# Comparison of visual risk assessment methods applied in street trees of Montevideo city, Uruguay

## Comparación de métodos de evaluación visual del riesgo aplicados en árboles de veredas de la ciudad de Montevideo, Uruguay

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### Abstract

Risk assessment of urban trees is an incipient practice in Latin America, generally performed with foreign methods, due to the lack of qualified personnel and locally validated or adapted methodology. This article evaluates the application of three methods on street trees in Montevideo city, Uruguay: Tree Hazard Risk Evaluation and Treatment System (THREATS), Quantified Tree Risk Assessment (QTRA) and Best Management Practices - Tree Risk Assessment (ISA BMP). Three assessors with similar experience applied three methods in 36 trees of three widely used genera, totaling 324 assessments and 1,296 data. The methods were decomposed into the components: Likelihood of Failure, Likelihood of Impact, Consequence and Risk Rating. The data were statistically analyzed through a generalized linear mixed model ($p<0.05$), for the factors: assessor, method, genus, and their interactions. Results showed no significant differences among assessors, but there were differences among methods, specifically for the Likelihood of Impact and Risk Rating components. The ISA BMP method presented higher means in these last two components. Still, this method is suggested for street trees in Montevideo until a more appropriate method is adapted or developed for local conditions.

**Keywords**
arboriculture • hazard tree • risk component • tree risk • urban forest

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**Resumen**

La evaluación del riesgo de árboles urbanos es una práctica incipiente en América Latina, debido a la falta de personal calificado y métodos locales validados o adaptados, debiendo utilizarse métodos foráneos. Este artículo evalúa la aplicación de tres de estos métodos en árboles de veredas de la ciudad de Montevideo, Uruguay: Tree Hazard Risk Evaluation and Treatment System (THREATS), Quantified Tree Risk Assessment (QTRA) and Best Management Practices - Tree Risk Assessment (ISA BMP). Estos fueron aplicados por tres evaluadores con similar nivel de experiencia, en 36 árboles de tres géneros ampliamente utilizados, totalizando 324 evaluaciones y 1.296 datos. Los métodos fueron descompuestos en los componentes: Probabilidad de Falla, Probabilidad de Impacto, Consecuencia y Clasificación del Riesgo. Los datos fueron analizados estadísticamente a través de un modelo lineal generalizado mixto (p<0,05), considerando los factores: evaluador, método, género, y sus interacciones. Los resultados no muestran diferencias significativas entre evaluadores, pero sí entre métodos, específicamente para Probabilidad de Impacto y Clasificación del Riesgo. El método ISA BMP presentó mayores promedios en estos dos últimos componentes, aun así, se sugiere su uso para árboles ubicados en calles de Montevideo mientras no se desarrolle o adapte un método a las condiciones locales.



**Palabras clave**

arboricultura • árbol peligroso • componentes del riesgo • riesgo del árbol • bosque urbano


## INTRODUCTION

Urban trees (UT) take part in the physiognomic and structural configuration of cities (2), as fundamental elements of well-being in urban landscape and environment (10, 24). Given the importance of UT, keeping them in the best possible conditions turns relevant. This implies incorporating risk management (32), favoring people, goods, and activities at the same time.

Tree development in a constantly changing environment presents new challenges, especially related to management. As climate change progresses, trees live less than expected (29) causing damage to infrastructure, requiring extra maintenance, and exposing the community to higher risks, resulting in additional management costs (2). In this sense, good UT management should minimize costs and maximize benefits (21).

Although eliminating risks turns impossible, controlling tree damages (2, 6) allows reaching an acceptable risk level for stakeholders (22). Trees exceeding this level are considered dangerous (2).

Initiatives developing visual assessment methods for UT risk date from 1990 (6, 7, 9, 20, 23). These methods can be classified into qualitative, quantitative, or semiquantitative methods, depending on the structure used for categorization of each risk component (13). For a method to be incorporated as a management tool it must be complete, credible, feasible (substantiated), reliable, repeatable, robust, simple, and valid (22). In general, different methods are organized according to the components "likelihood of failure" and "likelihood of impact", with possible "consequences" of the eventual failure for people or property (31), as well as a corresponding "risk rating". This decomposition in components is a useful way to analyze method applicability (3, 17).

UT likelihood of failure is related to tree defects, with the most likely-to-fail trait being the most relevant when assessing a potential failure directly related to the potential consequences (3). The likelihood of impact is associated with the area that the failed part or entire tree can impact -the target zone-, related to the occupancy rate of people, goods and services potentially impacted (20). Therefore, high-use public spaces require the best attention (7, 15). Tree health and condition (7), as well as the targets, failing part size, falling distance and target zone (6, 7, 31), influence consequence (i.e. damage caused by the part of the tree that affects the targets, 19).

As mentioned, risk rating is calculated in quantitative, qualitative, or semiquantitative terms (6, 13, 20). In quantitative terms, real values are estimated for consequences and likelihoods. For qualitative assessment, expressions such as "low", "moderate", and "high" are used. Finally, semiquantitative risks may be a sum or multiplication of the components, associated with a scale, whether linear, logarithmic, or other. Nonetheless, finding methodologies that use different scales for different components, is possible (9).

Regardless of the method used, risk assessment should reduce uncertainty and help manage the risk. This should be of assistance in deciding whether to adhere to an existing method or adapt a previous one, particularly in the case of those countries that do not possess their own (26). Therefore, method evaluation tests different factors, assessors, trees, and sites, ensuring adequate reliability and repeatability (17, 18, 19, 22, 26).

Studies show significant differences when comparing risk ratings of different visual assessment methods (3, 22, 26) and assessor performance (3, 19, 22). Furthermore, when analyzing each component, some authors (19) observe greater variability in likelihood of impact than in likelihood of failure.

Considering that the methods available were developed in Anglo-Saxon countries, in other countries, especially in Latin America (1), method adaptation or development is still incipient, with few available studies (3, 4, 14, 26).

The aim of this article is to compare three methods of UT visual risk assessment qualifying their performance and possible adaptation to assess UT in Montevideo city.

## Materials and methods

Fieldwork was carried out in December 2018, by assessing streets in different neighborhoods of Montevideo (34°54'04.3" S, 56°08'18.4" W and 136 m a. s. l.), Uruguay. Average temperatures range from 11°C in winter to 21.5°C during summer. Precipitation is spatially irregular and variable, presenting a maximum in autumn and a secondary maximum in spring (11). Northbound winds are the most frequent but less intense (< 65 km/h) while south-southeast and west-northwest winds are the most intense (> 80 km/h) (12).

In 2012, the city of Montevideo had 211,402 sidewalk trees, totaling 422 species (30). Four species within the most cultivated genera in Montevideo, were selected (30): *Melia azedarach* L., *Fraxinus excelsior* L., *Fraxinus pennsylvanica* Marshall and *Platanus* x *acerifolia* (Aiton) Willd. The decision was based on a registry of tree failures during storms in the 2012 - 2017 period, indicating that these species have failed the most. For this research, 36 trees were selected, 12 of each genus, with different scenarios of likelihood of failure, impact, and consequence, incorporating trees at all possible risk levels.

Three visual risk assessment methods were selected: "Quantified Tree Risk Assessment" (8), "Best Management Practices - Tree Risk Assessment" (6) and "Tree Hazard: Risk Evaluation and Treatment System" (9), so that all types of methodologies (quantitative, qualitative and semiquantitative) were considered (table 1, page 41). Risk ratings and the use of methods focused on street trees were also considered. These last considerations, along with assessor training, were decisive in the methodological selections.

The assessment methods used provide different final risk ratings, and evaluate each component, resulting in different qualitative scales or quantitative evaluations. For that reason, data analysis was standardized according to Coelho-Duarte *et al.* (2021).

Due to the limited availability of trained personnel, three assessors with basic knowledge in arboriculture applied the methods. These people received prior training consisting of theoretical and practical capacitation, totalizing about fourteen hours.

Each tree was measured considering height (m), diameter at breast height (DBH) (m) and crown projection diameter in N-S and E-W directions (m).

Three hundred and twenty-four assessments were analyzed. ANOVA considered the methods, genera, assessors, and the interaction between them as sources of variation. For the ANOVA, a generalized linear mixed model ($p < 0.05$) selected "tree" effect as random factor, since the three methods were applied in the same trees. When significant differences were found, means were compared using Fisher's Least Significant Difference (LSD) test ($\alpha = 0.05$). The data were analyzed with the glmer function of R's lme4 library (25), interconnected to InfoStat software version 2020 (5). Plots were developed using SigmaPlot software version 12 (Systat Software Inc.).

**Table 1.** Method characteristics.
**Tabla 1.** Características de los métodos.

| Method | Characteristics |
|---|---|
| THREATS<br><br>Tree Hazard: Risk Evaluation and Treatment System (9) | - Semiquantitative method.<br>- Developed in the U.K.<br>- After assessing tree risk, it provides recommendations for risk mitigation.<br>- Free access and available online. |
| QTRA Quantified Tree Risk Assessment (8) | - Quantitative method.<br>- Developed in the U.K.<br>- Assumes that high risks would only occur in areas with high occupancy rate of targets or with high value properties. In case of low occupancy rate or low value, properties assessing the structural weakness of the tree would not be necessary.<br>- The ranking is divided into four ranges defining a risk threshold under 1:10.000.<br>- The method is available online free but requires training and licensing.<br>- The management risk is based on a cost/benefit ratio (ALARP). |
| ISA BMP<br><br>Best Management Practices (6) | - Qualitative method.<br>- Developed in the USA.<br>- Uses decision matrix for risk rating.<br>- Includes an evaluation of biological and mechanical variables.<br>- The method has an extensive and detailed form including a residual risk for each treatment recommended for the tree.<br>- It can recommend the use of diagnostic equipment for advanced assessment.<br>- Training is necessary for certification. |

## Results

The studied trees had different crown sizes given by reduction pruning intended to adequate size to the available space. Specimens of *Platanus* were mostly located in avenues with wide sidewalks and were considerably larger in height and crown diameter than *Melia* trees, which were more abundant in streets with narrower sidewalks. *Fraxinus* individuals were of smaller size, with lower DBH than the other genera (table 2).

**Table 2.** Mean dendrometric values per genus.
**Tabla 2.** Valores promedios de las medidas dendrométricas por género.

| | *Fraxinus* | *Melia* | *Platanus* |
|---|---|---|---|
| Height (m) | 10.8 ± 2.3 | 15.6 ± 4.2 | 21.6 ± 3.9 |
| DBH* (m) | 0.4 ± 0.1 | 0.7 ± 0.2 | 0.7 ± 0.2 |
| CD N-S* (m) | 8.0 ± 2.6 | 9.9 ± 2.3 | 13.5 ± 3.4 |
| CD E-W* (m) | 8.19 ± 1.55 | 10.2 ± 2.2 | 13.7 ± 3.7 |

*DBH = Diameter at Breast Height; CD N-S = Crown Diameter N-S; CD E-W: Crown Diameter E-W.

*DBH = Diámetro a la Altura del Pecho; CD N-S = Diámetro de Copa N-S; CD E-W: Diámetro de Copa E-O.

Regarding risk assessments, no interactions were found between factors. The results showed significant differences among methods only for likelihood of impact ($p = 0.016$) and risk rating ($p = 0.046$) (figure 1b and figure 1d, page 42). Among genera, differences were only found for likelihood of impact ($p = 0.013$) (figure 2, page 42), while no significant differences were found among assessors for any of the components.

Black points represent the adjusted mean; stars depict outliers; white circles show medians. Dissimilar letters denote statistically significant differences in mean ratings for LSD Fisher test (α = 5%).

Puntos negros representan la media ajustada; estrellas negras son valores atípicos; letras diferentes denotan diferencias estadísticamente diferentes en las medias determinadas con una prueba de LSD Fisher (α = 5%).

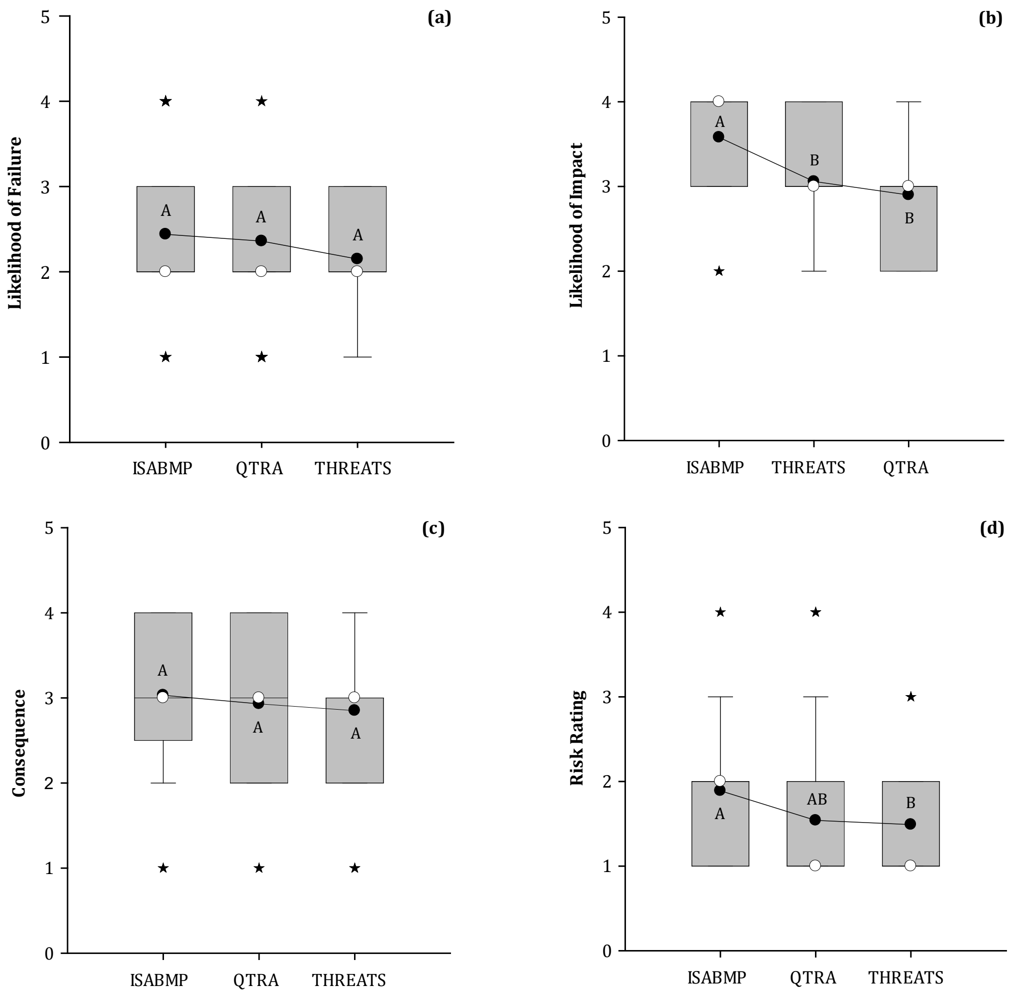


**Figure 1.** Boxplot (bars): (a) likelihood of failure, (b) likelihood of impact, (c) consequence, and (d) risk ratings for the three methods of visual assessment.

**Figura 1.** Diagrama de caja (barras): (a) probabilidad de falla, (b) probabilidad de impacto, (c) consecuencia, (d) clasificación del riesgo para los tres métodos de evaluación visual.

Black points represent adjusted mean; stars depict outliers; white circles are medians. Dissimilar letters denote statistically significant differences in mean ratings as determined with LSD Fisher test (α = 5%).

Puntos negros representan la media ajustada; estrellas negras son valores atípicos; letras diferentes denotan diferencias estadísticamente diferentes en las medias determinadas con una prueba de LSD Fisher (α = 5%).

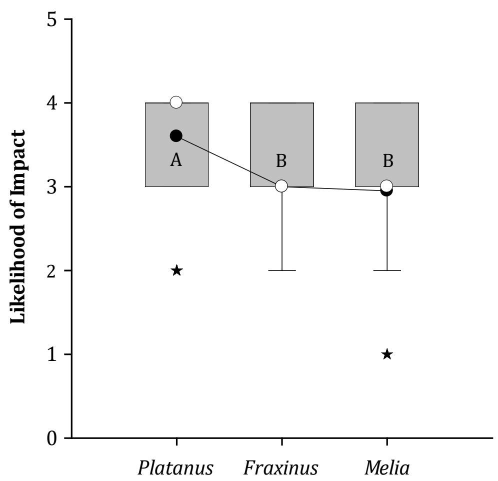


**Figure 2.** Boxplot (bars): likelihood of impact by genus.

**Figura 2.** Diagrama de cajas (barras): probabilidad de impacto por género.

## Results per component

### Likelihood of failure

No significant differences were found for any factor. Results distribution showed 94.4% (QTRA), 93.5% (ISA BMP) and 85.2% (THREATS) in the standardized indices 2 and 3 (figure 3). Essentially, likelihood of failure of the evaluated individuals was possible/probable. It must be noted that for the THREATS method, 14.8% of the assessments are located in the standardized index 1, referring to defect absence or minor defect presence, and none in index 4, which represents an imminent failure.

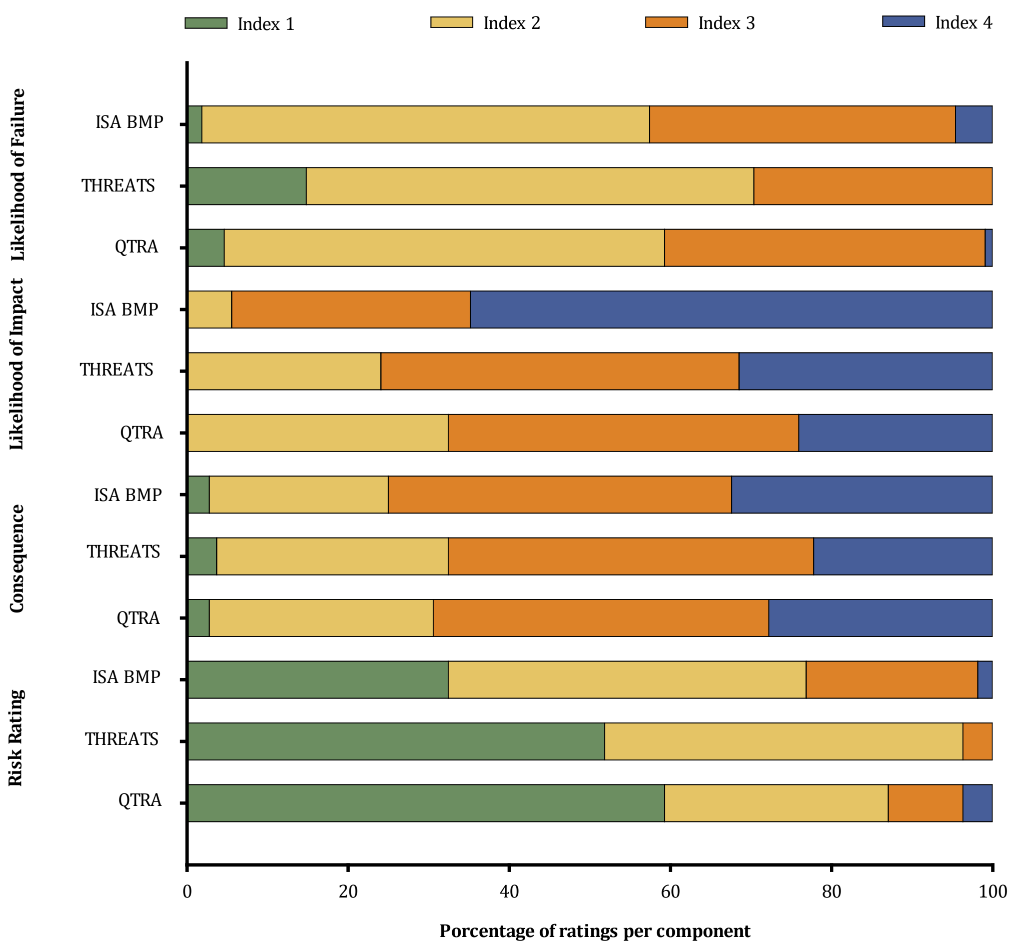


**Figure 3.** Assessment distribution by component for three methods (ISA BMP, THREATS and QTRA).

**Figura 3.** Distribución de las evaluaciones por componente para tres métodos (ISA BMP, THREATS y QTRA).

### Likelihood of impact

The methods resulted in two homogeneous groups for this component (figure 1b, page 42), with the ISA BMP method bringing about the highest mean. None of the methods resulted in the standardized index 1. For QTRA and THREATS the distribution was similar within the standardized indices 2, 3 and 4, while in ISA BMP 64.8% of the results were in the standardized index 4 (figure 3). For both QTRA and THREATS it was possible to discriminate the highest occupancy rates effectively (figure 4, page 44).

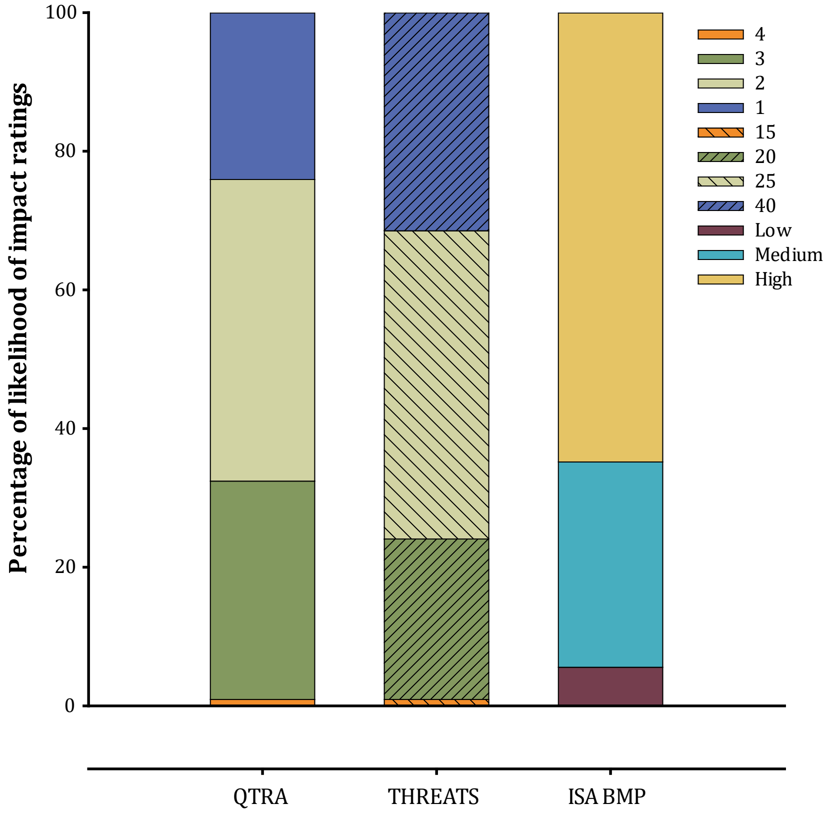


**Figure 4.** Assessment distribution using original ranges in each method (QTRA: 1, 2, 3, 4; THREATS: 15, 20, 25, 40; ISA BMP: Low, Medium, High) for likelihood of impact.

**Figura 4.** Distribución de las evaluaciones utilizando los rangos originales de cada método (QTRA: 1, 2, 3, 4; THREATS: 15, 20, 25, 40; ISA BMP: Low, Medium, High) para la probabilidad de impacto.

### Consequence

No significant differences were found among factors. Thus, for the "most likely-to-fail part", branches represented 77%, 95% and 74% in *Fraxinus*, *Platanus* and *Melia* respectively; while 23%, 24% and 5% resulted for the trunk. As for the entire tree, only Melia had a 2% of the total assessments. Concerning branches, valuations fluctuated, between 11 and 16 cm.

### Risk rating

The methods yielded two groups, with significant differences between ISA BMP and THREATS (figure 1d, page 42). ISA BMP resulted in "moderate" risk, even when the other components had the highest values amongst these results, No ratings were found in the "extreme" category for the THREATS method.

## Discussion

Other studies had found similar results when considering the same methods (3), with the addition of significant differences for likelihood of failure. Significant differences among the genera for the likelihood of impact (figure 2, page 42) could be explained by tree location since *Platanus* sp. were located on avenues where vehicle and pedestrian circulation is constant, while *Fraxinus* sp. and *Melia* sp. were located in low-traffic streets.

The lack of significant differences among assessors for any of the components differs from previous results (3, 19). However, further perception studies state that individuals of equal age (16), gender, educational level (16, 28), and social ties (27) tend to judge possible risks in a similar way, explaining our results.

**Discussion per component**

*Likelihood of failure*

The THREATS method presented a different dispersion, in accordance with Coelho-Duarte *et al*. (2021). Assessor equal training level at the moment of categorizing likelihood of failure could explain the observed non-significant differences. In this regard, other authors (19) founding differences among assessors for this likelihood, highlighted the component as presenting the lowest variability among them. A different research distinguished knowledge levels among assessors, finding differences in likelihood of failure between a more experienced group and a less experienced one (3).

*Likelihood of impact*

The lack of results for the standardized index 1 for all methods, could be explained by the "rare occupancy" rate of street trees. The distinct predomination of index 4 for ISA BMP may be due, on the one hand, to the fact that the ISA BMP proposes four categories to assess the impact, while the other tested methods propose six, resulting to be more similar. On the other hand, the difference could be also due to the standardization, which might allow the other two methods a better discrimination between the highest categories. Therefore, the qualitative assessment of the ISA BMP method could be overestimating this component, as previously found (3).

For a more precise measurement of the occupancy rate, traffic counters have been proposed (15), reducing variability among methods, after reducing assessor subjectivity.

*Consequence*

As each method has a particular way of consequence evaluation in terms of tree-part size and the attributes to be considered, significant differences were expected among them. No difference, as already observed (3), may be associated with the branches being the part with the highest likelihood of failure in most of the assessments.

No significant differences among assessors in consequence analysis differ from that previously reported (19), where the second component showed the highest variability among assessors.

*Risk rating*

When observing the ISA BMP matrix and the obtained risk rating (6), most of the possible combinations between components resulted in "low" risk level.This explained that the final average resulted lower than individual risk components.

Low ratings in the "extreme" category for THREATS (index 4, figure 3, page 43) could be influenced by the likelihood of failure component, as indicated by Coelho-Duarte *et al.* (2021).

Regarding the observed assessment dispersion (figure 1d, page 42), the ISA BMP and QTRA methods resulted in the more adequate tree risk classifications, with a reduced number of trees at the "extreme" level, similarly to that previously found (3). The difference between both methods is that QTRA resulted in 59.2% of the assessments at "low" level (figure 3, page 43), in which the trees would not need treatment, while ISA BMP yielded 44.4% "moderate" level, where treatment depends on the benefits outweighing handling costs (8).

Unlike that reported in other studies (3, 19, 22) in our study, risk assessors were not significantly different from each other. In this context, the used basic visual assessment methods proved to efficiently determine tree fall risks, complying with that already proposed (22). However, in the case of Montevideo, not all methods resulted completely appropriate. Some of the descriptors used do not apply to meteorological conditions and city infrastructure, such as urban furniture, pedestrian and vehicular transport, and space for the tree itself, amongst others.

Considering the abovementioned, we observed that the ISA BMP method resulted in the best option, with defect analysis in depth and residual risk designation. When recommending management, the THREATS method is the only presenting a list of treatments, stipulating a period for their performance and re-inspection. It is stated that the qualitative features of this method use some ambiguous descriptors (22), thus, any suggested treatment could not be necessary when ambiguously interpreting them. For its part, the QTRA method provided few details during the assessment, probably making subsequent risk management more difficult, but considering consequent risk costs (8).

The lack of certified arborists for tree risk assessment is evident in many cities of the Latin American Region. In this case, the number of assessors is compensated by the amount of data analyzed, reason for considering the methodology as adequate for the exploratory and descriptive characteristics of this research. Therefore, we recommend increasing the number of assessors and trees in future research.

## Conclusions

No significant differences were found among assessors, allowing the application of these methods by those with similar training level. Additionally, this would constitute encouraging standard trainings for all assessors.

Methods for the likelihood of impact and risk rating showed significant differences. In both cases, the ISA BMP method presented the highest results, being the most relevant comparison aspects.

Differences among genera were found for the likelihood of impact component, influenced by target occupation rate and characteristics.

Compared to the ISA BMP The QTRA and THREATS methods, in the highest categories of likelihood of impact, distinguished two ranges.

The absence of descriptors and categorizations, and application time resulted characteristics to be improved, where ISA BMP exceeded the limit for application time. Still, ISA BMP method is suggested for street trees risk assessment in Montevideo, until an appropriate method including treatment recommendations and guidelines for risk management is adapted or developed.

Regardless of the method used, we suggest complementing visual assessment with advanced equipment for those trees classified as higher risks.

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