver region. The scenarios will provide a method for evaluating trade-offs and conflicts between different urban forest structures, a need addressed by McPherson et al. [35]. Once the scenarios are developed, the same indicators will be used to measure the performance of each scenario. The indicators can then be used to compare the scenarios and assess the potential co-benefits or trade-offs between scenarios.

5. Conclusions

This study developed a framework, including a short list of key indicators, to guide planning and design of future urban forests. Experts and practitioners rated a set of indicators in terms of their importance for urban forest planning and design. As Dobbs et al. argue, indicators "are one approach that could be used to better understand the structure of an urban forest, the suite of ESG provided by urban forests, and their influence on human well-being using a simple, innovative and repeatable metric" [21] (p.1). This paper extends this idea to include indicators as inputs to guide design and planning of urban forest structure. The ranking of the indicators within this study reveals a range of values that are important to capture when planning and designing future urban forests. When planting trees, communities should think beyond basic canopy cover targets to focus on tree diversity, distribution, and other design requirements to maximize ecosystem services provided by urban forests, including social benefits such as human health and well-being.

Acknowledgments: The author would like to thank all participants for volunteering their time to answer the surveys. Funding for this project was provided through the University of British Columbia's Future Forest Fellowship.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix

Table A1. Existing Urban Forest Indicator Sets.

	i-Tree	**Dobbs et al. 2011**	**Kenney et al. 2011**	**Clark et al. 1997**	**USDA Forest Health Indicators. (Woodall et al. 2011)**	**Parameters Östberg (2011)**
Canopy Cover/volume	Number of Trees Tree Density	Tree Canopy Cover Tree Structure	Relative Canopy Cover	Canopy cover		Scientific name:tree specie & genera Vitality
Diversity	Species Composition	Shannon diversity index	Species distribution Age distribution	Species mix Age distribution	Vegetation diversity	Coordinates Hazard class
Tree Health/Risk	Tree Health Pests risk analysis	Crown dieback Damage to infrastructure	Condition of publicly owned trees		Crown condition Ozone injury	Identification number Presence of fruit bodies
Air Quality Improvement	Ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide, particulate matter (<10 microns) removal VOC emissions Economic benefit based on effect of trees on air quality improvement	Air pollutant removal Decrease in air quality Pm 10 removal				Date of latest inventory Category of care Conservation value
Allergenicity	Tree pollen allergenicity index	Allergenicity				Street or park trees Age class
Greenhouse gas storage/sequestration	Carbon stored Net carbon annually sequestered	C02 sequestration			Down woody material	Stem circumference at 1 m height at planting Date of planting
Energy conservation	Effects of trees on building energy use + consequent effects on co2 emissions	Temperature Reduction				Name of disease or pest
Stormwater management	Canopy rainfall interception summarized by species or land use	Soil Infiltration				Reason for felling
Property value benefits	Property value increase					
Habitat provision		Ratio of native trees	Native vegetation	Native vegetation	Lichen communities	
Human health/well-being	Public health incidence reduction	Recreation cover				
Economic Value	Replacement value					
Soils/growing space		Soil Infiltration Soil fertility Soil bulk density Soil nutrients Heavy metals			Soils	
Other		Leaf area and distance to roads Type of foliage Curve Number Fruit fall Tree biomass	Species suitability			

Table A2. Decision Support Framework.

Vision	Goal	Objective	Proposed Indicators
Healthy and resilient urban forests that contribute to residents' well-being, climate mitigation, and ecosystem services.	A forest that adapts to predicted climate change	The urban forest is resilient to predicted changes in weather, water availability, and/or potential invasion by insects and diseases	Urban Forest Diversity
			Available Growing Space
			Canopy Cover
			Tree Risk
	A forest that helps mitigate future climate change	The urban forest supports a community that releases fewer greenhouse gases through daily transportation and building energy uses, while storing and sequestering optimal amounts of carbon dioxide	Greenhouse Gas Sequestration and Storage
			Energy Conservation
	A forest that contributes to local residents' well-being	The urban forest supports health and well-being by providing a variety of recreation opportunities, an aesthetically pleasing environment that lowers stress levels and maximizes filtration of air pollution	Air Quality Improvement
			Visual Access to Nature
			Physical Access to Nature
			Property Value Benefits
	A forest that supports a resilient local ecosystem	The urban forest supports local flora and fauna through habitat and food provision, while infiltrating storm water to support health local streams and rivers	Storm water Control
			Habitat Provision

References

1. Dobbs, C.; Kendal, D.; Nitschke, C.R. Multiple Ecosystem Services and Disservices of the Urban Forest Establishing Their Connections with Landscape Structure and Sociodemographics. *Ecol. Indic.* **2014**, *43*. [CrossRef]
2. Escobedo, F.J.; Kroeger, T.; Wagner, J.E. Urban Forests and Pollution Mitigation: Analyzing Ecosystem Services and Disservices. *Environ. Pollut.* **2011**, *159*, 2078–2087. [CrossRef] [PubMed]
3. Nowak, D.J.; Hoehn, R.E.; Bodine, A.R.; Greenfield, E.; Ellis, A.; Endreny, T.A.; Yang, Y.; Zhou, T.; Henry, R. *Assessing Urban Forest Effects and Values: Toronto's Urban Forest*; Resource Bulletin NRS-79; Department of Agriculture, Forest Service, Northern Research Station: Newtown Square, PA, USA, 2013; p. 59. Available online: http://www.nrs.fs.fed.us/pubs/43543 (accessed on 29 April 2016).
4. Gill, S.E.; Handley, J.F.; Ennos, A.R.; Pauleit, S. Adapting Cities for Climate Change: The Role of the Green Infrastructure. *Built Environ.* **2007**, *33*, 115–133. [CrossRef]
5. Hall, J.M.; Handley, J.F.; Ennos, A.R. The Potential of Tree Planting to Climate-proof High Density Residential Areas in Manchester, UK. *Landsc. Urban Plan.* **2012**, *104*, 410–417. [CrossRef]
6. Akbari, H. Shade Trees Reduce Building Energy Use and CO_2 Emissions from Power Plants. *Environ. Pollut.* **2002**, *116* (Suppl. 1), S119–S126. [CrossRef]
7. Nowak, D.J.; Crane, D.E. Carbon Storage and Sequestration by Urban Trees in the USA. *Environ. Pollut.* **2002**, *116*, 381–389. [CrossRef]
8. Yesilonis, I.D.; Pouyat, R.V. Carbon Stocks in Urban Forest Remnants: Atlanta and Baltimore as Case Studies. In *Carbon Sequestration in Urban Ecosystems*; Rattan, L., Bruce, A., Eds.; Springer: Dordrecht, Netherlands, 2012; pp. 103–120.
9. Donovan, G.H.; Butry, D.T.; Michael, Y.L.; Prestemon, J.P.; Liebhold, A.M.; Gatziolis, D.; Mao, M.Y. The Relationship between Trees and Human Health: Evidence from the Spread of the Emerald Ash Borer. *Am. J. Prev. Med.* **2013**, *44*, 139–145. [CrossRef] [PubMed]
10. Kaplan, R. The Nature of the View from Home Psychological Benefits. *Environ. Behav.* **2001**, *33*, 507–542. [CrossRef]
11. Hartig, T.; Richard, M.; Sjerp, V.; Howard, F. Nature and Health. *Annu. Rev. Public Health* **2014**, *35*, 207–228. [CrossRef] [PubMed]
12. Eigenbrod, F.; Bell, V.A.; Davies, H.N.; Heinemeyer, A.; Armsworth, P.R.; Gaston, K.J. The Impact of Projected Increases in Urbanization on Ecosystem Services. *Proc. R. Soc. B Biol. Sci.* **2011**, *278*, 3201–3208. [CrossRef] [PubMed]
13. Turner, W.R.; Nakamura, T.; Dinetti, M. Global Urbanization and the Separation of Humans from Nature. *BioScience* **2004**, *54*, 585–590. [CrossRef]
14. City of Vancouver. Developing Vancouver's Urban Forest Strategy, City of Vancouver. 2015. Available online: http://vancouver.ca/home-property-development/urba-forest-strategy.aspx (accessed on 22 April 2016).
15. MillionTrees NYC. Available online: http://www.milliontreesnyc.org/html/home/home.shtml (accessed on 22 April 2016).
16. Kellett, R.; Fryer, S.; Budke, I. Specification of Indicators and Selection Methodology for a Potential Community Demonstration Project. 2012. Available online: http://www.dcs.sala.ubc.ca/docs/cmhc_sustainability_indicators_final_report_sec.pdf (accessed on 22 April 2016).
17. Harshaw, H.W.; Sheppard, S.; Lewis, J.L. A Review and Synthesis of Social Indicators for Sustainable Forest Management. *J. Ecosyst. Manag.* **2007**, *8*, 17–37.
18. Gough, A.D.; Innes, J.L.; Allen, S.D. Development of common indicators of sustainable forest management. *Ecol. Indic.* **2008**, *8*, 425–430. [CrossRef]
19. Sheppard, S.R.; Meitner, M. Using multi-criteria analysis and visualisation for sustainable forest management planning with stakeholder groups. *For. Ecol. Manag.* **2005**, *207*, 171–187. [CrossRef]
20. Kellett, R. *Sustainability Indicators for Computer-Based Tools in Community Design, 1*; Canada Mortgage and Housing Corporation: Ottawa, ON, Canada, 2009.
21. Dobbs, C.; Escobedo, F.J.; Zipperer, W.C. A framework for developing urban forest ecosystem services and goods indicators. *Landsc. Urban Plan.* **2011**, *99*, 196–206. [CrossRef]
22. Kenney, W.A.; Van Wassenaer, P.J.; Satel, A.L. Criteria and indicators for strategic urban forest planning and management. *Arboric. Urban For.* **2011**, *37*, 108–117.

23. Clark, J.R.; Matheny, N.P.; Cross, G.; Wake, V. A model of urban forest sustainability. *J. Arboric.* **1997**, *23*, 17–30.
24. Östberg, J.; Delshammar, T.; Wiström, B.; Nielsen, A.B. Grading of Parameters for Urban Tree Inventories by City Officials, Arborists, and Academics Using the Delphi Method. *Environ. Manag.* **2013**, *51*, 694–708. [CrossRef] [PubMed]
25. Woodall, C.W.; Amacher, M.C.; Bechtold, W.A.; Coulston, J.W.; Jovan, S.; Perry, C.H.; Randolph, K.C.; Schulz, B.K.; Smith, G.C.; Tkacz, B.; et al. Status and Future of the Forest Health Indicators Program of the USA. *Environ. Monit. Assess.* **2011**, *177*, 419–436. [CrossRef] [PubMed]
26. Nowak, D.J.; Dwyer, J.F. Understanding the benefits and costs of urban forest ecosystems. In *Urban and Community Forestry in the Northeast*; Springer: Dordrecht, Netherlands, 2007; pp. 25–46.
27. Landeta, J. Current Validity of the Delphi Method in Social Sciences. *Technol. Forecast. Soc. Chang.* **2006**, *73*, 467–482. [CrossRef]
28. Linstone, H.A.; Turoff, M. (Eds.) *Delphi Method: Techniques and Applications*; Addison-Wesley: Boston, MA, USA, 1975.
29. Peckham, S.C.; Duinker, P.N.; Ordóñez, C. Urban Forest Values in Canada: Views of Citizens in Calgary and Halifax. *Urban For. Urban Green.* **2013**, *12*, 154–162. [CrossRef]
30. Takano, T.; Nakamura, K.; Watanabe, M. Urban Residential Environments and Senior Citizens' Longevity in Megacity Areas: The Importance of Walkable Green Spaces. *J. Epidemiol. Commun. Health* **2002**, *56*, 913–918. [CrossRef]
31. Bowler, D.E.; Buyung-Ali, L.M.; Knight, T.M.; Pullin, A.S. A Systematic Review of Evidence for the Added Benefits to Health of Exposure to Natural Environments. *BMC Public Health* **2010**, *10*, 456. [CrossRef] [PubMed]
32. Bell, J.F.; Wilson, J.S.; Liu, G.C. Neighborhood Greenness and 2-year Changes in Body Mass Index of Children and Youth. *Am. J. Prev. Med.* **2008**, *35*, 547–553. [CrossRef] [PubMed]
33. Lovasi, G.S.; Jacobson, J.S.; Quinn, J.W.; Neckerman, K.M.; Ashby-Thompson, M.N.; Rundle, A. Is the Environment near Home and School Associated with Physical Activity and Adiposity of Urban Preschool Children? *J. Urban Health* **2011**, *88*, 1143–1157. [CrossRef] [PubMed]
34. Ulrich, R.S. Human Responses to Vegetation and Landscapes. *Landsc. Urban Plan.* **1986**, *13*, 29–44. [CrossRef]
35. McPherson, E.G.; Nowak, D.; Heisler, G.; Grimmond, S.; Souch, C.; Grant, R.; Rowntree, R. Quantifying urban forest structure, function, and value: The Chicago Urban Forest Climate Project. *Urban Ecosyst.* **1997**, *1*, 49–61. [CrossRef]

© 2016 by the authors; licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC-BY) license (http://creativecommons.org/licenses/by/4.0/).