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Rating of parameters used to assess tree vitality by urban foresters and ecologists in Sweden, using the Delphi method

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ABSTRACT

Management of urban trees is key to sustaining and increasing essential ecosystem services, and most management decisions are made based on urban tree inventories. Vitality is one of the key parameters when conducting tree inventories. However, consensus on how vitality should be assessed is lacking, and there is limited understanding of how visual vitality assessments are affected by aspects of different professional background, growing sites and tree age. In a Delphi study with 19 participants completing the whole study, we asked urban foresters and ecologists to assess the vitality of 21 trees in urban and rural settings and to rate how important 40 different parameters were for their assessment of each tree's vitality. The data obtained were analysed using Cronbach's alpha, unconstrained ordination, hierarchal clustering and indicator values. In testing for differences, mixed general linear models and constrained ordination were used. Professionals participating in the study showed good overall agreement in ranking trees as more or less vital, but with large differences in what was considered a fully vital tree. When performing vitality assessments, the parameters used differed between old and young trees, and between urban and rural sites. There was also a systematic difference between urban foresters and ecologists in performing tree vitality assessments, with ecologists consistently rating tree vitality higher and using fewer parameters. Parameters used for assessing vitality comprised aspects relating to sign of decay, external damage, loss/death of biomass, growth performance and site conditions. Vitality should thus be regarded as a complex parameter that needs calibration-based assessment approaches and the person performing the assessment should always be included as an additional variable. Overall, this study clearly showed the need to establish consensus on how tree vitality should be assessed and rated.

1. Introduction

During recent decades, numerous studies have shown the importance of urban trees for sustainable development, through their capacity for delivering multiple ecosystem services. These range from provisioning services (e.g. fuel and food) to regulating services (e.g. stormwater management, urban heat island mitigation, air pollution regulation), cultural services (e.g. recreation, physical and mental health benefits) and supporting services (e.g. wildlife habitats) (Grahn and Stigsdotter, 2003; Tyrväinen et al., 2005; Gill et al., 2007; Jones, 2008; Morgenroth et al., 2016; Dobbs et al., 2017). Trees are also host to a large number of organisms such as fungi, butterflies and moths, beetles, hemipterans, hymenopterans, lichens and dipterans (Sundberg et al., 2019) and urban trees contribute to a higher diversity of birds and pollinating insects (Barth et al., 2015; Somme et al., 2016).

Management of urban trees is key to sustaining and increasing these important ecosystem services (Dobbs et al., 2017) and reducing the amount of ecosystem disservices (Roman et al., 2020a). Tree inventories are the foundation on which management of urban trees is based (Kielbaso, 2008; Miller et al., 2015; Morgenroth et al., 2016). In recent decades, there has therefore been increasing interest in tree inventories, resulting from e.g. growing problems with pest and disease attacks on the urban tree stock (Raupp et al., 2006) and growing awareness among decision-makers of the multiple ecosystem services trees provide in the cityscape (Roy et al., 2011; Hubacek and Kronenberg, 2013). Municipalities, especially in North America and Europe, have therefore increasingly started to perform tree inventories (e.g. Nowak et al., 2001; Keller and Konijnendijk, 2012; Sjöman et al., 2012). Municipal tree inventories in North America have largely involved the use of i-Tree (i-Tree, 2021) to perform economic valuations of urban trees (Kielbaso,

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2008; Morgenroth and Östberg, 2017; Rogers et al., 2017). Northern Europe has focused more on management issues, e.g. tree health and management, related to monitoring the dynamics of urban tree stands (Keller and Konijnendijk, 2012; Morgenroth and Östberg, 2017; Östberg et al., 2018) and biological values (Sörensson, 2008; Claesson et al., 2009). Given the wide range of services that urban trees provide, urban tree inventory and management involve multiple academic disciplines and professions, which might affect how different parameters are perceived and valued (Östberg et al., 2013). For example, professionals within urban forestry, such as arborists and urban foresters, are often trained in management of urban trees to produce provisional and cultural ecosystem services (Davies et al., 2017). In contrast, ecologists and biologists, with their knowledge of multiple species groups, may often have a stronger interest in supporting services.

Vitality, sometimes referred to as 'condition', is one of the key parameters assessed when conducting tree inventories (Östberg et al., 2012; Roman et al., 2013; Morgenroth and Östberg, 2017). Even though vitality is frequently used in both research (e.g. Sepúlveda and Johnstone, 2018) and municipal inventories (Roman et al., 2013; Östberg et al., 2018), no previous study has investigated how different users visually assess this important parameter. Some common definitions are used, e.g. '*overall health' and 'ability of a plant to deal effectively with stress'* (ISA, 2020), but it is unclear which method should be used when rating tree vitality (Roloff, 2001; Martinez-Trinidad et al., 2010; Sepúlveda and Johnstone, 2018). There might also be some confusion on the difference between vitality and structural integrity, which both might be included in the term condition.

The present study sought to address these knowledge gaps through a systematic expert rating of tree inventory parameters at national level in Sweden. The study aim was to: 1) identify a list of parameters for use when rating tree vitality; and 2) test for differences in ratings between the main groups of experts engaged in urban tree inventory. More specifically, the work was guided by the following two research questions:

- Which parameters do experts from the field of urban forestry and ecology rate as most relevant when assessing tree vitality?
- Does the rating of parameters deviate between the urban forestry professionals and ecologists?

2. Materials and methods

The study was conducted in two steps. The first step involving screening for tree inventory parameters that might be useful in rating tree vitality, and their definitions. These parameters were then fed into a Delphi survey, where two expert panels (urban forestry professionals and ecologists) rated the relative importance of the individual parameters for assessing tree vitality in urban and rural settings.

2.1. Screening of parameters

A list of 26 relevant parameters normally used when rating tree vitality was created, based on e.g. the Swedish Tree Inventory Standard (Östberg et al., 2012), Swedish Environmental Protection Agency's tree inventory standard (Claesson et al., 2009), international reports (Roman et al., 2020b) and scientific studies (Östberg et al., 2013; Roman et al., 2013; Morgenroth and Östberg, 2017). All participants in the Delphi study were first asked to contribute other relevant parameters to the suggested list. This led to a final list of 40 parameters.

2.2. Delphi survey

The Delphi method is an established research technique that seeks to provide a reliable group opinion using expert judgment (Landeta, 2006). The first Delphi study was performed in the 1950s (Dalkey and Helmer, 1963) and since then a large number of research fields have used the method, including e.g. medical science (Graham et al., 2003) organisation science (Nevo and Chan, 2007) and environmental science (Bryant and Abkowitz, 2007). The Delphi method has also been used in the areas of urban green structure science (James et al., 2009), forest preference research (Edwards et al., 2012), assessment of hazard tree parameters (Maruthaveeran and Yaman, 2010) and rating of tree inventory parameters (Östberg et al., 2013).

The steps involved in the Delphi process used in this study were adapted from Okoli and Pawlowski (2004), who describe the methodology to be used for identification and categorisation of experts, and from Graham et al. (2003), who describe the method to be used for rating parameters. The survey was conducted in parallel with two panels considered to represent different responsibilities for, and interest in, tree inventories. The *urban foresters* panel included employees at city administrations procuring and managing urban tree care and urban tree inventories, arboricultural companies and consultants. The *ecologists* panel included representatives from the County Administrative Boards and consultants working with biological values connected to trees.

2.3. Identification and categorisation of expert panels

The aim in panel creation was to select experts with reliable knowledge on urban trees, but also with a variety of perspectives. A total of 30 experts were selected, of which 19 completed the full study (10 in the urban foresters panel and nine in the ecologists panel). The aim of creating panel sizes similar to those in other Delphi studies, e.g. 10 per panel in Edwards et al. (2012), was therefore achieved.

Directly after each expert agreed to take part in the study, they were sent a detailed description of the project by e-mail, together with the list of tree inventory parameters. The list contained the 26 provisional tree inventory parameters identified in the screening phase, together with a short description and an example of how each parameter could be used. The panellists were asked to suggest and describe any missing parameters. In this way, the final list was expanded to 40 parameters.

2.4. Selection of trees to rate

A total of 21 trees, representing 11 species, were selected for assessment by the panels, to span a wide range of different contexts. These trees were growing in an urban park environment (n = 5), in an urban sealed surface (n = 8) and at a rural site (n = 8), and represented two age groups, younger (n = 10) and older (n = 14) trees (Table 1). The focus of *Quercus robur* in the category *older* and *rural site* depends on

Table 1
Trees (n = 21) selected for the study and their species, growing site and age (younger/older).

ID	Species	Environment	Age
1	*Betula pendula*	Urban park environment	Younger
2	*Aesculus hippocastanum*	Urban park environment	Older
3	*Castanea sativa*	Urban park environment	Younger
4	*Platanus x hispanica*	Urban sealed surface	Younger
5	*Tilia x europaea*	Urban park environment	Older
6	*Acer platanoides*	Urban sealed surface	Younger
7	*Acer platanoides*	Urban sealed surface	Younger
8	*Carpinus betulus*	Urban sealed surface	Younger
9	*Tilia tomentosa*	Urban sealed surface	Younger
10	*Tilia x europaea*	Urban sealed surface	Younger
11	*Fraxinus excelsior*	Urban sealed surface	Older
12	*Quercus robur*	Rural	Older
13	*Quercus robur*	Rural	Older
14	*Quercus robur*	Rural	Older
15	*Tilia cordata*	Rural	Older
16	*Quercus robur*	Rural	Older
17	*Quercus robur*	Rural	Younger
18	*Quercus robur*	Rural	Older
19	*Salix alba*	Urban park environment	Older
20	*Quercus robur*	Urban sealed surface	Older
21	*Quercus robur*	Rural	Younger

their high biological diversity and thus have a great focus among ecologists. The study thereby did not aim for an even distribution, instead including tree that are part of the management activities by ecologists and urban foresters, which for ecologists is large, old, trees often *Q. robur* and for urban foresters consists of a diverse tree stand in different urban environments.

Photos were taken of all available parameters for the 21 trees during summer and winter, e.g. photos of the whole tree, the topmost part of the crown, the stem, the buds close up, the leaves close up, the soil and existing damage to the tree. Based on the photos, the panellists were asked to rate the vitality of the trees according to the 40 parameters on the final list. The trees were presented to the panellists in random order.

2.5. Delphi rating of parameters and vitality

The final list of 40 parameters was e-mailed as an Excel document to the panellists, together with the photos of the 21 trees. The panellists were asked to rate the vitality of the individual trees as a percentage from 0 (dead) to 100 and to rate all tree inventory parameters used in their assessments of tree vitality on a scale from 0 to 10, where 0 was *not important* and 10 was *very important*.

Before the second round of rating, the ratings given to the parameters by individual panellists were compiled for each panel, so they could see the (anonymous) ratings of all the other experts, irrespective of background. The panellists were then instructed to rate the vitality of each tree and the importance of the parameters again, especially considering parameters for which their previous rating deviated considerably from the mean value of the first round.

2.6. Analysis of Delphi data

All statistical testing was performed in the statistical program R (R core team, 2019), with a significance level of 0.05. To determine when consensus was achieved, standardised Cronbach's alpha was calculated using the alpha function in the R package psych (Revelle, 2018). Cronbach's alpha is a measurement of agreement, with a coefficient of one representing total agreement. The value obtained for Cronbach's alpha is dependent on the number of items, and therefore needs to be adjusted for the specific dataset (Cortina, 1993). In studies by Graham et al. (2003) and Östberg et al. (2013), a standardised Cronbach's alpha of 0.8 was considered to indicate good internal consistency, in accordance with George and Mallery (2008).

To test for overall differences between urban foresters and ecologists, constrained principal component analysis (cPCA), also known as redundancy analysis (RDA), was performed using the vegan package in R (Oksanen et al., 2019), with professional background as constrained factor with two levels on the correlation matrix of the vitality rankings. The significance was tested using the permutation test. The relationship was visualised by plotting 95 % confidence areas on the unconstrained biplot of the principal component analysis (PCA).

To test for overall differences in use of parameters for the different trees, the mean value for each parameter per tree was calculated in a matrix. The correlation matrix was then tested by cPCA with the permutation test, with tree age (class variable with two levels) and site (class variable with three levels) as constraints. An attempt was made to isolate the effect of the different constraints by including them as conditional 'co-variates' in separate runs of the model. To visualise the class variables, they were plotted with 95 % confidence areas on the unconstrained biplot of the PCAs. To get a better insight into the relationship between parameters used for assessing vitality, the scores for the first four components of the unconstrained PCA were extracted. The number of components extracted was decided using the Kaiser-Guttman criterion and a broken stick model of eigenvalues obtained (Borcard et al., 2011).

To test for differences in overall vitality rankings and number of evaluation parameters in relation to background and tree types, univariate mixed models in the function lme were used (Pinheiro et al., 2019). The average vitality ranking and average number of evaluation parameters per background group of the individual tree were used as response variables. Explanatory variables were professional background (fixed with two levels), tree age (fixed with two levels) and site (fixed with three levels). The random part was set as tree ID, with the explanatory variables nested under it to avoid pseudoreplication. The final models were based on manual backward selection of the full model, including all interactions and applying an inclusion level of 0.05.

To visualise the relationships and groupings in the use of different evaluation parameters for the different trees, four of the most common hierarchical clustering approaches were applied using Chord transformed data and Euclidian distance. The four clustering approaches were: single linkage agglomerative clustering, complete linkage agglomerative clustering, average agglomerative clustering using the unweighted pair group method with arithmetic mean (UPGMA) and Ward's minimum variance clustering, using the cluster package in R (Maechler et al., 2019) with syntax departing from Borcard et al. (2011). To compare the different clustering methods, the correlation coefficient between the original dissimilarity matrix and the cophenetic matrix from the clustering was calculated. The methods were also visually evaluated in Shepard-like diagrams (Legendre and Legendre, 1998) with a lowess smoothing function. Based on this, the most appropriate clustering method was selected for further analysis, where the clustering dendrogram was plotted against a compact matrix table of the evaluation parameters using the tabasco function in vegan (Oksanen et al., 2019). This gave a colour image of the importance of the valuation parameters, ordered in relation to the clustering and the trees evaluated.

To gain insights into the valuation parameters that differed between different groups, indicator values were calculated for the different groups using the approach developed by Dufrene and Legendre (1997) and implemented in the labdsv package in R (Roberts, 2019). In addition, the probability of obtaining as high a value as that observed was calculated using permutation tests. The pairs of groupings compared were *Ecologist* vs *Urban Foresters*, *Old* vs *Younger Tree* and *Rural* vs *Urban Tree* (combined urban sealed surfaces and park categories, due to their similarity in earlier ordination). The ranking of valuation parameters in table format was then sorted according to average value for all trees evaluated.

3. Results

3.1. First and second Delphi round

The standardised Cronbach's alpha was already high (0.96) in the first round of tree vitality assessment by the two panels and the second round only marginally increased the coefficient (to 0.97), indicating strong internal consistency of the vitality rankings in the first round. There was a significant difference between the two professional backgrounds (panels) in round one ($p = 0.004$), with the 'background' constraint explaining 24.4 % of total variation (adjusted $R^2 = 0.244$) (Fig. 1). In the second round, there was again a significant difference in the cPCA for the different backgrounds ($p = 0.002$), with 25.1 % of total variation explained (adjusted $R^2 = 0.0251$) (Fig. 2). For the average parameter ratings, the standardised Cronbach's alpha was high (0.93) in the first round and only marginally higher in the second round. Based on the above, further statistical analysis was only performed on the first round of ratings, which were provided by the respondents independently of each other.

3.2. Differences in use of parameters

Constrained PCA (cPCA) revealed a significant difference in the parameters used by panellists for assessing tree vitality. The first two axes in the cPCA were both significant ($p = 0.001$ and $p = 0.024$, respectively), as were the factors tree age ($p = 0.002$), which loaded towards

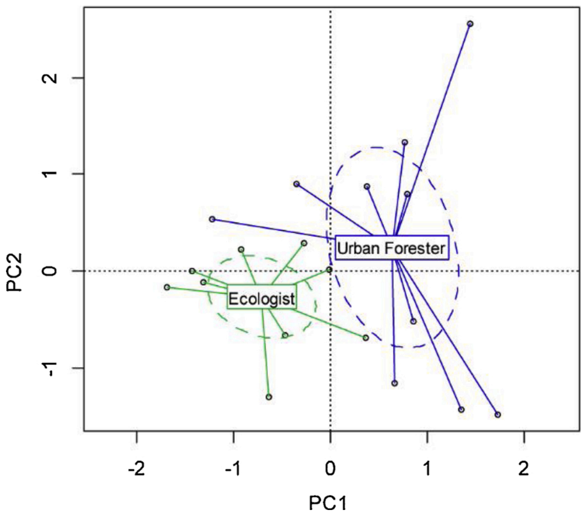

Fig. 1. Unconstrained biplot of principal component analysis (PCA) on the first round of panel assessment, with 95 % confidence area (within dotted lines) for the different backgrounds of the panellists (urban forester, ecologist).

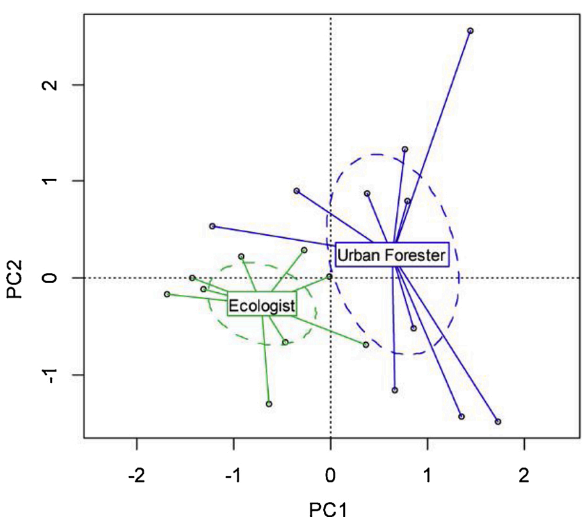

Fig. 2. Unconstrained biplot of principal component analysis (PCA) on the second round of panel assessment, with 95 % confidence area (within dotted lines) for the different backgrounds of the panellists (urban forester, ecologist).

the first axis (Fig. 3), and tree site, i.e. urban vs rural ($p = 0.021$), which loaded towards the second axis (Fig. 4). None of the factors was cancelled out by the other.

Only professional background had a significant effect ($F_{1,20} = 74.44$; $p < 0.0001$) on the individual vitality ranking, with ecologists on average giving higher vitality rankings (95 % confidence interval (CI) 70.8–87.6 %) than urban foresters (95 % CI 52.7–69.4 %). Professional background ($F_{1,20} = 774.36$; $p < 0.0001$) and tree age ($F_{1,19} = 5.0594$; $p = 0.0365$) affected the numbers of parameters used for estimating vitality. On average, urban foresters used 20.6 parameters (95 % CI 19.8–21.5), while ecologists used 11.6 parameters (95 % CI 10.8–12.5). For older trees, the average number of parameters used was 17.0 (95 % CI 15.9–18.1), while for younger trees it was slightly lower (mean 15.3, 95 % CI 14.1–16.4). An overview of the overall statistical models and test performed together with their results are summarised in Table 2.

The differences in use of parameters for tree age and site seen in the PCA:s and related tests was evident in the heatmap (Fig. 5), where tree age showed a clear gradient in the clustering of parameters used for estimating vitality, with an additional group of parameters applied for

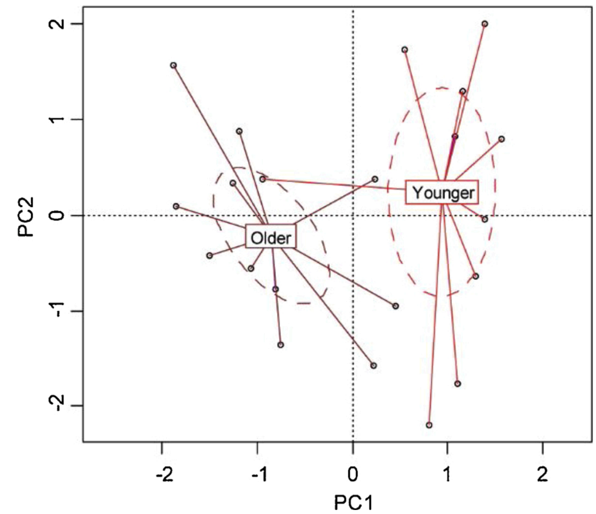

Fig. 3. Unconstrained biplot of principal component analysis (PCA) on average parameters used by panellists for assessing the vitality of each tree, with 95 % confidence areas (within dotted lines) for the two age classes rated (younger and older trees).

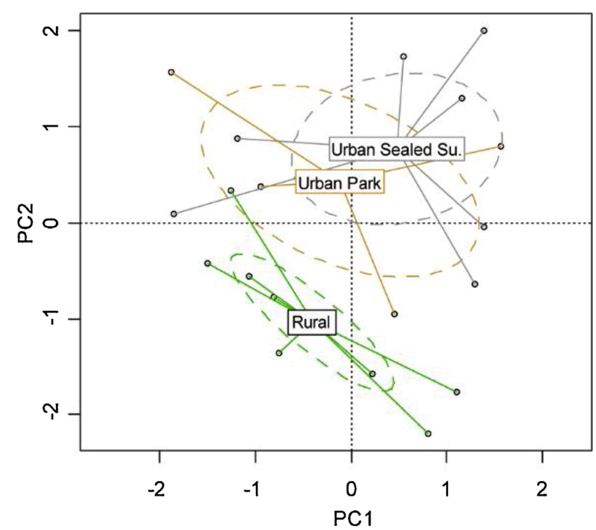

Fig. 4. Unconstrained biplot of principal component analysis (PCA) on average parameters used by panellists for assessing the vitality of each tree, with 95 % confidence areas (within dotted lines) for the three classes of site for the trees evaluated (urban sealed surfaces, urban park, rural). Note the overlap of the two urban categories.

these trees compared with younger trees.

The complete list of parameters used in the study is shown in Table 3. Of the 40 parameters that panellists were asked to rate on a scale of importance from 0 to 10, only six were rated higher than 4 when comparing the average rating per person, while 16 parameters were given a mean rating lower than 2. In comparison for the average rating per tree, 14 parameters received a rating higher than 4 when comparing, and eight parameters had a mean rating lower than 2. Urban foresters differed from ecologists in their use of multiple parameters related to tree growth and pruning. Parameters relating to growth, together with more anthropogenic damage (root damage and pruning), were more often related to urban trees. For the older trees assessed, more parameters were connected strongly to damage, decay and fungi, whereas growth related to shoots in the crown was related more to younger trees. On breaking down the variation into four principal components (PC) and examining the parameters that loaded most towards these components,

Table 2
Overview of statistical models and related tests in the study. *Response* column indicated the response used in the statistical model and *Round* which of the two Delphi rounds used for the model. *Type* indicates if the response was multivariate or univariate and *Model* the use of constrained principal component analysis (cPCA) or mixed linear model (MLM). Explanatory variables included are denoted according to level of significance using the codes: '***' 0.001 '**' 0.01 '*' 0.05 'ns' none significant.

				Explanatory variables		
Response	*Round*	*Type*	*Model*	Background	Tree Age	Site
Overall Vitality assessment	I	Multivariate	cPCA	**		
Overall Vitality assessment	II	Multivariate	cPCA	**		
Overall use of Parameters	I	Multivariate	cPCA		**	*
Nr. of Parameters used	I	Univariate	MLM	***	*	ns
Individual Tree Vitality	I	Univariate	MLM	***	ns	ns

the following patterns were seen: PC1 captured aspects related mostly to damage and fungi, while PC2 related mostly to reduced functionality in the crown (dead leaves, dieback and fruiting). PC3 also had a strong relationship with different crown parameters, including crown transparency and shoot growth in the crown top. PC4 had strongest relationship with parameters related to the growing site.

The majority of the parameters was categorized as belonging to the group *Growth performance*, which in total made up 14 of the 40 parameters. *Loss/death of biomass* (7), *External damage* (6) and *Basic tree information* (6 parameters) was rather well used, whereas parameters relating to *Site condition* (4) and *Decay/pests* (3) was less used (Table 3).

Since inventories are conducted the year round, it is interesting to note that 31 of the 40 parameters can be rated all year round, while the remaining nine parameters (marked with ^ in Table 3) can only be assessed in specific periods during the year. On comparing the parameters used for the vitality rating, *Shoot growth*, *Shoot growth in top* and *Size of buds* all had relationships with younger trees, trees in urban areas and urban foresters (Table 3).Vitality rating after the second round

The results from the second rating round of the Delphi study showed that, when comparing the mean vitality rating, no tree was on average rated fully vital (mean score = 100). In some more extreme cases, the minimum and maximum rating differed by 80 points (range 10–90) and with a mean rating of 45 (Table 4).

4. Discussion

The urban tree parameters measured in an inventory have a direct impact on the potential use of the inventory results (Miller, 1997; Östberg et al., 2013; Miller et al., 2015). It is therefore crucial to define and select appropriate tree inventory parameters (Östberg et al., 2013) for the specific purpose of the study/inventory (Morgenroth et al., 2016). In a Swedish context, urban foresters have a clear risk and management focus (Östberg et al., 2018a,b), whereas many ecologist use the inventory to assess a trees probability of supporting red listed species and thereafter to plan for management action to preserve valuable trees (Claesson et al., 2009). These different focuses can also be linked to the different types of ecosystem services where both groups primarily focus on regulating services, but urban foresters also have a clear focus on the cultural services. With that said, there has in recent years, been an increase in overlap between the two groups where ecologist has focuses more on protecting urban trees for their role in ensuring biodiversity and at the same time urban foresters has started to shift their management to focus more on biodiversity. This has occurred during the same time as the Swedish government has put into legislation that all Swedish municipalities must have a strategic plan on ecosystem services, clearly showing the importance of these services and the focus on urban and peri-urban environments (Riksdagen, 2013).

In selecting trees for the study, we tried to include trees that are commonly inventoried by the two groups. This resulted in a higher number of older trees and the species *Quercus robur* than many urban foresters encounter in their work. At the same time ecologist was exposed to species and growing sites that are uncommon in their work e. g. *Platanus x hispanica* in a street environment. This decision might have affected the result, but at the same time the aim of the study was to compare how the two groups differed in their views on how to rate tree vitality.

In this study, there was strong agreement in ranking trees as more or less vital between two different groups of professionals (urban foresters, ecologists). However, there were large differences between these two groups in what was seen as a fully vital tree, indicating that vitality assessment needs to be handled with particular care when setting up tree inventories.

A number of parameters were used in assessing tree vitality and these could not be simply reduced to a single set of parameters using ordination. This in line with findings by e.g. Martinez-Trinidad et al. (2010) that vitality is a complex environmental characteristic, which includes multiple variables (e.g. Jansen and Oksanen, 2013). The assessment of tree vitality by the panellists probably also reflected how many practitioners act when facing complex environments and problems, e.g. a medical doctor investigating a patient considers multiple aspects and combines them to find a solution (treatment) for the problem (Schön, 1984). This might be one of the reasons why urban foresters included more parameters in their tree assessments, since they are often trained to find a solution or action in relation to low vitality and tree decline (Bassuk, 2017). This suggestion is supported by the fact that, compared with ecologists, urban foresters used more parameters in rating trees growing in urban settings, which are generally environments with more stresses and disturbances (e.g. Sæbø et al., 2003; Sjöman et al., 2018).

Even though the panellists was sent the definition of vitality: *'ability of a plant to deal effectively with stress',* some of the parameters listed in Table 2 are connected to the trees structural integrity e.g. parameters on root, trunk and storm damage. Even though there often is a connection with growing site and vitality a newly planted tree in a tough environment can still have a good vitality and vice versa. To entangle to what extent the different experts included causes of vitality and not only the vitality itself is not possible within this study. This might to some extent influence the result, however it also showcase that the experts to some extent intermixes these aspects.

In contrast to urban foresters, ecologists are not trained to solve specific tree problems, but to understand the patterns and mechanisms that determine how species are distributed and co-exist (Puettmann et al., 2008; Wiström, 2015). Such a process-oriented approach might make it easier for ecologists to focus on vitality itself, and thus reduce the number of parameters. However, reduced use of parameters might also reflect less practical experience of tree inventories in an urban context, as professionals facing a new situation are often guided more by available rules (Dreyfus and Dreyfus, 1986; Nielsen and Nielsen, 2005), such as specific guidelines for tree inventories.

Ecologists overall rated tree vitality higher than urban foresters, which might be related to their use of fewer parameters, thereby increasing the possibility that they overlooked some aspects correlated to low vitality. Urban foresters, on the other hand, might have had a higher focus on factors correlated to low vitality, such as growing site, thereby rating the vitality after the growing site and not vice versa.

On comparing parameters used for the vitality rating, it was found that *Shoot growth*, *Shoot growth in top* and *Size of buds* all had strong connections to younger trees, trees in urban areas and urban foresters.

A shortcoming of this study is that it was by necessity subject to

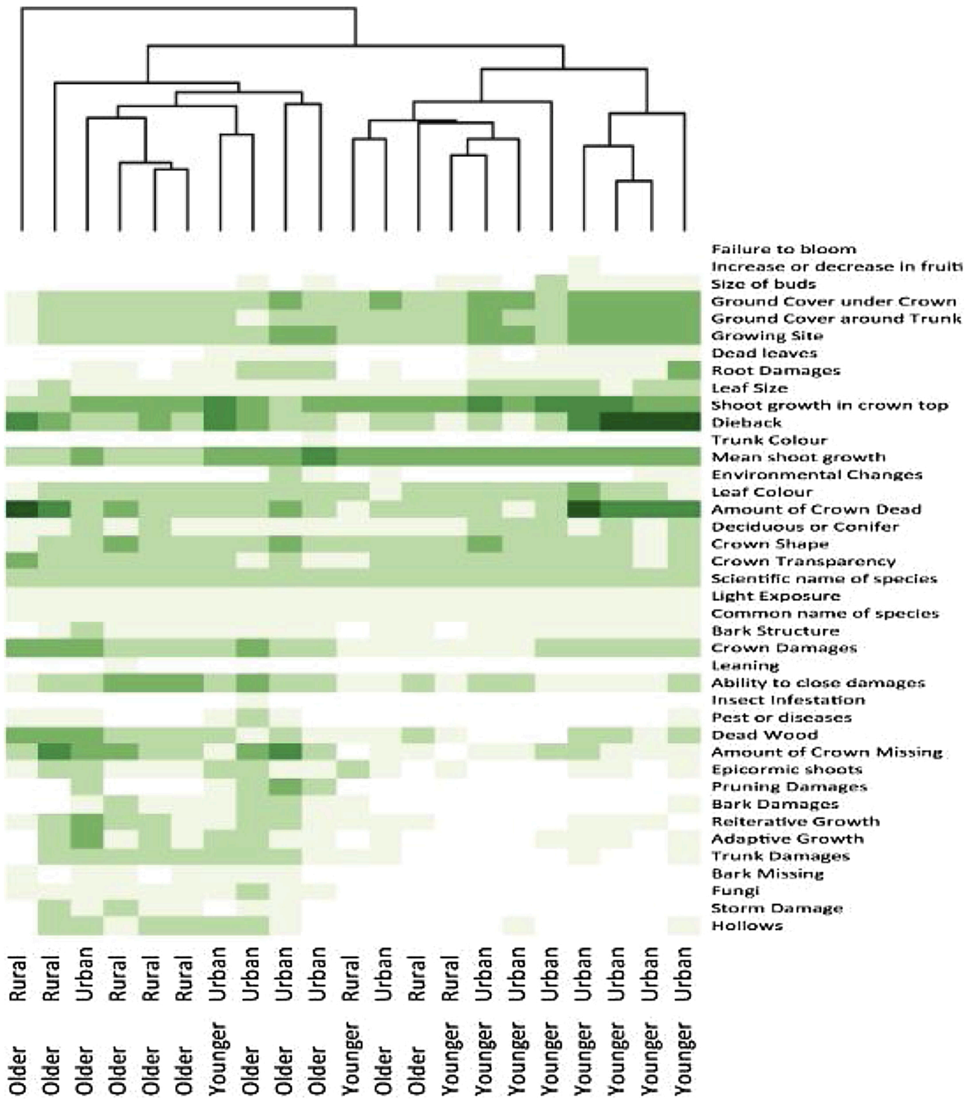

Fig. 5. Heatmap of clustering results obtained using unweighted pair group method with arithmetic mean (UPGMA), which was the clustering method with the highest cophenetic correlation coefficient. Upper diagram: Dendrogram of the clustering results. Lower diagram: Category of trees evaluated. Right: Parameters used for estimating vitality. Darker colour indicates highest weighting of a particular parameter.

limitations of time and place. It is also worth noting that both groups of panellists might have been influenced by the Swedish Tree Inventory Standard, where parameters such as shoot growth, amount of crown dead, crown transparency and ability to close damage are considered (Östberg et al., 2012), and the Swedish Environmental Protection Agency's tree inventory standard, where vitality is mostly defined as amount of crown dead (Claesson et al., 2009). This might have resulted in the highest rated parameters being in line with the parameters and recommendations in these standards, which might have affected the results.

There are few other studies that provide guidance on how to rate tree vitality during a visual tree inventory, with most vitality studies focusing on laboratory-based parameters (Sepúlveda and Johnstone, 2018). Martinez-Trinidad et al. (2010) compared such measuring approaches and concluded that visual aspects are still required in tree vitality determination. Some visual parameters can only be rated during a specific time of the year (e.g. Levinsson et al., 2015). Even though *Shoot growth*, *Shoot growth in top* and *Size of bud* were rated highest of the 40 parameters in the present study, there were significant differences between expert groups and with age of the tree and growing site, showing inconsistency in how tree vitality is rated in the field.

This study involved a systematic expert rating of tree vitality, with the Delphi method being applied to allow broader conclusions to be drawn. The number of panellists recruited for the study (30) was higher than in the study by Graham et al. (2003), where 13 panellists took part, and in line with Edwards et al. (2012), where 10 experts made up each panel. Due to the high number of dropouts, only 19 panellists completed the full study (10 and 9 per panel).

The minimum and maximum rating per tree differed by up to 80 points and it is interesting to note that no tree was rated fully vital (100 %) by all panellists. The cause of these differences and the reason for no tree being rated fully vital by all experts is unknown, but the panellists had access to pictures from both winter and summer, which is more information than they would normally have during a regular tree inventory. This might have influenced the rating, since the panellists might have noticed aspects normally overlooked during regular inventories. The result might also have been affected by the scale used (0–100), which differs from that commonly used in regular tree inventories, e.g. *Good*, *Fair* and *Poor*, making assessments in this study more detailed. Given the large variation seen in this study using a percentage scale while at the same time upholding an high agreement in relation to rank order of vitality in the form of high Cronbach alpha scores, we provide support that the more commonly used groupings or scales of *Good*, *Fair* and *Poor,* 1–4 or A–D are advisable in the everyday

Table 3
Indicator values according to Dufrene and Legendre (1997) for the each pairwise comparison, where high values derive from a combination of large mean abundance within a group compared with the other group (i.e. specificity), together with presence in most matrix rows of the group (i.e. fidelity). The probability of obtaining as high an indicator value as that observed is denoted (***p < 0.001, **p < 0.01, * p < 0.05), based on permutation test. The parameters are listed in decreasing order based on mean value per rated tree. Seasonal parameters are denoted ˆ. The four highest loading parameters for each principal component (PC) are shown in bold type.

Variable	Type of parameter	Type of Tree		Type of Tree		Type of Professional		Average Rating		PCA scores			
		Older	Younger	Rural	Urban	Ecologist	Urban Fore.	Aver. Per Person	Aver. Per Tree	PC1	PC2	PC3	PC4
Shoot growth in crown top	Growth performance	0.47	**0.53****	0.47	**0.53***	0.20	**0.70****	5.01	5.69	0.568	0.188	**0.462**	−0.079
Mean shoot growth	Growth performance	0.46	**0.54****	0.46	**0.54****	0.21	**0.69***	4.78	5.52	0.5136	0.314	0.349	−0.188
Amount of crown dead	Loss/death of biomass	0.51	0.49	0.50	0.50	0.59	0.41	4.53	5.47	−0.160	0.449	**−0.597**	0.176
Dieback	Growth performance	0.48	0.52	0.45	0.55	0.40	0.55	4.59	5.45	−0.086	**0.630**	−0.327	−0.001
Growing site	Site condition	0.47	**0.53***	0.47	0.53	0.26	0.43	4.19	5.06	0.429	0.269	0.296	**0.453**
Ground cover under the crown	Site condition	0.47	**0.53***	0.48	0.52	0.30	0.43	4.07	4.91	0.479	0.274	0.126	**0.531**
Ground cover around the trunk	Site condition	0.47	0.53	0.50	0.50	0.22	0.46	3.71	4.86	0.383	0.224	0.024	**0.659**
Crown shape	Growth performance	0.50	0.50	0.50	0.50	0.28	0.58	3.70	4.50	0.292	−0.061	0.374	0.397
Crown damage	External damage	0.54	0.46	0.48	0.52	0.42	0.36	3.53	4.49	−0.507	0.483	−0.360	0.077
Leaf colourˆ	Growth performance	0.48	0.52	0.48	0.52	0.27	0.66	3.51	4.37	0.304	0.313	−0.170	0.146
Crown transparencyˆ	Growth performance	0.49	0.51	0.51	0.49	0.28	0.58	3.40	4.33	0.152	0.080	**−0.501**	0.379
Deciduous or conifers	Basic tree information	0.48	0.52	0.48	0.52	0.17	0.24	2.75	4.20	0.310	0.247	0.123	0.022
Scientific name	Basic tree information	0.50	0.50	0.50	0.50	0.11	0.33	3.07	4.14	0.010	−0.124	0.216	−0.044
Ability to close damage	External damage	**0.55***	0.45	0.51	0.49	0.23	**0.70***	3.24	4.02	−0.463	−0.080	**0.567**	0.090
Amount of crown missing	Loss/death of biomass	**0.60***	0.40	0.50	0.50	0.44	0.50	3.25	3.85	−0.554	0.385	−0.119	0.228
Dead wood	Loss/death of biomass	**0.58***	0.42	0.55	0.45	0.33	0.52	2.86	3.78	−0.541	0.129	−0.535	0.162
Common name of species	Basic tree information	**0.53*****	0.47	**0.52***	0.48	0.11	0.27	2.26	3.57	−0.523	−0.321	−0.043	0.132
Leaf sizeˆ	Growth performance	0.45	**0.55****	0.46	0.54	0.08	**0.81****	2.76	3.53	0.433	0.556	0.026	0.058
Reiterative growth	Growth performance	**0.61*****	0.39	0.53	0.47	0.15	**0.73***	2.41	3.22	−0.713	0.062	0.085	0.226
Light exposure	Basic tree information	0.52	0.48	**0.54***	0.46	0.23	0.34	2.08	3.08	−0.116	−0.363	0.147	0.502
Bark structure	Growth performance	0.54	0.46	0.50	0.50	0.17	0.56	2.12	3.01	−0.321	0.014	0.274	0.249
Root damage	External damage	0.46	0.54	0.34	**0.66*****	0.28	0.45	2.16	2.86	0.074	**0.618**	0.334	−0.143
Trunk damage	External damage	**0.62****	0.38	0.51	0.49	0.41	0.43	2.30	2.84	−0.715	0.227	0.257	0.107
Epicormic shoots	Growth performance	0.58	0.42	0.49	0.51	0.25	0.63	2.17	2.76	−0.502	0.158	0.157	−0.094
Adaptive growth	Growth performance	**0.63****	0.37	0.50	0.50	0.16	**0.71***	1.93	2.62	−0.683	0.256	0.106	0.117
Bark damage	External damage	**0.59***	0.41	0.48	0.52	0.30	0.43	1.81	2.45	−0.641	0.149	0.388	−0.058
Hollows	Loss/death of biomass	**0.68****	0.32	0.56	0.44	0.31	0.48	1.83	2.42	**−0.727**	0.0059	0.135	0.017
Size of buds	Growth performance	0.43	**0.57***	0.43	**0.57****	0.05	**0.70***	1.57	2.34	0.430	0.419	0.338	−0.289
Dead leavesˆ	Loss/death of biomass	0.44	0.56	0.38	**0.62*****	0.18	0.41	1.55	2.33	0.178	**0.687**	0.157	−0.134
Environmental changes close to the tree	Site condition	0.50	0.50	0.43	0.57	0.03	**0.57***	1.41	2.31	0.033	0.216	0.378	0.125
Pruning damage	Loss/death of biomass	0.64	0.36	0.31	**0.69***	0.16	**0.71***	1.56	2.13	−0.482	0.326	0.415	−0.207
Fungi	Decay/pests	**0.64****	0.36	0.52	0.48	0.24	0.34	1.46	2.02	**−0.752**	0.049	−0.080	−0.145
Storm damage		**0.72*****	0.28	0.60	0.40	0.28	0.29	1.34	1.91	**−0.729**	0.052	0.077	0.317

(continued on next page)

Table 3 (*continued*)

Variable	Type of parameter	Type of Tree: Older	Type of Tree: Younger	Type of Tree: Rural	Type of Tree: Urban	Type of Professional: Ecologist	Urban Fore.	Average Rating Aver. Per Person	Aver. Per Tree	PCA scores: PC1	PC2	PC3	PC4
	External damage												
Bark missing	Loss/death of biomass	**0.65****	0.35	0.51	0.49	0.29	0.44	1.26	1.83	**−0.722**	0.132	0.174	0.104
Pest or diseases	Decay/pests	0.56	0.44	0.46	0.54	0.32	0.42	1.35	1.82	−0.560	0.371	−0.103	−0.373
Trunk colour	Basic tree information	0.48	0.52	0.45	0.55	0.03	**0.69***	1.02	1.60	0.294	−0.079	−0.008	−0.297
Insect infestation	Decay/pests	**0.57***	0.43	0.46	0.54	0.12	0.58	0.94	1.30	−0.548	0.205	−0.013	**−0.441**
Leaning	Basic tree information	**0.62*****	0.38	0.54	0.46	0.16	0.21	0.79	1.25	−0.524	−0.035	0.281	0.349
Increase or decrease in fruiting^	Growth performance	0.40	0.60	0.39	0.61	0.04	0.44	0.57	0.85	0.213	**0.608**	−0.311	−0.003
Failure to bloom^	Growth performance	0.38	0.62	0.40	0.60	0.13	0.20	0.42	0.66	0.322	0.449	−0.012	0.135
Number of significant ind. variables per group		14	6	2	6	0	10						

Table 4
Rating given to each tree (n = 21) after the second round of the Delphi study.

ID	Species	Environment	Tree age	Min	Max	Mean	Median
1	*Betula pendula*	Urban park environment	Younger	40	100	75	80
2	*Aesculus hippocastanum*	Urban park environment	Older	50	100	72	70
3	*Castanea sativa*	Urban park environment	Younger	60	100	88	90
4	*Platanus x hispanica*	Urban sealed surface	Younger	30	90	58	60
5	*Tilia x europaea*	Urban park environment	Oldere	40	100	75	80
6	*Acer platanoides*	Urban sealed surface	Younger	40	100	66	70
7	*Acer platanoides*	Urban sealed surface	Younger	20	90	57	60
8	*Carpinus betulus*	Urban sealed surface	Younger	80	100	91	90
9	*Tilia tomentosa*	Urban sealed surface	Younger	40	100	85	88
10	*Tilia x europaea*	Urban sealed surface	Younger	10	90	45	40
11	*Fraxinus excelsior*	Urban sealed surface	Older	15	100	74	80
12	*Quercus robur*	Rural	Older	40	100	75	75
13	*Quercus robur*	Rural	Older	30	100	67	65
14	*Quercus robur*	Rural	Older	50	100	77	80
15	*Tilia cordata*	Rural	Older	15	100	44	40
16	*Quercus robur*	Rural	Older	40	100	78	80
17	*Quercus robur*	Rural	Younger	50	100	85	90
18	*Quercus robur*	Rural	Older	0	50	14	10
19	*Salix alba*	Urban park environment	Older	65	100	85	90
20	*Quercus robur*	Urban sealed surface	Older	30	100	66	70
21	*Quercus robur*	Rural	Younger	80	100	89	90

practical use of vitality rankings and inventories. Although large variation was evident, the statistical testing accounting for this, still clearly showed that different professional groups had different ways to address tree vitality and arrived at different results. Therefore, independent of the scale used, further focus is needed to create agreement on how to rate tree vitality.

4.1. Practical implications

As the professionals showed consistency in ranking trees concerning vitality, but differed concerning absolute values, introducing calibration material in the form of e.g. the photo set used in the present study with stated reference values could be one way of calibrating vitality. This approach is sometimes practised for ordinal variables (e.g. Fors et al., 2019) or cover percentages (e.g. Bergstedt et al., 2009) in field studies. A caveat when using such approaches is that in this study there were still clear differences between urban foresters and ecologists, even though cross-validation was performed in the second round of Delphi rating. This implies that including the person doing the inventory as a parameter is essential to enable comparison over time and between studies, e.g. by including the specific assessors as a random effect in statistical modelling (Zuur et al., 2009).

4.2. Selecting parameters for visual assessment of vitality

Vitality is the second most commonly assessed tree inventory parameter in Swedish municipalities and is included in 74 % of inventories, second to tree species (89 % of inventories) (Östberg et al., 2018a,b). This conforms with the international trend of prioritising species, diameter at breast height (DBH) and vitality (Roman et al., 2013; Östberg et al., 2013). A key reason is probably that vitality in its complexity captures directly and indirectly multiple aspects related to tree management, in the same way that DBH correlates to several key management aspects. Thus respecting the complexity of vitality while making it feasible to assess in the field has to be an important rationale for tree inventories, enabling a reduction in key parameters to use for visual evaluation of trees.

Given the high number of parameters used and their context-dependent importance, i.e. they varied between sites and with tree age, identification of suitable base parameters is not straightforward. Only including the parameters with the highest mean importance values might overlook the odd parameter useful in certain contexts. One approach could therefore be to depart from the different main multivariate dimensions they capture and select a core of set of parameters that covers decay, external damage, loss/death of biomass, growth performance and site conditions. Ranking of parameters would be advisable, e.g. external damage (disturbance) and growing site (abiotic stress) are probable causes of low vitality, but not vitality per se. Similarly, decay and loss/death of biomass are products of low vitality, whereas growth-related parameters could be a more direct measure of vitality. Low growth cannot be directly translated to low vitality, since growth is affected by e.g. age, species and growing site. Therefore parameters capturing growth need to be considered in the light of other variables. We suggest selecting those parameters with mean high ratings and that cover the above aspects, while also considering whether they capture special aspects of context and tree age. To avoid redundancy, highly correlated parameters covering the same mean aspects should be avoided.

5. Conclusions

Tree vitality assessment is a common and an important task in managing urban and rural trees, but there is a lack of consensus on how this important parameter should be assessed. This study showed that the parameters used in rating tree vitality also differ between professions and with tree age and growing site. On a more detailed level, the study revealed distinct dissimilarities between urban foresters and ecologists in the ranking of parameters for use when rating tree vitality. Keeping in mind the differences in responsibility for, and use of, tree vitality information, these dissimilarities are understandable, but problems can arise if the gap between the groups becomes too wide. In relation to this, the differences identified and the indicative explanations given improve the ability to capture diverging agendas within urban forestry more fully. Broadly speaking, the results emphasise the need for collaboration between the different groups managing inventories. Only by applying a transdisciplinary approach to the use of parameters to rate tree vitality can urban tree inventories be strengthened and made more relevant.

Author statement

Johan Östberg Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Validation; Roles/Writing - original draft; Writing - review & editing

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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